International Journal of Technology and Design Education
https://doi.org/10.1007/s10798-024-09905-6

Robotics in universal prekindergarten classrooms

Tess Levinson[1] · Marina Bers[1]

Accepted: 23 May 2024

Abstract

Policy emphases on early childhood and elementary computer science education have led to the development of many developmentally appropriate computer science and robotics tools, pedagogies, and high-quality curricula. One example is the integrated Coding as Another Language pedagogy for coding, literacy, and social and emotional learning. The pedagogy was initially developed for students in kindergarten and early elementary school and has not previously been aligned to prekindergarten learning frameworks or used in the prekindergarten setting. In this paper, we describe a pilot program if the CAL pedagogy could be successfully used for the prekindergarten setting. The study used a design-based method to adapt the Coding as Another Language curriculum for the prekindergarten setting and a mixed-methods protocol to evaluate the program at a preschool site serving children experiencing homelessness in classrooms that are part of the local school district's universal prekindergarten program. Students were assessed using the Coding Stages Assessment of coding knowledge and the TechCheck-PreK assessment of computational thinking. Teachers completed semi-structured interviews over the course of the project. Teachers reported overall positive experiences teaching the curriculum including for English language learners, although some reported challenges integrating the curricula in their bilingual classrooms. Children participating in the program significantly improved on their coding knowledge by 4.60 points on the Coding Stages Assessment, $p < .0001$. These findings suggest that the Coding as Another Language pedagogy can be successfully integrated with preschool learning frameworks and implemented in preschool classrooms.

Keywords Computer science education · Robotics education · Computational thinking · Universal prekindergarten · Head start · Homelessness

✉ Tess Levinson
tess.levinson@bc.edu

[1] Lynch School of Education and Human Development, Boston College, 140 Commonwealth Ave, Chestnut Hill, MA 02467, US

Published online: 01 June 2024

Introduction

Research suggests that high-quality programming in early childhood education can have long lasting impacts (Jenkins, 2014; Ludwig & Phillips, 2008). One federally funded prekindergarten program, Head Start, has been shown to have both immediate and lasting effects on academic and nonacademic domains. Head Start enrollment has been associated with increased language skills and social competence (Zhai et al., 2011). These positive effects also last longer than the preschool years, with one study finding middle school students who had attended Head Start programs had higher math scores, had lower absenteeism, and were less likely to have repeated a grade than their peers who had not attended Head Start programs (Phillips et al., 2016). In Boston, where the Universal Pre-Kindergarten (UPK) program was initially piloted through a lottery between 1997 and 2003, four year old children who received lottery entrance into the UPK program were more likely to enroll in and graduate from college on time compared to their peers who did not receive lottery entry (Gray-Lobe et al., 2021).

The effects of introducing high quality programming in the early years are seen as well within the specific domain of computer science education. Prior research has suggested several benefits to introducing coding, robotics, and computer science in early childhood. For example, studies have shown the potential of early childhood coding and robotics programs to help children understand foundational concepts such as sequencing, promote collaboration in the classroom, support early cognitive development, and mitigate or prevent gender stereotypes in STEM disciplines (Flannery & Bers, 2013; Kazakoff et al., 2013; Kazakoff & Bers, 2014; Lee et al., 2013; Sullivan & Bers, 2016). In the United States, many initiatives and high quality educational programs are being developed for students beginning in the early elementary years ("About CSforAll," n.d.; Bers, Govind et al., 2022; Code.org, 2021; CSforCA CS Equity Guide, 2020; ISTE-S, 2016). However, these high-quality programs and initiatives often start in kindergarten and similar initiatives and programs do not exist for children in prekindergarten and Head Start programs.

This paper describes a pilot of a high-quality, co-created integrated robotics curriculum, called Coding as Another Language, utilizing the developmentally appropriate KIBO robotic kit, in a Boston preschool offering Head Start and UPK services. The purpose of the pilot was to understand if such a curriculum could a valuable resource for this setting. To ask this, we explored two primary research questions: (1) What was the impact of the CAL-KIBO PreK curriculum on student coding and computational thinking at an early childhood center for children experiencing homelessness? and (2) What were preschool teachers' perceptions of teaching CAL-KIBO PreK at an early childhood center for children experiencing homelessness?

Early childhood coding and robotics

In recent years, developmentally appropriate educational robotics tools, such as KIBO and Bee-Bot, have been created for young children to learn computer science and computational thinking (Bers, 2018; Bers, Strawhacker et al., 2022; Caballero-González et al., 2019; Flannery et al., 2013; Sullivan et al., 2017). Building from the work of Papert and the LOGO turtle programming language, which taught children programming through an embodied coding experience, these robotics platforms include a coding language with which children can program the robot to engage physically with their environment (Caballero-González et al., 2019; Papert, 1980; Resnick et al., 1988; Solomon & Papert, 1976; Sullivan et al., 2015). Another feature of these tools is that they are screen-free, as research suggests that tangible interfaces may be more beneficial for engaging young children in early coding experiences (e.g., Pugnali, Sullivan, & Bers, 2017; Strawhacker, Sullivan, & Bers, 2013). Research has shown that children across early childhood settings gain computational thinking and social skills from working with these tools in the classroom and in controlled experimental settings (Bers, Govind et al., 2022; Caballero-Gonzalez et al., 2019; Relkin et al., 2021; Sullivan et al., 2017).

This study used the KIBO robot, a screen-free robotic kit for children to program using wooden blocks (Bers, 2018; Sullivan et al., 2015, 2017). The robot is designed for children as young as four, but as a tool with a "low floor and high ceiling," it is accessible, approachable, and appropriate for use by children in both prekindergarten and second grade classrooms. Over a decade of research has been conducted on KIBO, involving thousands of children, teachers and families from schools around the US and the world (Albo-Canals et al., 2018; Bers, 2018, 2019, 2020a; Bers et al., 2019; Elkin et al., 2016, 2018; Govind & Bers, 2020; Strawhacker & Bers, 2018; Sullivan et al., 2015, 2017). This research has found that KIBO supports learning of computational thinking skills such as sequencing, iterative design, debugging, and more (Bers et al., 2019; Bers, 2020a; Kazakoff & Bers, 2012).

Further, this learning has been demonstrated in children from a range of backgrounds and in various learning settings, including: PreK-2nd graders in US classroom settings (Bers, 2019, 2020b; Elkin et al., 2016); international early childhood students in countries such as Singapore (Bers, 2020a; Elkin et al., 2018), Argentina (Bers, 2020a; Hunt & Bers, 2021), and Denmark (Strawhacker & Bers, 2018); children in informal settings like makerspaces, libraries, and family centers (Govind & Bers, 2020; Strawhacker & Bers, 2018); and children on the Autism spectrum (Albo-Canals et al., 2018). In addition, the learning of discipline-specific content learning in foundational areas of math and literacy can be supported through KIBO (Bers, 2019, 2020a, b; Kazakoff & Bers, 2012).

A disadvantage of KIBO is that it is one of the more expensive early childhood CS and robotics platforms, with a single kit costing hundreds of dollars. As the platform itself is only the tool, this cost leads to an increased consideration in high-quality and research-based pedagogies and curricula for schools to use when implementing KIBO, as schools consider the financial worth of such platforms and programs. Like many pedagogies for computer science and robotics for early childhood, these require additional time and training for teachers who already operate with limited time, in addition to the cost of the tool, so schools also must consider the ease of use, as well as potential teacher buy-in, for the tool and curriculum.

Coding as another language: an integrated framework for early childhood

As described earlier, tools and platforms themselves are not enough; children also need access to high-quality educational programs. These programs are usually grounded on theoretical frameworks and approaches that set the pedagogical direction of the curriculum used. One such approach is the Coding as Another Language (CAL) framework (Bers, 2019). The CAL framework is an integrated model to teach coding and computational thinking alongside literacy, approaches to learning, and social emotional learning. The framework proposes that coding is a new literacy of the 21st century and as such, coding languages offer a new method for children to communicate, tell stories, share ideas, and creatively express themselves.

The CAL framework focuses on social emotional learning (SEL) and approaches to learning (ATL) (a set of behaviors relating to how children engage in classroom learning) development through two metaphors: the Coding as a Palette of Virtues and the Coding as a Playground and described by Bers (Bers, 2020; Fantuzzo et al., 2004). The Coding as a Palette of Virtues metaphor invites teachers to be intentional about the values or virtues, they bring into the teaching of computer science in the classroom. Bers identifies 10 virtues which have been observed over the years in many different settings: curiosity, perseverance, patience, open-mindedness, optimism, honesty, fairness, generosity, gratitude and forgiveness. However, the "palette" metaphor explains how individuals can not only select virtues from those given, but also to combine them or bring their own new virtues. In the CAL approach, different curricular activities support the development of each of these virtues.

The Coding as a Playground metaphor describes children's behaviors while engaging in a developmentally appropriate, open-ended coding environment as similar to those that appear on a physical playground. This metaphor is grounded on the Positive Technological Development (PTD) framework (Bers, 2006, 2010, 2012). The PTD framework guides the development, implementation and evaluation of educational programs that use new technologies to promote learning as an aspect of positive youth development. The PTD framework is a natural extension of the computer literacy and the technological fluency movements that have influenced the world of education but adds psychosocial and ethical components to the cognitive ones.

As a theoretical framework, PTD proposes six positive behaviors (six C's) that should be supported by educational programs that use new educational technologies, such as KIBO robotics and ScratchJr. These are: content creation, creativity, communication, collaboration, community building and choices of conduct. Some of the Cs support behaviors that enrich the intrapersonal domain (content creation, creativity, and choices of conduct); others address the interpersonal domain and look at social aspects (communication, collaboration, and community building). These behaviors are associated with developmental assets that have been described by decades of research on positive youth development. PTD provides a framework for understanding how technology can be designed and used to promote positive behaviors and how, in turn, those behaviors can promote developmental assets.

Both the C's constructing the Positive Technological Development framework and the virtues identified in the Coding as a Palette of Virtues metaphor align with the key domains for early childhood education such as approaches to learning, a set of behaviors relating to how children engage in classroom learning (Fantuzzo et al., 2004). These behaviors include skills such as curiosity, persistence, and emotion regulation, and are difficult to teach in isolation as they are not domain-specific (Bustamante et al., 2018). Approaches to learning is identified as one of the five central domains of school readiness and early learning outcomes used by organizations across the country, including Head Start and the New York State Education Department (Administration for Children and Families, 2015; The New York State Prekindergarten Learning Standards, 2019). Development of approaches to learning and curiosity in preschool are also important for later educational success (McWayne et al., 2004; Shah et al., 2018).

Grounded in this perspective, CAL curricula for kindergarten, first, and second grades using ScratchJr and KIBO coding languages were developed (Devtech Research Group, 2021). Designed to align with other early elementary curricula, the CAL curricula consist of 24, 45-minute lessons including songs, games, creative coding activities, structured learning sessions, and whole-class sharing activities. The lessons are aligned with many early elementary standards, including the Common Core standards for English and Language Arts and Mathematics, the ISTE student standards, and the K-12 Computer Science framework (ISTE-S, 2016; K-12 Computer Science Framework Steering Committee, 2016; National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010a, b). Prior research with the CAL curriculum has shown that elementary students using the CAL curriculum gain coding language knowledge, and that gains in coding knowledge associated with the CAL curriculum are associated with children's literacy abilities (Bers, Govind, & Relkin, 2022).

The early childhood classroom and curricula

As mentioned, previous development of and research with the CAL pedagogy and curricula has taken place in the elementary setting. However, there are a few key differences between the elementary school environment and the prekindergarten and Head Start environment, which can be seen in the pedagogical frameworks, the curricula, and the physical classroom setting. As seen in the Head Start Early Learning Outcomes Framework, childhood prekindergarten classrooms target a wide range of developmental preacademic and nonacademic domains and objectives (Administration for Children and Families, 2015). The standards include domains for fine and gross motor development, approaches to learning, receptive and expressive language development, and pre-academic skills in domains such as reading, math, and science. In contrast, K-12 classrooms traditionally focus on academic standards such as the Common Core ELA and Math standards and the Next Generation Science Standards (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010a, b; National Research Council, 2015). However, technology is not included in the early childhood standards, and the existing ISTE and Computer Science K-12 standards do not encompass prekindergarten years (ISTE-S, 2016).

There are also differences in curriculum and instruction style between prekindergarten and elementary years. One common curriculum used in Head Start and related programs is the *Creative Curriculum*, which suggests themes for integrative lessons consisting of short whole-group and small-group activities (Research Foundation: The Creative Curriculum®, 2010). However, by kindergarten, there is a reduction in integrated and thematic instruction, and in creative child-led programming such as dramatic play (Brown et al., 2020). The thematic model of instruction in the *Creative Curriculum* lends itself nicely to the introduction of STEM programming (Aldemir & Kermani, 2017). Research with Head Start teachers in North Carolina found that teachers were able to successfully integrate a STEM program with their existing curriculum and found the engineering topic to be their favorite.

This paper describes and uses data from a pilot of the CAL-KIBO PreK curriculum conducted in partnership with a local preschool serving children experiencing homelessness that offered both Head Start and UPK programming to ask two primary research questions: (1) What was the impact of the CAL-KIBO PreK curriculum on student coding and computational thinking at an early childhood center for children experiencing homelessness?

and (2) What were preschool teachers' perceptions of teaching CAL-KIBO PreK at an early childhood center for children experiencing homelessness?

Method

This paper describes and uses data from the first year of a research-practice partnership implementing a KIBO curriculum with a local preschool serving homeless children over the 2021–2022 school year. Students in six classrooms at the preschool participated in the program and were exposed to the CAL-KIBO PreK robotics curriculum in some form. Three of the classrooms were general preschool classrooms serving children ages three and four, while three classrooms were part of the Boston Public Schools UPK program serving ages four and five. Of these six classrooms, the three UPK classrooms piloted the CAL-KIBO PreK curriculum in its entirety.

We used a mixed methods approach, analyzing qualitative and quantitative data from the study, to understand both the measured impact of the curriculum on students' learning and the teachers' perception of the curriculum. We opted for a mixed-methods approach to objectively measure student learning according to validated measures and to gain a deeper understanding of how teachers understood the curriculum implementation and student response in the curriculum. With an integrated and open-ended pedagogy and curriculum, we expected that not all student outcomes would be measured by the validated assessments specific to computer science and computational thinking but could instead be seen in the children's classroom behaviors, so qualitative analysis of interviews allowed us to gain a richer understanding of student outcomes and how the teachers perceived such outcomes for their students. Additionally, for a curriculum to be valuable for schools and early childhood centers, it is important to determine both the efficacy of the curriculum using validated measures, but also to what extent the curriculum would be usable and valuable to the classroom teachers whose buy-in in essential when introducing a new content-domain, curriculum, and pedagogy in an already busy schedule. We specifically opted for a convergent-parallel analysis approach as both the quantitative and qualitative data was collected throughout the course of the pilot program.

The CAL-KIBO PreK curriculum

The Coding as Another Language KIBO curriculum for PreK (CAL-KIBO PreK) was co-developed with the support of early childhood teachers and Head Start administrators to teach the CAL pedagogy to and adapt the existing CAL curricula for students in a prekindergarten setting (anonymized). In alignment with the existing classroom practices of preschool classrooms and the developmental abilities of preschool students, the curriculum is comprised of 30 half-hour lessons and aligned to the Head Start Learning Outcomes Framework (Administration for Children and Families, 2015). The curriculum is freely available online.

The integrated curriculum includes many forms of plugged and unplugged activities, including read-alouds, songs, movement activities, and coding activities. Literacy and language are incorporated both through books and through creative expression with the KIBO robot (see Fig. 1). The curriculum is developed with four suggested books including as

Fig. 1 Photos from classrooms implementing CAL-KIBO PreK curriculum

Fig. 2 Kind and safe with KIBO chart to promote social-emotional and approaches to learning development

Robots, Robots, Everywhere, *Click, Clack, Moo: Cows That Type*, *The Very Hungry Caterpillar*, and *Pete the Cat: Robo-Pete*, but teachers can adapt lessons to include alternate books related to their existing curricula or lesson activities (Carle, 1969; Cronin, 2016; Dean & Dean, 2015; Fliess, 2013).

Additional developmental skills such as approaches to learning, social and emotional learning, and motor development are also targeted through the activities. Teachers are provided with KIBO-specific language to promote expected behaviors when engaging with KIBO, including more traditional classroom expectations such as kind words and safely respecting bodies (both human and robot) as well as approaches to learning behaviors such as persistence and forgiveness of mistakes (Fig. 2). Building and scanning with the KIBO robot and dancing alongside KIBO programs provides opportunities for development of both fine and gross motor skills. The curriculum also provides opportunities and scaffolding for collaboration and communication between peers, including instruction on providing complements and positive feedback.

While there is much research with KIBO and young children, the work presented in this paper is the first study conducted with an integrated robotics curriculum in a preschool population. Furthermore, this is the first study to implement a robotics curriculum for children experiencing homelessness.

Protocol

To prepare for the CAL-KIBO PreK curriculum, teachers attended a four-hour professional development training where they learned about the KIBO robotics language and the CAL-KIBO PreK curriculum. The three UPK classrooms taught the 30 lesson CAL-KIBO PreK curriculum in the winter and spring of 2022. Additionally, the three non-UPK classrooms taught some KIBO lessons during this time but did not teach the whole curriculum. Multiple forms of data were collected from students and teachers over the course of this pilot study. The timeline of the study procedure is in Fig. 3, and a detailed description of the measures is below.

Participants

As mentioned above, we this pilot took place in six classrooms at a local preschool center, and our sample included all teachers and students who consented in the preschool classrooms. Twenty-six teachers took part in the project over the course of the study, with two to three teachers in each classroom. Additionally, each classroom had at least one designated Spanish-speaking teacher who could formally lead bilingual instruction. Teachers had a mean classroom experience of 11.67 years (*SD* = *7.18*), but only three (14.3%) teachers had prior experience teaching computer science or robotics in some form and none of the teachers had prior experience teaching KIBO robotics.

Some teachers left or joined the school (and therefore the study) over the course of the project, and not all classrooms completed the curricula, so not all teachers completed all research protocols over the course of the project. Teachers who joined the school mid-year also did not complete the professional development (as they were not present and employed at the school at the time), but all classrooms had at least one teacher who completed the professional development and could lead KIBO instruction.

Eighty-five children (40 girls, 45 boys) at the preschool for children experiencing homelessness enrolled in the study. As mentioned above, three of the classrooms were general preschool classrooms, while three classrooms were part of the Boston Public Schools UPK program. UPK classrooms completed the pilot curriculum, while general preschool class-

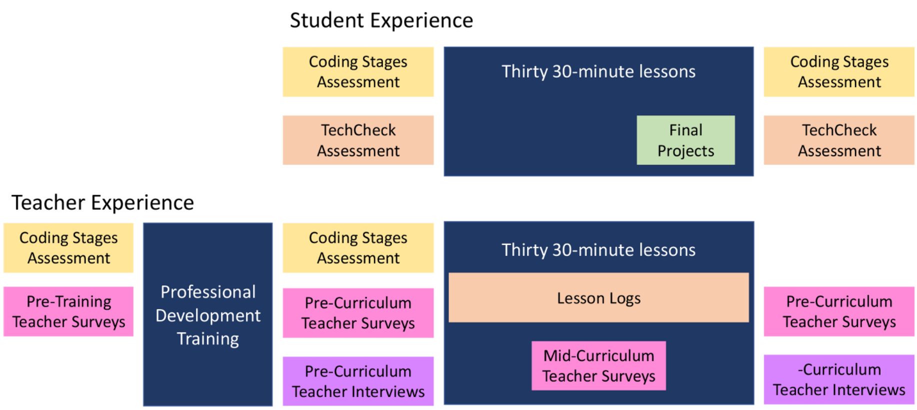

Fig. 3 General Study Procedure for CAL-KIBO PreK Pilot

rooms completed either some KIBO lessons or no KIBO programming at all. Over the course of the research project, 11 children disenrolled from the program while other children transitioned from the general preschool classroom to the UPK classrooms. Forty-six of the eighty-five children were enrolled in a UPK classroom for some portion of time during the CAL-KIBO program.

As mentioned above, the school served local children experiencing homelessness and the students were from multiple racial, ethnic, and linguistic backgrounds. Forty-eight children were Hispanic, including 13 children who identified as Hispanic and Black/African-American. Thirty children identified as non-Hispanic Black/African-American, five identified as white, and one identified as American Indian/Alaska Native. Five primary languages were spoken by the families of children enrolled in the pilot: English ($n=41$), Spanish ($n=33$), Cape Verdean Creole ($n=2$), Haitian Creole ($n=7$), and Amharic ($n=2$).

The research design consisted of two assessment periods, one in the fall and one in the spring. Children who began in preschool or UPK classrooms after the study began were enrolled in the study and completed assessments upon enrollment. Post-assessments were only completed for children who spent time in a UPK classroom and therefore experienced the curriculum and children enrolled in the study in the fall and spent the entire year in the general preschool classroom. Children who enrolled in the general preschool classroom in the early spring and did not experience the curriculum did not complete a second spring assessment.

Forty-nine children completed post-assessments – 40 in UPK classrooms and nine in general preschool classrooms. As we are interested in understanding the impacts of the pilot implementation of the CAL-KIBO curriculum on children's coding knowledge, only data from children who spent time in the UPK classrooms and experienced the CAL-KIBO PreK curriculum is included in the quantitative analysis. However, our qualitative dataset includes teachers in both UPK and general classrooms in order to holistically understand the program implementation including barriers.

Measures

Coding knowledge

Coding knowledge and skills were assessed using the KIBO Coding Stages Assessment (Strawhacker et al., 2022). This is an assessment of coding specific to the KIBO coding language that looks at how children develop from emergent programmers to purposefulness in their use of coding for expressive purposes (Bers, 2020a; de Ruiter & Bers, 2021). The assessment accounts for transitioning between five stages (Emergent, Coding and Decoding, Fluency, New Knowledge, and Purposefulness) with six questions specific to the KIBO coding language for each coding stage. Participants must answer five of the six questions in each stage correctly to move on to the questions associated with the next stage. Both children and teachers completed this assessment. Teachers were assessed before and after the professional development training, while children were assessed before and after curriculum implementation. Because this tool assesses the full spectrum of KIBO language fluency and is used to assess KIBO language use for all ages, a perfect score indicating that the user has reached full control of the KIBO programming language is not the expected outcome for a single prekindergarten coding curriculum or intervention.

Computational thinking

Computational thinking was assessed using the validated TechCheck assessment (Relkin, 2022; Relkin et al., 2020; Relkin & Bers, 2021). TechCheck is a computational thinking assessment for prekindergarten, kindergarten, first, and second grade students, and has been validated for kindergarten, first, and second grade students. As the children in this study were between the ages of three and five and were enrolled in preschool, this study utilized the TechCheck PreK assessment. The TechCheck PreK assessment consists of fifteen multiple choice questions, each with three possible answers. Each item is indicated as either correct or incorrect, and students receive a summed score of up to fifteen. Figure 4 displays an example question regarding sequencing and algorithms. For this question, the assessor asks the child, “Which comes next? The first one, the middle one, or the last one?” prompting the child to complete the pattern.

Teacher interviews

We interviewed teachers using a semi-structed interview protocol at two time points: following the professional development training prior to curriculum implementation, and at the conclusion of the KIBO project. We opted for semi-structured interviews as they would allow us to ask similar questions for each participant while also allowing for individual teachers’ elaborations and unique answers to gain an understanding of teachers’ individual perspectives. The interview guide consisted of open-ended questions and follow-up prompts across a number of themes, with interviewers able to ask additional follow-up questions based on teachers’ responses.

Interviews were conducted individually over zoom by graduate research assistants who were involved with the project and familiar to the teachers. Zoom was used both because the project began in Fall 2021 during the Covid-19 pandemic and because Zoom offered an auto transcription feature. Interview transcripts were then cleaned by undergraduate research assistants. Initial interviews took between 15 and 30 min, and post-teaching interviews took between 40 min and an hour.

In initial interviews, teachers were asked about their experiences with the professional development training, their thoughts about KIBO, their prior experiences with coding, and their expectations for implementing KIBO and the curriculum in their classrooms. In the post-teaching interviews, we asked the teachers who taught the curriculum about their experiences teaching KIBO and the curriculum. We also asked these teachers about their observations related to development, literacy, and the CAL pedagogies in their students and themselves. We asked teachers in the general preschool classrooms who did not teach the curriculum or only taught individual KIBO lessons about their experiences and observations

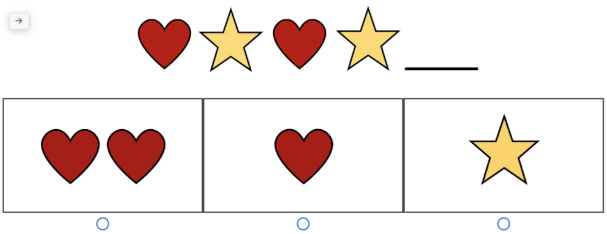

Fig. 4 Example TechCheck-PreK question

teaching KIBO in their classrooms, as well as about specific barriers to teaching KIBO and the CAL-KIBO PreK curriculum in their classrooms.

Analysis

Quantitative

Thirty-five students completed both the CAL-KIBO PreK curriculum and pre- and post-curriculum testing on the Coding Stages Assessment of coding language knowledge and the TechCheck assessment of computational thinking. These scores were analyzed quantitatively in R using the tidyverse and effsize packages (R Core Team, 2020; Torchiano & Torchiano, 2020; Wickham et al., 2019).

Qualitative

The teacher interviews were analyzed qualitatively in NVivo using a thematic analysis approach (Clarke & Braun, 2013; Kiger & Varpio, 2020; Lumivero, 2023). We used a combination deductive-inductive approach where first, quotes from the interviews were identified according to a deductively-created codebook developed from our research question. This hybrid method allowed us to narrow in on our research question of teachers' perceptions of the CAL curriculum (Clarke & Braun, 2013). During this time, we familiarized ourselves with the data. We then generated first-level codes from these quotes. In a recursive process, we then searched for, refined, and defined and named themes. No unexpected obstacles were encountered during the analysis process.

Coding was conducted by one author, the research coordinator of the project based at a university in the Northeast United States. The author was on the curriculum development team, had positive experiences with teaching STEM, and had previously worked in early childhood centers, but was not an employee of the center in question.

Results

The findings of this project are organized around the two research questions that were explored.

Outcomes of CAL-KIBO PreK

The first research question revolved around student outcomes from the CAL-KIBO curriculum. To answer this, we analyzed student assessments of coding knowledge and computational thinking. We also analyzed teacher interviews using a thematic approach, and descriptions of powerful ideas of computational thinking outside of the CAL-KIBO curriculum activities emerged from the interviews.

Coding knowledge

Coding knowledge before and after the curriculum was measured with the Coding Stages Assessment (CSA) (Fig. 5). Students significantly improved in their coding knowledge between their pre-curriculum (M=3.57, SD=2.94), and post-curriculum (M=8.17, SD=5.16) assessments, $t(53.98) = -4.58$, $p < .0001$. This was a large effect as determined by Cohen's d (d=1.09). When scores were converted to developmental coding stages, 88.6% of children were in the *Pre-Coding* stage prior to the curriculum, but 25.8% of children were in the *Emergent* stage and 25.8% were in the *Coding and Decoding* stage after completing the curriculum (Fig. 6).

Computational thinking

Computational thinking knowledge was assessed using the TechCheck-PreK assessment. There was no significant difference between pre-curriculum (M=7.60, SD=3.04) and post-curriculum (M=7.68, SD=2.95) TechCheck scores, p=.96 (Fig. 7). This suggests that the curriculum may not target the computational thinking skills assessed by the TechCheck assessment.

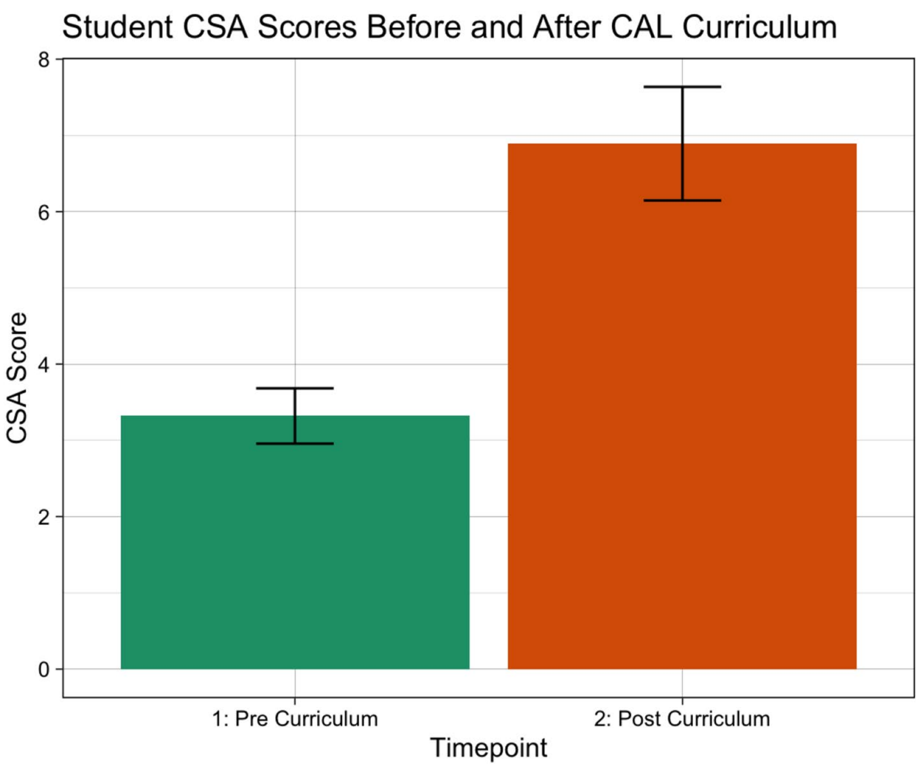

Fig. 5 Children's coding knowledge pre and post curriculum

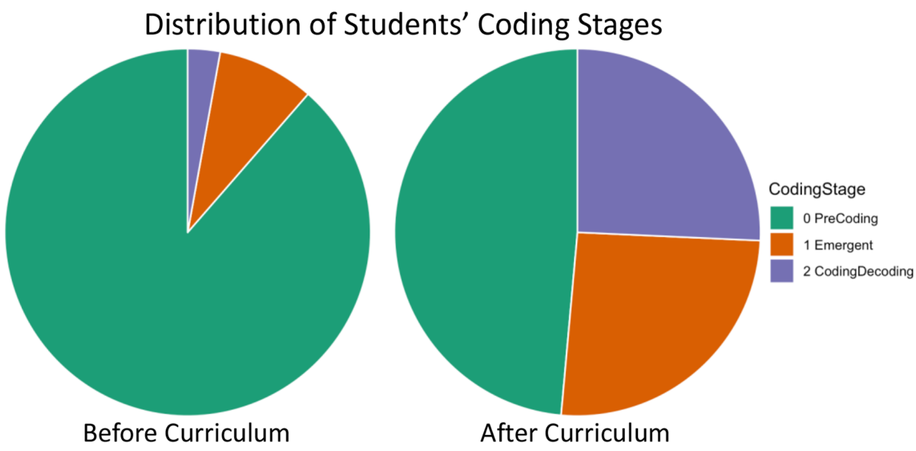

Fig. 6 Distribution of coding stages pre- and post- curriculum

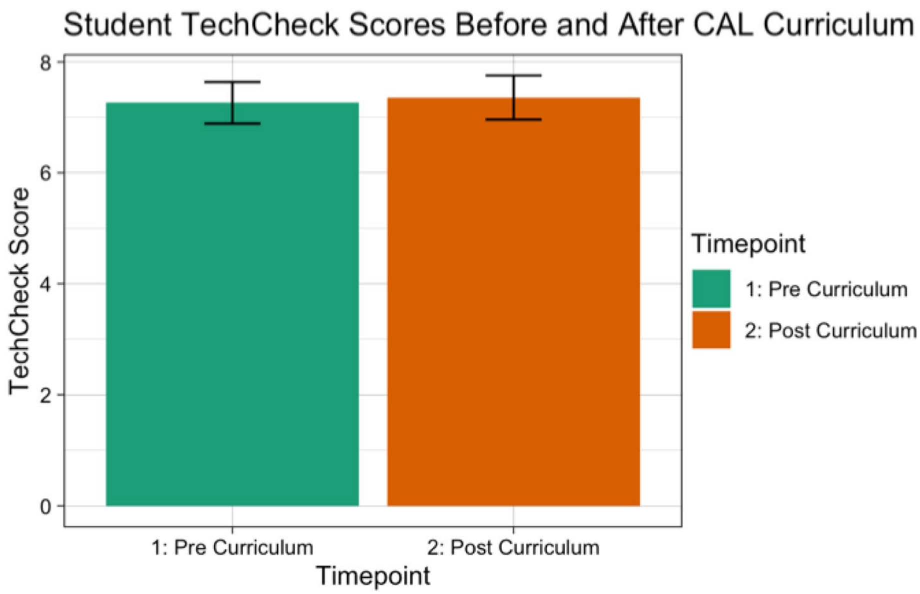

Fig. 7 Children's computational knowledge pre and post curriculum

Computational thinking in the classroom

A theme that emerged from the interviews was descriptions of developmentally appropriate computational skills carrying over to lessons and activities outside of the CAL-KIBO curriculum. Specifically, descriptions of algorithmic thinking, debugging behavior, and the understanding and recognition of robots as programmed items rather than sentient beings were described in teacher interviews. One teacher described children's understanding of algorithms in their morning routine: "even with following directions, we will talk about step two, step [three], and they were correlated with KIBO. Like KIBO, we have to begin, and then we do this, and then we finished. So…like our morning routines when they walk in – so they walk in, they go to the cubby, they wash their hands, they sit for breakfast, then the ending is we sitting for circle." One teacher described students' problem solving and debugging skills carrying over outside of KIBO activities, explaining "Even in things not related to KIBO, like I noticed them trying to talk it through and work it out and figure out how to when they didn't as much before." Finally, one teacher described the value of working with and programming robots on the children's understanding of robots as programmed items rather than sentient beings as seen in media. "They [the children] watch a lot of cartoons, a lot of robotic sentient beings who are operating on by their own volition, but then realize in the real world right now, robots are all programmable. They do things that we tell them to do."

Teachers' perceptions of CAL-KIBO PreK

The second research question was about teachers' perceptions of the CAL-KIBO program, and a few themes emerged from the interviews regarding the teachers' perceptions of the curriculum and its implementation. Themes included the integration of the curriculum into the existing curriculum, barriers to teaching the CAL-KIBO curriculum, and student and teacher enjoyment from the curriculum.

Integration of CAL-KIBO PreK with existing curriculum

One theme that emerged from the interviews was the integration of the CAL-KIBO PreK curriculum in the teachers' existing teaching practice. Specifically, sub-themes emerged about teachers' initial hesitancy towards the curriculum, the alignment of the CAL-KIBO curriculum with existing curricular content, and further connections made by students and teachers to integrate KIBO in their curriculum.

The hesitancy initially described by teachers at the introduction of the CAL-KIBO curriculum was primarily related to the challenge of adding a new curriculum and material to an already busy schedule. One teacher, reflecting in the post-interviews, explained, "I was skeptical at first…about where we got to fit this in."

Additionally, teachers described the content of the CAL-KIBO curriculum as aligning nicely with existing curricular content in their prekindergarten classroom. One teacher described how the discussions of language in the CAL-KIBO PreK curriculum aligned with existing whole-classroom discussions of the languages and the multiple languages spoken in their classroom. Multiple teachers described how KIBO lessons on sequencing and respecting space helped reinforce the learning goals of calmly and safely lining up for activities.

Finally, the teachers described further connections made by themselves and the students incorporating KIBO in the classroom. Some teachers explicitly integrated KIBO and KIBO learning into additional activities such as classroom centers beyond the formal KIBO lessons, with one teacher describing "in dramatic play, I think we did a cash register or a store… they like would put something on KIBO and do the program where it will go to the left and go to the right, and the kids would use it to serve the customers." Other teachers described how children organically made connections and brought attention to KIBO during non-KIBO programs. One teacher explained that the children would "reference KIBO in the most random of situations. The forever loop as well. They were like ‘We can’t walk forever like KIBO’ to the playground, and it was so far for them, they were so tired.”

Barriers in implementing CAL-KIBO PreK

Descriptions of two barriers to KIBO implementation emerged from the teacher interviews: language-related barriers in the UPK classrooms, and developmental barriers in the non-UPK classrooms with younger children who did not teach the full CAL-KIBO PreK curriculum.

In the UPK classrooms, the primary barriers identified by teachers in teaching the CAL-KIBO PreK curriculum were related to implementing the monolingual CAL-KIBO PreK curriculum in bilingual classrooms. One non-Spanish-speaking teacher said, “if I’m not Spanish-speaking, and we have children in the classroom who need to learn -- how would we be able to implement it?” Additionally, one Spanish-speaking teacher mentioned some of the coding and robotics specific vocabulary was difficult to translate.

In addition to descriptions of the challenges, there were also descriptions of the adaptations teachers made to their instructional practices to accommodate the needs of Spanish speaking students. One method used in bilingual classrooms was grouping students by language for small-group activities to provide Spanish-language support to the Spanish-speaking students, with one small group receiving KIBO time in translated Spanish and one group receiving KIBO time in English. One teacher said, “once we split the groups into the Spanish speaking groups – we still did some whole group activities with them, but in a split whole group – it work[ed] so much better.” When not grouping students by language, teachers also taught bilingually, translating materials in real time and alternating instruction in English and Spanish.

As reported above, the non-UPK classrooms did not teach the CAL-KIBO PreK curriculum, although some completed some KIBO lessons. These classrooms had younger children, between the ages of 2.9 and four years old. Within these lessons, the challenge described by teachers was the developmental appropriateness of the curriculum for children as young as 2.9 years old. One teacher noted that “they just don’t understand the concept or have the focus to really even try to understand the concept but they like messing around with it and seeing how things move, even if the teachers do it for them.” This challenge was expected, as neither curriculum and the KIBO robotics set were developed for children three years old or younger. However, teachers still found benefits of introducing KIBO in the younger classrooms. One teacher explained how “one of the things that we’re doing in this the younger preschool classroom is taking out a group of children that can focus and having them do it… so that some of the children are getting that hands-on experience with little disruption… every lesson they enjoyed that individual, you know the smaller group size, and being able to put the hands on it and explore it.”

Teacher feelings of KIBO and curriculum

The final theme to emerge from teacher interviews relating to the teacher perception of the program was teacher descriptions of feelings relating to KIBO and CAL-KIBO-PreK implementation in the classroom. These descriptions included feelings of nervousness before teaching the curriculum, and feelings of enjoyment from teaching the curriculum.

Before teaching the curriculum, some teachers expressed nervousness regarding teaching robotics, which was a novel subject some had initial anxieties regarding themselves. One teacher explained the initial worry as relating to her own lack of knowledge, saying “oh no, how am I going to teach them something that I don’t know nothing about?” Another teacher explained that “I’m not really like the robotic type person…Because when I first heard the idea I’m like: “How are we going to teach kids how to use this?”

However, in the post-curriculum interviews, descriptions of feelings centered around of teachers’ enjoyment with the KIBO robot and CAL-KIBO curriculum. When one teacher described a debugging activity, she highlighted the fun element of the lesson, explaining “I really enjoyed acting like ‘Oh my gosh, I don’t know what to do. My KIBO’s not working. I need your help.’ I’m very dramatic sometimes. I’m a little over the top and dramatic with them sometimes, so that was really fun, whenever I would do something, and they would help me.”

Discussion

This paper describes a pilot study of the CAL-KIBO PreK curriculum, a preschool curriculum infusing coding and robotics instruction with language, literacy, social emotional learning, and approaches to learning. The research questions of the paper were (1) What was the impact of the CAL-KIBO PreK curriculum on student coding and computational thinking at an early childhood center for children experiencing homelessness? and (2) What were preschool teachers’ perceptions of teaching CAL-KIBO PreK at an early childhood center for children experiencing homelessness?

Assessments of student outcomes suggested that children as young as four gained knowledge of the coding language of the KIBO robot. There was large significant improvement in coding language knowledge over the course of the curriculum, suggesting that the curriculum was effective for teaching young children to code with the robot. Computational thinking as assessed by the TechCheck instrument did not statistically improve over the course of the curriculum. However, teachers described evidence of computational thinking learning through powerful ideas such as algorithmic knowledge, debugging, and the recognition of robots as programmed artifacts rather than sentient beings. This suggests that children were learning about and gaining skills in computational thinking, even if that growth was not measured on the TechCheck assessment. This may be for a few reasons. The curriculum may not be targeting the same CT skills as the TechCheck assessment. Additionally, the population of this preschool is primarily minoritized children and includes second language learners and students with trauma-related developmental delays. As the TechCheck assessment has been validated using a sample of majority English-speaking children without disabilities, it is possible that TechCheck is not culturally sensitive for or is not accurately measuring the computational thinking knowledge of this sample. Finally, TechCheck is an assessment of computational thinking unplugged from the coding context, meaning that it required students to transfer any learned computational thinking skills to a novel and unrelated setting. It is possible that developmentally, the students were not developmentally yet able to transfer the learned computational thinking skills to the TechCheck setting, even if they were able to display them in the classroom or during coding lessons.

We found that teachers of four- and five-year old students had an overall positive experience with the curriculum. These teachers found the curriculum to fit nicely within their existing classroom curricula and practices and to be developmentally appropriate for their students. Teachers of three-year old students found the curricula to be too advanced for their children and that it did not fit within their existing classroom setting, although they enjoyed introducing their children to the KIBO tool. This finding met our expectations, as the curriculum was designed for four- and five-year old children in the year before entering kindergarten and as the KIBO tool is designed for children as young as four years old.

Additionally, we found that teachers at the participating pilot preschool site were challenged by the monolingual aspect of the curriculum, which was available only in English. Teachers commented on how a bilingual curriculum would have better served their specific site and community. As mentioned above, this preschool provides bilingual programming in Spanish and English. The teachers were provided with the curriculum materials in English, as well as an English professional development. However, no materials or additional training was provided in Spanish, which may have limited teachers' confidence in providing CS instruction bilingually. The teachers, who have training and expertise in bilingual education, were able to adapt and provide the instruction by translating materials and intentionally grouping students. However, not all teachers in of English language learners or bilingual students have this training and expertise, suggesting that simply introducing KIBO or an early childhood robotics program to a classroom of English language learners without adapted materials would not necessarily provide opportunities for bilingual students to access the computer program. Additionally, providing KIBO or an early childhood robotics program to bilingual teachers without bilingual materials creates additional work or requires an additional time investment for the teachers in preparing or translating lessons, in addition to the time investment required to learn the curriculum and pedagogy. Without consideration of the needs of bilingual students, English-language learners, and their teachers in Head Start and UPK classrooms, simply introducing CAL-KIBO or early childhood robotics and CS programs are not guaranteed to improve equity. Future research should explore how scaffolded supports such as the translation of key materials or additional multilingual professional development options may provide better support for bilingual early childhood CS teachers.

Previous work with the CAL curriculum has examined the original CAL curriculum for early elementary classrooms, which as mentioned above, is designed for children in kindergarten through second-grade classrooms in alignment with Common Core standards for ELA and math. This pilot was the first to apply the Coding as Another Language pedagogy to an alternate classroom setting and set of standards, reconfiguring the curriculum to align with the Head Start Early Outcomes Framework and a preschool classroom using the Creative Curriculum. As mentioned above, findings from classrooms implementing the elementary CAL curricula have shown that the curriculum can lead to increases in coding knowledge and that coding knowledge growth is associated with language and literacy skills. The findings from this paper suggest that the CAL pedagogy, and its benefits for early childhood coding and literacy learning, are not limited to the original K-2 curricula and the K-2 classroom setting. The findings from this pilot suggest that the CAL pedagogy can be adapted to other classroom settings, such as a center-based early childhood classroom, and aligned with pedagogical frameworks beyond the Common Core, such as the Head Start Early Learning Framework.

In addition, these findings suggest that teachers see value in implementing the curriculum in their classrooms. When introducing early childhood computer science and robotics programs in schools, many questions revolve around the costs of such implementation and if the curricular outcomes are worth it. Robotics platforms such as KIBO are expensive, and as described by the teachers, many teachers are not comfortable with robotics and must learn the subject themselves in addition to learning the curriculum to teach it, meaning that already limited time must be dedicated to professional development and coaching. However, our findings suggest that the teachers saw value in investing and implementing KIBO in their UPK classrooms of four- and five-year-old children. This not only points to the value of the curriculum in improving student outcomes as seen by teachers, but also suggests that teachers would enjoy and be willing and open to implementing the program. For this reason, the curriculum and platform may be worth the cost and instructional time, as administrators would be providing a tool that teachers would enjoy using and see benefit from.

Limitations

This pilot was conducted in the 2021–2022 school year, which was an atypical year as preschool sites transitioned out of the COVID-19 pandemic. At times, our partner site engaged in pandemic protocols including limiting visitors and shutting down the classrooms after exposures. These limited our ability to conduct all research activities at all times as well as the ability of the classrooms to smoothly and consistently implement the lessons without disruption. As such, the results from this pilot may not generalize to every school year, especially coming out of the COVID-19 pandemic and now that vaccinations are available for preschool age children.

Conclusion

This pilot study showed that the CAL pedagogy could be adapted for the preschool setting using the Head Start Early Learning Outcomes Framework and implemented in classrooms of four- to five-year-old students. The CAL-KIBO PreK curriculum was feasible for teachers, blended nicely with their existing curriculum, and led to increased coding and robotics knowledge for prekindergarten students. The curriculum was less successful in classrooms with students under four years old, possibly because those students are under the recommended age for KIBO. Future work should examine the curriculum in a larger sample of four- and five-year-old students and with a control group, as to examine the effect of time on quantitative measures of student performance such as coding knowledge and computational thinking. Future work should also include a bilingual curriculum and curricular resources, to reduce the barriers experienced by teachers in bilingual classrooms.

Acknowledgements We would like to thank Amanda Martinez, Jayd Rodrigues, Sheila O'Neil, and the teachers at Horizons for Homeless Children for their partnership on the CAL-KIBO Prekindergarten project. We would also like to thank Dr. Amanda Strawhacker, Dr. Emily Relkin, Dr. Madhu Govind, Madeline Nievera, Sam Schwamm, Aliza Bromberg Gaber, Alexa Hasse, Mira Eschtruth, and Miela Efraim for their assistance with the CAL-KIBO Prekindergarten project.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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