Augmented Reality for Sustainable Collaborative Design

Ms. Eunice Kang

Eunice Kang is an undergraduate student at Boston College studying international studies with a concentration in ethics and social justice as well as a minor in computer science. She is a research assistant in Dr. Avneet Hira's HER lab.

Dr. Shulong Yan

Shulong Yan is a Postdoctoral Research Fellow in the Human-Centered Engineering program at Boston College. Her research focuses on designing and developing equitable learning environments to foster K-12^{+} students' collaborative learning and human-centered design skills in informal spaces.

Ms. Sophia Brady

Sophia Brady is an undergraduate student at Boston College studying Computer Science and Political Science. She is a research assistant in Dr. Avneet Hira's HER lab.

Dr. Andrew Katz

Andrew Katz is an Assistant Professor in the Department of Engineering Education at Virginia Tech. He received his Ph.D. in engineering education from Purdue University, has a master's degree in environmental engineering from Texas A&M University and a bachelor's degree in chemical engineering from Tulane University. His research focuses on engineering ethics, decision-making, and system development. To do this, he examines topics such as faculty mental models of engineering ethics and education, processes of change in ethics education, and students' views of ethics and social responsibility.

Dr. Avneet Hira

Avneet Hira is an Assistant Professor in the Human-Centered Engineering program at Boston College with a courtesy appointment in the Department of Teaching, Curriculum, and Society. Her scholarship is motivated by the fundamental question of how engineering and technology can support people in living well in an increasingly engineered world. Her research, which is in engineering education, focuses on affordances of technology, humanistic design, and engineering epistemology. Her work is inspired by Making and tinkering practices, especially those from different local knowledge systems.

Augmented Reality for Sustainable Collaborative Design

Introduction

This paper proposes a conceptual framework to explore the affordances of augmented reality (AR) in supporting collaborative learning within sustainability and engineering education. Our framework is informed by prior literature and affordances of relevant technologies and engineering design processes. After introducing the framework, we describe an example activity in which we specifically seek to understand the development of civic engagement and sustainability-related mental models among middle and high school students. This activity is mediated by the digital learning platform of MergeCube (an AR platform) and grounded in engineering design.

Our primary goal is to understand *how engaging with augmented reality in an engineering design setting facilitates the development of knowledge and skills related to sustainability and the role of engineers in creating sustainable solutions?* Specifically, *how does working hands-on in teams of two with the MergeCube facilitate discussion, negotiation, and understanding of sustainability and the role of engineering*?

Background literature

Adopting a complex systems-oriented pedagogical approach to support sustainability education. Tackling environmental issues and motivating sustainable living practices require us to approach them from a complex systems perspective. They require us to understand the interconnectedness of systems and make a collective effort to address environmental problems [1]. An individualistic approach to life is considered a major factor contributing to the current environmental challenges [2]. Scholars have recognized the need for inviting multiple stakeholders to jointly tackle these complex and interconnected environmental issues [2]–[5]. As the challenge of creating sustainable living is intrinsically a *team sport*, individual efforts are not enough.

However, collaboration among multiple stakeholders does not always deliver expected positive results [3] since the quality of micro-level (person to person) collaboration plays a critical role in any joint endeavor [6]. The term *system* within the complex systems perspective is often limited to macro-level systematic relations and seldom encompasses micro-level interactions. Most prior work in sustainability education has focused on macro-level collaboration between organizations, such as those between schools, communities, and local governments. Fewer studies focus on micro-level collaboration at an individual and the small group level and explore how individuals work together to discuss sustainability issues and practices. The success of any collaborative effort is influenced by multiple skills that actors draw upon and carefully navigate for creative problem-solving [7]. Scholars consistently recognize how dysfunctional communication can lead to failed collaborations in multiple fields, such as in Computer-Supported Cooperative Work (CSCW) and Computer-Supported Collaborative Learning

(CSCL), and the field of organizational psychology or business studies [6], [8], [9]. In other words, though ideal collaboration has the potential to deliver innovative solutions that individual endeavors cannot achieve, this ideal is rare to observe.

Use emerging technologies to create participatory and relevant learning experiences to support sustainability education during the pandemic. When it comes to sustainability education, scholars argue the importance of developing learning environments *relevant* to learners' daily lives and designing *participatory* activities [1], [10]. Such environments allow learners to engage in authentic ecological problems, construct their learnings collaboratively, and practice within a community. One of the pedagogical approaches to developing such learning environments is *place-based learning* which focuses on establishing partnerships between local communities and schools in project design and implementation [4], [11]. Studies show that schools that create collaborative partnerships with local communities allow students to work on real-world problems, and provide authentic learning experiences, which in return, improve their academic achievement and civic engagement, compared to traditional textbook and lecture modalities that focus on instilling abstract concepts to students [4], [12].

Equally crucial as engaging learners with authentic problems is creating a learning environment that encourages learners' participation to make changes in the ecological systems they are part of and develop a sense of connection with others and their physical spaces [13]. Design as an approach that centers on making changes to the environment also provides opportunities for learners to develop essential skills such as collaboration [14]. It encourages participants to innovate and solve complex problems through iteration. The iteration process creates more equitable learning methods and participation for learners with different needs and interests [15], [16].

The COVID-19 pandemic has unfortunately paused or limited learners' participation and interaction in their local communities and other hands-on learning activities at school that may have supported their emotional attachment to real-world problems—in this case, issues regarding the environment [4], [11], [17], [18]. Studies show that technology and its rapid evolution have the potential to play a significant role in increasing the engagement of students and improving their overall learning experiences [19]. As the field of technology continues to improve and offer newer and more accessible virtual experiences, scholars turn their attention towards exploring the role of emerging technologies in facilitating awareness and ultimately assisting students in taking further action [18].

Emerging technologies such as augmented reality can create blended learning environments that create new participatory learning methods. Augmented reality allows students to build knowledge using information they already perceive from the outside world and iterate different solutions sustainably [12], [20], [21]. Additionally, the tool supports the engineering design process in using mental models to develop a more holistic understanding of the presented problems [21]. Studies reveal that technologies like augmented reality can increase student motivation and interest by offering an on-site real-world experience that helps students understand their work to be relevant [20], [22]. For example, one study on an augmented reality mobile application (NetAR) developed for engineering students to complement traditional education showed increased student motivation by 11%, as measured in the study [22]. Through visual stimulation that students may interact with, AR allows for greater retention of information and material through a more hands-on, constructivist approach [23]. The use of emerging technologies (especially those that allow visualization of extended realities) has the potential to support students in understanding how their designs fit into the larger ecological systems [24]. This way, students can move past the immediate sense of novelty while interacting with AR to reflect on personal experiences and their surrounding community's needs to better address and ultimately alter their design solutions. Recent advancements in cell phone hardware and access to the internet have also made AR more accessible and cost-effective than most other emerging technologies. AR and other extended/virtual realities afford visualization of systems-level concepts that individuals often cannot comprehend within their everyday actions.

However, existing studies lack emphasis on the students' agency to *change* their designs because most AR protocols were pre-made prescriptive applications. As discussed earlier, learners should be able to know that they can change their designs based on what would make them more applicable to their everyday lives [1]. Though students feel an immediate sense of novelty while interacting with AR, their takeaways from the learning experiences are equally as important, making these takeaways relevant to their everyday lives. Also, current studies emphasize how AR may increase interest in, and retention of technical information but lack information on how working with AR on a design activity may simulate collaboration, negotiation, and agency. Some studies have recognized AR as a potential bridge between cognitive and emotive learning but have not explored its relation to the engineering design process and sustainability topics. Studies show the need for collaboration in learning about sustainability topics but lack information about how technology, like AR, may facilitate collaboration, negotiation, and agency among participants.

Conceptual framework

Synthesized from prior literature, we propose a conceptual framework to explore the affordances of augmented reality in supporting collaborative learning within sustainability education, addressing significant gaps in the current state of literature in the field. Figure 1 is a representation of our proposed conceptual framework. Sustainability-related Education, especially in design settings, necessitates a systems approach that supports students in practicing and developing skills for collaboration and iteration. Augmented reality allows students to collaborate on systems-level designs and iterate through several prototypes.

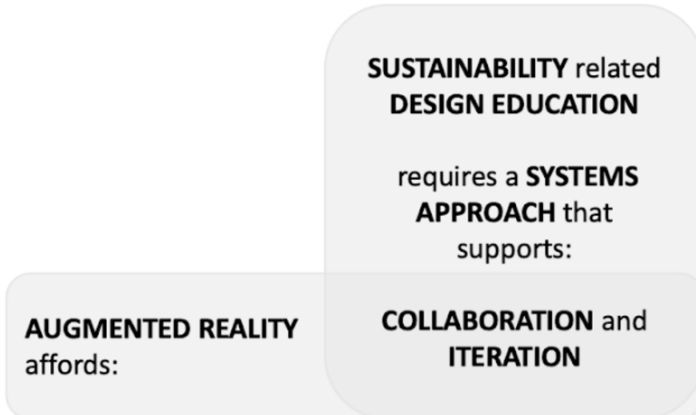

Fig 1. Representation of the conceptual framework

Design of a learning experience situated in the conceptual framework

This section describes a workshop design for elementary and middle school students grounded in the conceptual framework discussed earlier. In the workshop, students used CoSpaces (an online platform for students to build 3D creations and animate them with code) and MergeCube (a physical cube that acts as a digital canvas for augmented reality) to plan and create sustainable digital cities. Before they started building, students were asked to consider:

1. Who are engineers, and what do they do?
2. What role do engineers play in sustainable development?

Next, students were given a brief presentation on sustainable city planning and urban development with a specific focus on the role of engineers in promoting sustainability. Using this knowledge, students worked in pairs on Cospaces to create small-scale sustainable cities that can be visualized with MergeCube Augmented Reality. Design teams dragged and dropped various features like windmills, buses, bikes, and trees into the Cospaces scene. To introduce the concept of *constraints* in designing for sustainability, we created an end goal that included specific demands regarding housing, resources, and transport and a points system to calculate the "sustainable impact" of the various features in their cities.

After creating their cities, students coded text features describing why they included the sustainable features they chose. This activity was intended to facilitate discussion and negotiation between team members and engage students in computer programming. After finishing their projects, students shared their MergeCube world with their peers and explained their rationales.

Example activity. By default, students join the class Cospace. They see a cube with a grass background and a windmill placed atop the cube (Figure 2). The creator placed these features as a baseline for the students' design. At this point, students may drag and drop objects from the Cospace library, such as residential and industrial buildings, roads, trees, bikes, buses, and solar panels, onto their MergeCube to represent their sustainable design choices.

Figure 2. Default workspace created for students in Cospace

Once students have built-up their city to their liking, students are required to explain the reasoning behind their sustainable design choices via animated text boxes which are programmed with Cospaces block programming feature, "CoBlocks." (Figure 3) The students have to program a feature that allows their design explanations to remain hidden until the user taps on the text boxes.

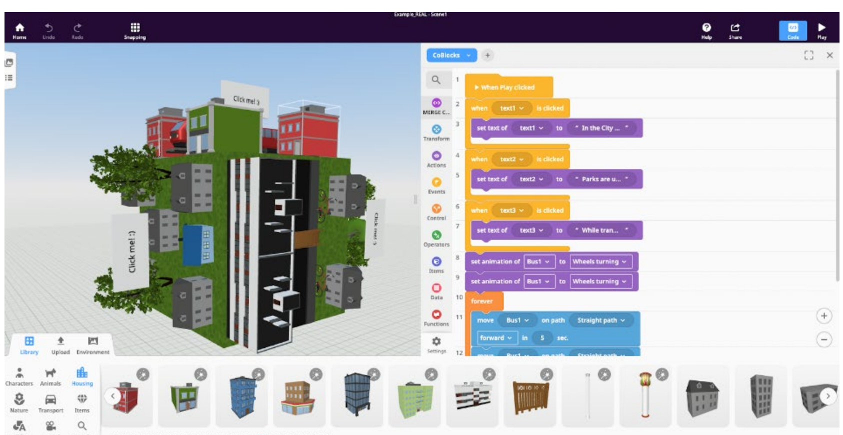

Figure 3. Block programming with CoBlocks

When the student is finished with the design and programming aspect of the project, they are able to project their Cospaces design onto the MergeCube (Figure 4). Students may physically interact with their design by turning the box on all sides to see all design aspects at different proximities and angles. Students may tap on their programmed text boxes to reveal text.

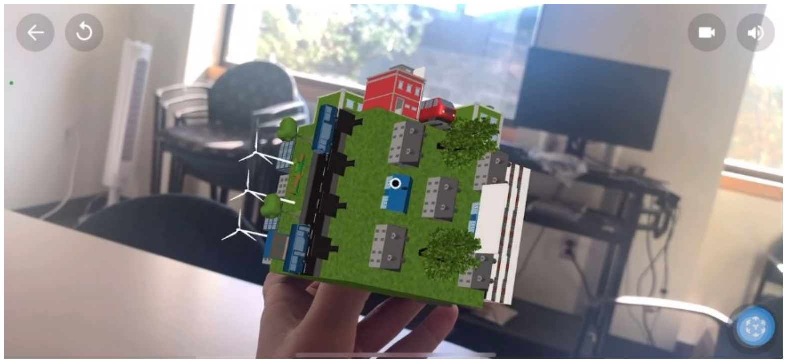

Figure 4. Projected designs on the MergeCube when looked at through a tablet or cell phone

Research method and preliminary findings

So far, we have implemented the workshop twice in an afterschool club in Massachusetts. Most elementary and middle school children who joined these two workshops identified themselves as Black or African American and multiracial. With the approval of the Institutional Review Board, we collected multiple types of data – observations and video/audio recordings, artifacts, pre, and post-semi-structured interviews. To answer our research questions and further evaluate the design of this workshop, we used thematic analysis [25] to analyze the interview data and interaction analysis [26] to analyze the observation data and recording data.

The preliminary findings from the pre and post interviews and the video recording show that the design of this learning environment provides multiple learning opportunities that strongly relate to sustainability education. Within the design process, learners had to negotiate with their teammates about the different design features they added to their cities. At the same time, they calculated their city's sustainability score based on a points system. They also gradually connected individual living elements such as housing and transportation to their city's ecological system. With the ability to project their design onto the MergeCube using augmented reality, they could get a more "real" visualization of their city. At the same time, the presence of the MergeCube allowed them to manipulate the visualization, such as flipping sides and zooming in, freely. Our findings suggest that the concept of "sustainability" was not very well understood by our participants, which was evident in our pre-interview data. Though they had a sense that sustainability relates to the environment, most participants regarded sustainability as a method of ending human suffering, such as hunger, sickness, and death. When they were asked what new information they gained at the end of the workshop, many of them mentioned the different things "humans need" to live well. As design as a practice requires them to synthesize both personal sensemaking and public framing, including understanding their teammate's ideas and the points system [27], learners started creating a new meaning of sustainability as a negotiation between the environment and what they believe are human needs.

Conclusions

The work presented in this paper explores the possibility of supporting sustainability education using collaborative design approaches and augmented reality. Grounded in our conceptual framework, we designed and implemented a study to understand the outcomes of a hands-on sustainable city-building exercise for youth. Our preliminary data analysis suggests that engaging students in hands-on engineering design activities with augmented reality supports learners to experience abstract and complex systems and construct meanings of sustainability through discourse, making, and visualizing.

References

[1] L. B. Allen and K. Crowley, "Moving beyond scientific knowledge: leveraging participation, relevance, and interconnectedness for climate education," *Int. J. Global Warming*, vol. 12, no. 3–4, pp. 299–312, 2017.

[2] R. Lozano, "Collaboration as a pathway for sustainability," *Sustainable Development*, vol. 15, no. 6, pp. 370–381, 2007, doi: 10.1002/sd.322.

[3] Z. Fadeeva, "Promise of sustainability collaboration—potential fulfilled?," *Journal of Cleaner Production*, vol. 13, no. 2, pp. 165–174, Jan. 2005, doi: 10.1016/S0959-6526(03)00125-2.

[4] A. L. Powers, "An Evaluation of Four Place-Based Education Programs," *The Journal of Environmental Education*, vol. 35, no. 4, pp. 17–32, Jul. 2004, doi: 10.3200/JOEE.35.4.17-32.

[5] D. X. Román, M. Castro, C. Baeza, R. Knab, S. Huss-Lederman, and M. Chacon, "Resilience, collaboration, and agency: Galapagos teachers confronting the disruption of COVID-19," *The Journal of Environmental Education*, vol. 52, no. 5, pp. 325–334, Sep. 2021, doi: 10.1080/00958964.2021.1981204.

[6] B. Barron, "When Smart Groups Fail," *The Journal of the Learning Sciences*, vol. 12, no. 3, pp. 307–359, 2003.

[7] M. Baker, J. Andriessen, K. Lund, M. van Amelsvoort, and M. Quignard, "Rainbow: A framework for analysing computer-mediated pedagogical debates," *Computer Supported Learning*, vol. 2, no. 2–3, pp. 315–357, Sep. 2007, doi: 10.1007/s11412-007-9022-4.

[8] Amy. Edmondson, "Psychological Safety, trust, and learning in organizations: A group-level lens," *Trust and Distrust In Organizations: Dilemmas and Approaches*, no. September, pp. 239–282, 2004.

[9] N. L. Kerr and R. S. Tindale, "Group Performance and Decision Making," *Annu. Rev. Psychol.*, vol. 55, no. 1, pp. 623–655, Feb. 2004, doi: 10.1146/annurev.psych.55.090902.142009.

[10] M. Barnett *et al.*, "Using the Urban Environment to Engage Youths in Urban Ecology Field Studies," *The Journal of Environmental Education*, vol. 37, no. 2, pp. 3–11, Jan. 2006, doi: 10.3200/JOEE.37.2.3-11.

[11] G. A. Lieberman and L. L. Hoody, "Closing the Achievement Gap: Using the Environment as an Integrating Context for Learning. Results of a Nationwide Study," Jul. 1998, Accessed: Feb. 12, 2022. [Online]. Available: https://eric.ed.gov/?id=ED428943

[12] G. A. Smith, “Linking Place-Based and Sustainability Education at Al Kennedy High School,” *Children, Youth and Environments*, vol. 21, no. 1, pp. 59–78, 2011.

[13] N. Blanchet-Cohen, “Taking a stance: child agency across the dimensions of early adolescents’ environmental involvement,” *Environmental Education Research*, vol. 14, no. 3, pp. 257–272, Jun. 2008, doi: 10.1080/13504620802156496.

[14] A. Collins, *What’s worth teaching? rethinking curriculum in the age of technology*. New York, NY: Teachers College Press, 2017.

[15] L. Martin, C. Dixon, and S. Betser, “Iterative Design toward Equity: Youth Repertoires of Practice in a High School Maker Space,” *Equity & Excellence in Education*, vol. 51, no. 1, pp. 36–47, Jan. 2018, doi: 10.1080/10665684.2018.1436997.

[16] J. J. Ryoo, N. Bulalacao, L. Kekelis, E. Mcleod, and B. Henriquez, “Tinkering with ‘failure’: Equity, learning, and the iterative design process,” *Presented at Fablearn Conference 2015*, 2015.

[17] T.-C. Huang, C.-C. Chen, and Y.-W. Chou, “Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment,” *Computers & Education*, vol. 96, pp. 72–82, May 2016, doi: 10.1016/j.compedu.2016.02.008.

[18] D. Karagozlu, “Creating a Sustainable Education Environment with Augmented Reality Technology,” *sustainability*, vol. 13, no. 11, Art. no. 11, Jan. 2021, doi: 10.3390/su13115851.

[19] D. Nincarean, M. B. Alia, N. D. A. Halim, and M. H. A. Rahman, “Mobile Augmented Reality: The Potential for Education,” *Procedia - Social and Behavioral Sciences*, vol. 103, pp. 657–664, Nov. 2013, doi: 10.1016/j.sbspro.2013.10.385.

[20] E. Abad-Segura, M.-D. González-Zamar, A. L. la Luque-de la Rosa, and M. B. Morales Cevallos, “Sustainability of Educational Technologies: An Approach to Augmented Reality Research,” *sustainability*, vol. 12, no. 10, p. 4091, May 2020, doi: 10.3390/su12104091.

[21] A. G. Earle and D. I. Leyva-de la Hiz, “The wicked problem of teaching about wicked problems: Design thinking and emerging technologies in sustainability education,” *Management Learning*, vol. 52, no. 5, pp. 581–603, Nov. 2021, doi: 10.1177/1350507620974857.

[22] S. Criollo-C, D. Abad-Vásquez, M. Martic-Nieto, F. A. Velásquez-G, J.-L. Pérez-Medina, and S. Luján-Mora, “Towards a New Learning Experience through a Mobile Application with Augmented Reality in Engineering Education,” *Applied Sciences*, vol. 11, no. 11, Art. no. 11, Jan. 2021, doi: 10.3390/app11114921.

[23] M. G. Badilla-Quintana, E. Sepulveda-Valenzuela, and M. Salazar Arias, “Augmented Reality as a Sustainable Technology to Improve Academic Achievement in Students with and without Special Educational Needs,” *sustainability*, vol. 12, no. 19, Art. no. 19, Jan. 2020, doi: 10.3390/su12198116.

[24] S. K. Ayer, J. I. Messner, and C. J. Anumba, “Augmented Reality Gaming in Sustainable Design Education,” *J. Archit. Eng.*, vol. 22, no. 1, p. 04015012, Mar. 2016, doi: 10.1061/(ASCE)AE.1943-5568.0000195.

[25] V. Braun and V. Clarke, “Using thematic analysis in psychology,” *Qualitative Research in Psychology*, vol. 3, no. May 2015, pp. 77–101, 2006, doi: 10.1191/1478088706qp063oa.

[26] B. Jordan and A. Henderson, “Interaction Analysis: Foundations and Practice,” *The Journal of the Learning Sciences*, vol. 4, no. 1, pp. 39–103, 1995.

[27] J. Kolko, “Sensemaking and Framing: A Theoretical Reflection on Perspective in Design Synthesis,” 2006.