EMBODIED LEARNING IN A MIXED-REALITY ENVIRONMENT: EXAMINATION OF STUDENT EMBODIMENT

Kyungbin Kwon
Indiana University, United States
kwonkyu@indiana.edu

Keunjae Kim
Indiana University, United States

Minhwi Seo
Indiana University, United States

Hyojung Kim
Indiana University, United States

Thomas A. Brush
Indiana University, United States

Abstract.

This study investigates the effects of embodied learning experiences in learning abstract concepts, such as computational thinking (CT), among young learners. Specifically, it examines whether the benefits of embodied learning can be replicated within a mixed-reality setting, where students engage with virtual objects to perform CT tasks. A group of 10 first-grade students from an elementary school participated, engaging in embodied learning activities followed by assessments in CT. Through the analysis of video recordings, it was observed that participants could effectively articulate CT concepts, including the understanding of programming code meanings and their sequences, through their bodily movements. The congruence between students' bodily movement and CT concepts was advantageous for their comprehension. However, the study also noted incongruent movements that did not align with the intended CT concepts, which attracted researchers' attention. The study identified two distinct types of embodiments manifested in the mixed-reality environment, which shed light on the nuanced dynamics of embodied learning in CT education.

Keywords: Embodied Learning Experiences; Computational Thinking; Mixed-Reality Learning.

INTRODUCTION

Embodied learning is a pedagogical approach emphasizing the crucial role of the body in the learning process based on embodied cognition, which suggests that human cognition is fundamentally rooted in our bodily interactions with the world (Barsalou, 2008). This perspective posits that learning encompasses cognitive, physical, emotional, and social dimensions (Glenberg, 2008; Lakoff, 2012). It underscores the significance of bodily actions in enhancing conceptual understanding and problem-solving abilities. Engaging in movement, gestures, expressions, and interactions deepens learners' conceptual understanding by grounding cognition in their bodily actions or physical environments (Alibali & Nathan, 2012; Hostetter & Alibali, 2008).

Embodied learning expands its scope from physical environments to virtual ones, empowered by Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). AR overlays digital information in the real world, enhancing the learning experience with interactive visual elements (Yu & Denham, 2023). VR creates a fully immersive digital environment, allowing students to explore and interact in virtual settings (Agbo et al., 2023). MR combines elements of both AR and VR, integrating digital objects into the real world in ways that interact seamlessly with physical surroundings (Johnson-Glenberg et al., 2014). These technologies have great potential to enhance educational outcomes by providing immersive, interactive, and engaging learning experiences, which need further exploration in educational settings.

Embodied Learning for Computational Thinking

Incorporating embodied learning into the pedagogical practices of computational thinking (CT) education gains more attention in K-12 settings, as it enhances engagement and improves conceptual understanding through active, physical participation (Kosmas et al., 2019). In teaching CT, educators are increasingly adopting hands-on, unplugged activities that promote students' physical engagement. Additionally, they introduce robot programming tasks, allowing students to directly apply what they have learned from physical activities to their programming projects (Bell et al., 2012; Kopcha et al., 2021; Kwon et al., 2022). Incorporating bodily movements has significantly enhanced students' understanding and mastery of CT concepts (Kwon et al., 2022). Furthermore, combining these physical actions with tangible learning tools and interactive technology, such as robots and block-based coding platforms, has proven to build up students' enthusiasm and engagement with the subject matter (Bers et al., 2014; Fofang et al., 2021; Kim & Kwon, 2024). In this context, we examined the impact of embodied learning experiences on developing CT skills among elementary students (Kwon et al., 2022). The findings highlighted a notable improvement in students' CT and spatial reasoning abilities, without gender differences in outcomes or attitudes, aligning with previous research emphasizing sensorimotor experiences' value in comprehending abstract STEM concepts (Zhong et al., 2023).

Embodied Learning in Virtual Contexts

The evolution of technology has broadened the scope of embodied learning to include virtual spaces, which are computer-generated environments that simulate real or imagined settings. Students interact with virtual objects in these virtual spaces, such as digital avatars, 3D models, and interactive simulations. These interactions are accompanied by immediate feedback, including visual cues, auditory signals, and real-time performance metrics, enhancing the immersive learning experience (Agbo et al., 2023). Recent studies affirm the benefits of embodied learning in these virtual or mixed-reality environments (Lindgren & Johnson-Glenberg, 2013; Lindgren et al., 2016; Oyelere et al., 2023; Yu & Denham, 2023). However, significant gaps remain in understanding the effects of virtual embodied learning, particularly regarding its long-term impact on cognitive and social development, best practices for classroom implementation, and equitable approaches for underrepresented students (Pellas et al., 2020).

Researchers argue that the impact of embodied learning varies with the degree of embodiment, suggesting a spectrum from superficial to profound embodied experiences. Skulmowski and Rey (2018) differentiated between merely incidental embodiment, where actions and cognitive processes are not related, and profoundly integrated embodiment, which links learning tasks (cognitive processes) with intended actions (embodiment). Johnson-Glenberg et al. (2014) also emphasized the importance of gestural congruency in embodied learning, highlighting the relevance of an action mapping onto the content to be learned. Considering these suggestions, examining students' embodied learning experiences in a mixed reality setting, where virtual spaces can affect how students interact with simulated environments, can provide valuable insights into the literature. In particular, a deeper understanding of embodied learning mechanisms in virtual contexts can identify effective learning methods and suggest instructional design principles for creating impactful embodied learning experiences.

A notable challenge in existing research is its focus on short-term retention rather than long-term performance and implementing embodied learning over limited periods. For embodied learning experiences to be meaningful, learners need ample practice associating actions with concepts (Xu et al., 2022). A lack of practice in embodiment may result in a superficial understanding of concepts, thus impeding the application of acquired skills to problem-solving tasks.

Differences in utilizing embodiment among students play a critical role in designing and implementing embodied learning activities. For instance, significant variations in adopting such activities have been noted when students are not accustomed to expressing programming codes through bodily movement (Kwon et al., 2024). While engaging in embodied learning activities, students often use their bodies and learning environments to express abstract concepts or reasoning according to their perception and understanding, which involve individual differences in their embodiment (Kopcha et al., 2021; Manches et al., 2020). Therefore, to effectively leverage embodied experiences for every student, it is essential to acknowledge the diverse ways students engage in these activities.

RESEARCH PURPOSE

Despite the increasing number of studies on embodied learning across various settings, research remains scarce examining its multifaceted impacts based on the learning environments, types of embodiments, and learning performance. Given the current state of the literature, this study aims to explore students' embodied learning behaviors within a mixed-reality environment. This will contribute to a more comprehensive understanding of embodied learning in education. The following research questions guide this study: (1) What types of embodiments do students demonstrate while practicing CT tasks in a mixed-reality learning environment? (2) How are the types of embodiments congruent with CT concepts? (3) How do embodied learning experiences affect students' CT problem-solving performance?

METHOD

Participants

Ten first-graders from a public elementary school in the Midwestern United States were recruited for this study using convenience sampling. Assent from the participants and consent from their parents/guardians had been obtained before the intervention. None of the participants had a mixed-reality experience and did not learn CT in the contexts.

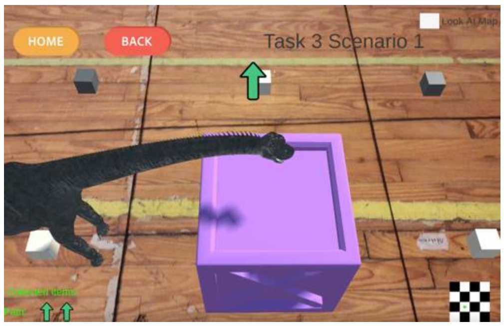
Learning Context

In this study, the researchers developed a mixed-reality learning environment to facilitate the understanding and application of CT concepts, focused explicitly on symbols and sequences (see Figure 1-a). Symbols represent programming language elements that indicate a robot's specific actions. At the same time, sequences refer to the organized arrangement of these symbols in a specific order to achieve desired outcomes. For CT tasks, students were guided to find appropriate paths to complete missions by moving like a robot, utilizing symbols and sequences. Within this environment, students navigated a chessboard-like arena, aiming to complete CT tasks through a strategic movement in an area of 92 square feet outlined in a five-by-five grid. Each grid cell served a dual purpose: it defined the coordinated positions of an agent and various objects, and it acted as a stage for the students to execute movements—either advancing forward or backward or turning right or left at 90° angles—emulating robotic actions to navigate towards a designated goal (see Figure 1-b). AR technology was employed to superimpose virtual objects at the center of each grid cell, with these objects serving as mission items to be collected, obstacles to be circumvented, or destinations to be reached. Figure 1-a illustrates the virtual objects selected to make the learning scenario more engaging by presenting a Jurassic Park theme. This AR setup was responsive to the students' physical movements across the grid, offering immediate feedback based on their positional coordination within the board.

The system introduced four key symbols to represent movement directions: ⬆ for Move Forward, ⬇ for Move Backward, ➡ for Turn Right, and ⬅ for Turn Left. These symbols were displayed on the students' handheld tablet screens and linked directly to their physical movements. For example, advancing towards the next grid cell triggered the display of the Move Forward symbol, accompanied by a verbal cue, "You just moved forward." As students navigated the grid, executing various movements and turns, the sequence of symbols corresponding to their actions was dynamically listed at the bottom of their screen, visually representing the accumulated sequence of movements.

Figure 1

Virtual objects displayed on a tablet (a) and the physical environment where the student moved (b)



(a)

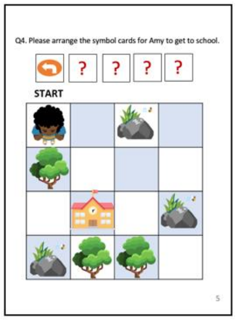

(b)

Research Data

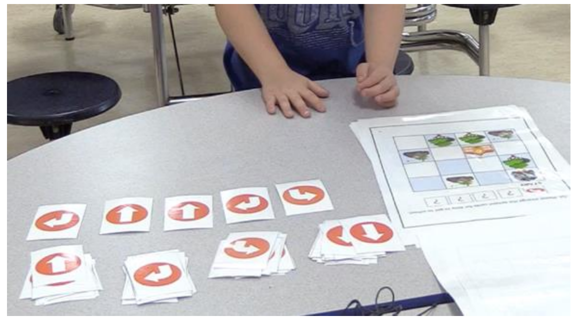
This study collected three types of research data: video recordings of students' embodied learning in the mixed-reality environment, CT tests, and post-intervention interviews. Each student's embodied learning was recorded for approximately 30 minutes using two cameras alongside screen captures of their interactions with virtual objects on the tablet. The CT assessment comprised eight items designed to evaluate students' comprehension of the meaning of symbols and their ability to organize these symbols to execute CT tasks, focusing on sequences. During the assessment, a researcher presented the questions sequentially, and students responded by physically manipulating symbol cards as appropriate. These responses were documented through video recording. After completing the CT tests, interviews were conducted with the students to explore their learning experiences and self-assessed confidence in CT practices.

Figure 2

Sample question(a) and its solution of a student(b)



(a)


(b)

Procedure

The teacher introduced the study's objectives and secured informed consent and assent from participants who voluntarily agreed. Students were escorted to a designated research site within a regular school day to engage in embodied learning activities within a mixed-reality environment. Each student independently undertook CT tasks with the assistance of two researchers. Utilizing a hand-held tablet, students navigated the mixed-reality learning environment, which involved collecting specific items, avoiding obstacles, and ultimately reaching a predetermined destination. The mixed-reality application provided immediate feedback, including symbols representing each movement, a cumulative sequence of these symbols, and directional guidance or warnings concerning mission items or obstacles encountered. This mixed-reality feature offered participants a first-person perspective of the CT tasks, effectively merging their bodily movements with virtual symbols and sequences to achieve the set goal. This integration served as the primary learning objective of the intervention. Following the embodied learning experience, students were administered CT tests and participated in the interview. Each of these activities was conducted on a one-on-one basis.

Analysis

We adopted thematic analysis to examine students' learning experiences in the mixed reality learning context. To ensure trustworthiness, we followed the iterative and reflective phases of thematic analysis (Nowell et al., 2017) by (1) familiarizing ourselves with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the report. We employed an inductive approach to understand learning experiences, relying primarily on the data rather than a theoretical framework (Braun & Clarke, 2006). Given the limited number of participants, students' performance on CT tests was analyzed statistically to show learning gains without testing a hypothesis.

FINDINGS

The study analyzed video recordings from a mixed-reality setting to explore how learners embodied and enacted CT concepts through physical actions. Two main themes were identified, indicating that students demonstrated congruent and incongruent embodiment. Congruent embodiment referred to students' actions aligned with the CT concepts they were learning, while incongruent embodiment did not.

The findings reveal that, in most scenarios, students successfully mapped their bodily movements to CT concepts, showcasing a congruent embodiment. This congruence reflects a profound comprehension and application of CT principles through physical interaction within the mixed-reality context and underscores the integral role of embodiment in the learning process. Furthermore, with increased participation in embodied learning activities, students exhibited a marked improvement in the congruence of their embodiment. This suggests that repeated practice in such an immersive environment enhances the natural and intuitive integration of CT concepts into physical actions.

However, the study also documented instances of incongruent embodiment where students' movements did not correspond with the anticipated CT concepts. For example, some students moved sideways instead of executing a turn followed by a linear advancement or diagonally towards an adjacent cell rather than performing these actions sequentially (e.g., moving forward, turning, and then moving forward). These occurrences suggest the challenges in aligning students' intuitive or habitual movements with structured actions to express CT concepts, revealing a gap between natural behaviors and the planned embodiment of CT concepts.

In the subsequent section, we examine the nuances of these observations by categorizing the types of embodiments. This classification aims to clarify how embodied learning in mixed-reality environments can facilitate and challenge the acquisition of CT concepts.

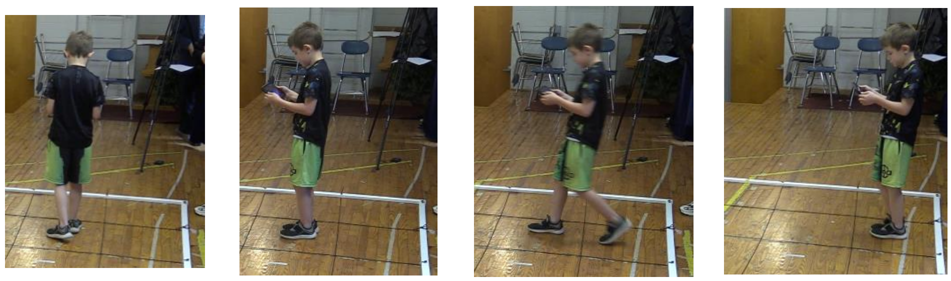
Congruent Embodiment

In this study, we adopted a unique approach to map physical movements and programming concepts, guiding students to "move like a robot" through four specific actions: Move Forward, Move Backward, Turn Right, and Turn Left. This deliberate restriction of movements aimed to immerse students in an experience that parallels programming tasks, engaging them with the symbolic systems that facilitate human-computer interaction. Thus, the instructional objectives were to grasp the underlying symbol system integral to programming and apply this understanding in executing CT tasks. The rationale behind instructing students to perform these four actions was to mimic the basic commands in programming, thereby deepening their comprehension of CT concepts through physical embodiment.

Throughout the study, in most scenarios, students adeptly navigated the mixed-reality environment by adhering to the predefined actions. A closer examination of their behavior unveiled a progressive enhancement in their embodiment of these concepts. For instance, initially, one student cautiously took several steps towards the front cell, embodying a careful Move Forward action. This was acknowledged by the application as "one" Move Forward action, with the student receiving dual-mode feedback: a visual symbol and an auditory confirmation ("You just moved forward"). As the practice sessions advanced, the same student confidently strode to the next cell in a single motion, showcasing a more sophisticated and intuitive understanding of the symbol for the Move Forward action (see Figure 3).

Figure 3

A student moved forward by one step and turned the right way, which represents two symbols: Move Forward and Turn Right (see from right to left)



During the CT tasks, students exhibited proficiency in debugging when they needed to correct their movements. For instance, one student encountered an obstacle and promptly received feedback via the application. In response, the student navigated backward and explored alternative pathways around the obstacle. Upon selecting a new route, the student adjusted his body movements using the learned embodied CT. This exemplifies the embodied CT practices the students experienced in the mixed-reality environment.

Incongruent Embodiment

Researchers observed incongruent embodiment among students whose physical actions did not align with the CT concepts intended to be mastered. Analysis of these occurrences suggests that students often demonstrated incongruent embodiment when they focused solely on completing the CT tasks, disregarding the intended embodied rules, such as moving like a robot using four symbols. The most common cases of incongruent embodiment were noted when students moved intuitively, akin to movements in natural settings. Four typical types of incongruent embodiment were identified.

Moving sideways. For instance, when facing north and attempting to move one step east, students might naturally opt for a side step to the east, an everyday movement in daily life. However, this movement was not permitted in the mixed-reality learning context because it did not represent the robot's movement. Instead, the correct movement would involve two steps: turning to the east and moving forward. Researchers observed that students sometimes moved sideways when transitioning to the next cell on their left or right without intentionally adhering to the embodied rule (see Figure 4-a). This movement deviated from the symbol system used in their embodied learning.

Diagonal movement. When students identified a target in a cell diagonally positioned, they tended to move diagonally towards it instead of taking multiple sequential steps. While diagonal movement is natural and efficient in daily life, in the embodied learning scenario, students were expected to execute multiple steps (e.g., Move Forward, Turn Right, Move Forward) to reach a diagonal cell. Researchers noted that students exhibited diagonal movement when rushing towards a target while overlooking the embodied rule (see Figure 4-b).

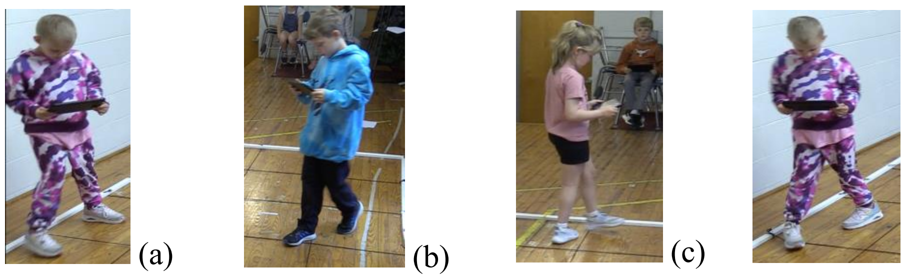
Combining multiple steps into one. Students sometimes combined forward movement with an immediate right turn in contexts similar to diagonal movement. While this could be interpreted as efficient performance, researchers classified it as incongruent embodiment because it did not adhere to the sequence of actions (Turn Right and Move Forward), instead reflecting intuitive movement (see Figure 4-c and 4-d).

Taking small steps represents one symbol. Students carefully move toward a path by taking small steps, identified as an incongruent embodiment. When students stopped in the center of a cell before taking the following actions, researchers identified it as congruent embodiment, even though it involved taking multiple small steps. However, taking small actions toward a sequence of steps was identified as incongruent embodiment because it did not represent the sequential order of symbols. Students demonstrated this action when they were not confident with their movement and needed to explore a route toward a goal.

These observations highlight the importance of aligning students' physical actions with the intended embodied rules during CT tasks. Incongruent embodiment appeared not to benefit students' understanding of CT concepts and their ability to practice them during CT tasks.

Figure 4

Incongruent embodiments: moving sideways (a), diagonal movement (b), and combining multiple steps into one (c and d)



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

Coordination of Virtual and Physical Information

As students navigated within the mixed-reality environment, they were required to integrate virtual information presented by the application with the physical environment around them. In most instances, students effortlessly coordinated between these dual sources of information and engaged with virtual objects without difficulty. This observation indicates that the mixed-reality environment naturally supported intuitive interactions, enabling students to effectively process and act upon information from both virtual and physical spaces.

Nonetheless, an exciting behavior was noted concerning students' spatial awareness and safety checks. When moving backwards, students often chose to turn their heads to visually confirm the space behind them rather than relying on the tablet's display. This behavior suggests a preference for direct physical verification over virtual assistance, particularly when students felt unsure or perceived a need for increased safety. It also highlights a reliance on physical cues for navigation and decision-making in uncertain or potentially unsafe situations within the mixed-reality context.

Performance on CT Tasks

The analysis of performance test results over two assessment periods revealed a nuanced yet overall positive shift in students' comprehension of CT, specifically in understanding symbols and sequences. The increase in the mean scores from the first test (mean = 8.75, SD = 15.65) to the second test (mean = 18.75, SD = 25.85) suggests a significant improvement in the students’ comprehension and application of CT concepts. This improvement reflects students’ enhanced ability to identify code meanings, predict outcomes, and logically arrange codes.

However, despite the positive trend, the data also underscores the substantial individual differences in learning outcomes. While some students have made significant advancements, others have not shown noticeable progress, as indicated by the standard deviation increase from the first to the second test. This variation suggests that while the embodied learning experiences might be practical for some students, they might not address all students’ learning needs or styles equally.

This result suggests the necessity for further investigation into the factors contributing to these individual differences. Specifically, future research should consider exploring the impact of embodied learning experiences on CT performance. It is hypothesized that students who exhibit more congruent embodiment with CT concepts might show enhanced performance, or conversely, a lack of congruence could hinder learning outcomes. Understanding these dynamics can inform the development of more effective, inclusive teaching strategies tailored to diverse student needs.

DISCUSSION AND CONCLUSION

This study explored how students demonstrated embodiment while expressing CT concepts in problem-solving contexts where a mixed reality provided immersive experiences. The analysis of student embodiment identified two distinct types: congruent and incongruent embodiments. The study demonstrates how congruent embodiment significantly helps students’ comprehension of abstract CT concepts through physically mapping movements to programming concepts. By engaging students in a physical representation of programming tasks, the study facilitated an immersive learning experience and enabled students to internalize the meaning of symbols and sequences underlying programming. As they manipulated and interacted with physical and virtual objects, they began associating their actions with abstract ideas of symbols and sequences. Students gained a deeper understanding by situating abstract concepts of CT in a concrete context of task-finding with AR. This finding aligned with the previous studies that embodied approaches within a mixed-reality context enhanced students’ understanding of CT and programming by grounding those ideas with bodily movements and hands-on experiences (Kwon et al., 2022; Lindgren et al., 2016).

Some students showed incongruent embodiments during the tasks. One of the possible reasons could be students' cognitive load. Mixed-reality environments can sometimes impose a high cognitive load on learners, especially young ones (Skulmowski & Rey, 2018). For instance, managing the physical interaction with the virtual elements, checking the physical spaces, and simultaneously processing abstract concepts like CT can be challenging. This cognitive overload can lead to mistakes in bodily movements that do not align with the intended learning objectives (Loup-Escande et al., 2017). Thus, educators must design tailored instruction with interactive learning environments, particularly for young students. This finding is consistent with the studies that emphasized bridging the gap of cognitive load within the mixed-reality context by designing age-appropriate interventions (Lai et al., 2019).

While this study provides valuable insights into the effects of embodied learning in a mixed-reality environment on computational thinking (CT) among young learners, several limitations should be acknowledged. The findings are limited by the small sample size of ten first-grade students, which affects generalizability. Additionally, the novelty of the mixed-reality environment and limited time for practice might impose a high cognitive load on the students, potentially affecting their learning performance and understanding. Future research should address these issues by including a larger, more diverse sample and exploring long-term effects.

This study calls for follow-up research to investigate individual differences in embodiment and the causal relationship between types of embodiments and learning performance. Several learner factors, such as prior knowledge, modal preferences, cognitive development, and learning strategies, affect the outcomes of embodied learning (Deininger et al., 2012; Kwon et al., 2022; Zhong et al., 2023). As shown in the current study, differences in embodiment among individual students can influence the dynamics of embodied learning settings, necessitating further investigation into this issue. The analysis of student embodiment also requires additional research into the causal impacts of the types and depth of embodiment on student learning. Although a growing body of research suggests the positive impacts of embodied learning, there remains a lack of studies identifying productive and meaningful embodiments that would provide insights into designing effective embodied learning environments and instruction (Duijzer et al., 2019).

ACKNOWLEDGMENT

This material is based upon work supported by the National Science Foundation under Grant #2048989.

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ABOUT THE AUTHORS

Kyungbin Kwon, Ph.D.

Dr. Kwon is an Associate Professor of Instructional Systems Technology at Indiana University, Bloomington. Dr. Kwon's research focuses on facilitating positive interactions among students in the contexts of Computer-Supported Collaborative Learning (CSCL) and designing effective instructions for computational thinking (CT).

Keunjae Kim

Keunjae Kim is a doctoral candidate in Instructional Systems Technology at Indiana University, Bloomington. His research interests focus on integrating Artificial Intelligence (AI), Computer Science (CS), and Computational Thinking (CT) with the K-12 STEM education context, by developing age-appropriate learning strategies and interventions, particularly with constructionist and embodied learning approaches.

Minhwi Seo

Minhwi Seo is a Ph.D. student of Instructional Systems Technology at Indiana University, Bloomington. Her research interests focus on human-centered design in learning practices in problem-based learning environments and instructions integrating emerging technologies.

Hyojung Kim

Hyojung Kim is a Ph.D. student of Instructional Systems Technology at Indiana University, Bloomington. She is interested in investigating the cognitive processes, learner characteristics, and the design of educational technologies that enhance student engagement, self-regulation, and motivation in online learning settings.

Thomas Brush, Ph.D.

Dr. Thomas Brush is the Barbara B. Jacobs Chair in Education and Technology and a Professor of Instructional Systems Technology within the School of Education at Indiana University, Bloomington. Dr. Brush's research interests focus on developing methods and strategies to promote inquiry-oriented learning, particularly with more open-ended instruction.