

Embodied Learning in a Mixed-Reality Environment: Examination of Student Embodiment

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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 ten 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 found to be advantageous for their comprehension. However, the study also noted instances of incongruent movements that did not align with the intended CT concepts, which attracted researchers' attentions. The study identified two distinct types of embodiment manifested in the mixed-reality environment, shedding light on the nuanced dynamics of embodied learning in the context of CT education.

Introduction

Embodied learning is a pedagogical approach emphasizing the crucial role of the body in the learning process, based on the concept of 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 not only cognitive but also 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 activities such as movement, gestures, expressions, and interactions is believed to deepen learners' conceptual understanding (Alibali & Nathan, 2012; Hostetter & Alibali, 2008).

Embodied Learning for Computational Thinking

The incorporation of embodied learning into the pedagogical practices of computational thinking (CT) education gains more attention in K-12 settings. 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 apply what they've learned from these physical activities directly into their programming projects (Bell et al., 2012; Kopcha et al., 2021; Kwon et al., 2022). This approach of incorporating bodily movements has been shown to significantly enhance students' understanding and mastery of CT concepts (Kwon et al., 2022). Furthermore, combining these physical actions with tangible learning tools and interactive tech, like robots and block-based coding platforms, has proven to build up students' enthusiasm and engagement with the material (Bers et al., 2014; Fofang et al., 2021; Kim & Kwon, 2024). In this context, authors (2022) examined the impact of embodied learning experiences on developing CT skills among first and second-grade students. The findings highlighted a notable improvement in students' CT and spatial reasoning abilities, without any gender

differences in outcomes or attitudes, aligning with previous research that emphasizes the value of sensorimotor experiences 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, providing students with immersive experiences through interactions with virtual objects and immediate feedback. 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 of its depth, long-term retention and transferability, and the influence of individual differences.

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). The latter are considered more effective in grounding concepts through physical actions. A deeper understanding of embodied learning mechanisms in virtual learning contexts could reveal which types of embodiment enhance learning outcomes and how educators can design more effective learning experiences.

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

Individual differences also play a critical role in the design and implementation of embodied learning activities. For instance, when students are not accustomed to expressing programming codes through bodily movement, significant variations in the adoption of such activities have been noted (Authors, 2024). Recognizing students' readiness and preferences is essential for leveraging embodied learning effectively.

Research Purpose

Despite the increasing number of studies on embodied learning across various settings, there remains a scarcity of research examining its multifaceted impacts. Given the current state of 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's role in education. The following research questions guide this study: (1) What types of embodiment do students demonstrate while practicing CT tasks in a mixed-reality learning environment? (2) How are the types of embodiment 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. 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 designed to facilitate the understanding and application of CT concepts, specifically symbols and sequences, through interactive engagement. 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 that has been outlined in a grid of five by five. 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-degree angles—emulating robotic actions to navigate towards a designated goal (see Figure 1-b). Augmented Reality (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 (see Figure 1-a). 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, 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.

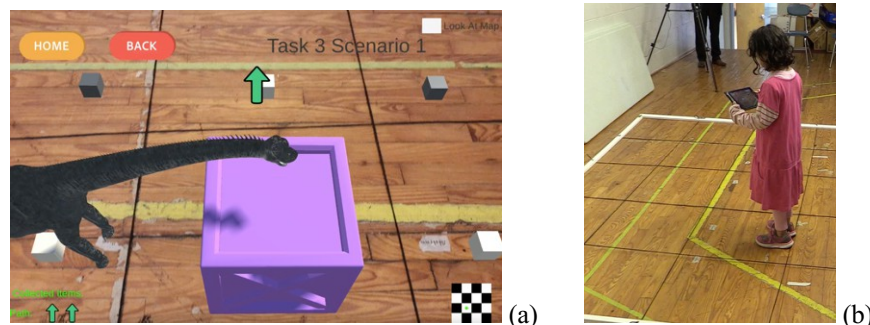


Figure 1. Virtual objects displayed on a tablet (a) and the physical environment where the student moved (b).

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 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. Following the completion of 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).

Procedure

The teacher introduced the study's objectives and secured informed consent as well as assent from participants who voluntarily agreed to partake in the research. Within a regular school day, students were escorted to a designated research site to engage in embodied learning activities within a mixed-reality environment. Each student, with the assistance of two researchers, independently undertook CT tasks. 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 subsequently participated in the interview. Each of these activities was conducted on a one-on-one basis.

Findings

The study analyzed video recordings from a mixed-reality setting to explore how learners embodied and enacted CT concepts through their physical actions. The findings reveal that, in most scenarios, students successfully mapped their bodily movements to CT concepts, showcasing a congruent embodiment. This congruence not only reflects a profound comprehension and application of CT principles through physical interaction within the mixed-reality context but also 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 they moved 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 embodiment. This classification aims to provide a clearer understanding of how embodied learning in mixed-reality environments can both 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 twofold: to grasp the underlying symbol system integral to programming and to 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).

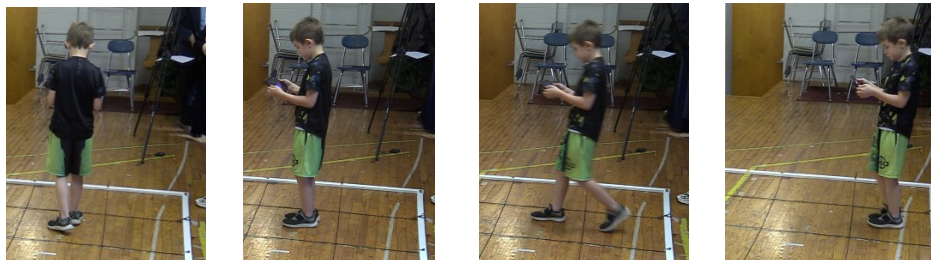


Figure 3. A student moved forward by one step and turned the right way which represents two symbols: Move Forward and Turn Right (see from right to left).

During the CT tasks, students exhibited proficiency in the debugging process 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 in accordance with the learned embodied CT. This exemplifies the embodied CT practices the students experienced in the mixed-reality environment.

Incongruent Embodiment

Researchers observed instances of incongruent embodiment among students, wherein their 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, which is a common movement in daily life. However, in the mixed-reality learning context, this movement was not permitted because it did not represent the robot's movement. Instead, the correct movement would involve a combination of two steps: turning to the east and then 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 type of 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: In contexts similar to diagonal movement, students sometimes combined forward movement with an immediate right turn. 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 representing one symbol: Students carefully moved toward a path by taking small steps, which was identified as incongruent embodiment. In instances where students stopped in the center of a cell before taking the next 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 type of action when they were not confident with their movement and/or 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.

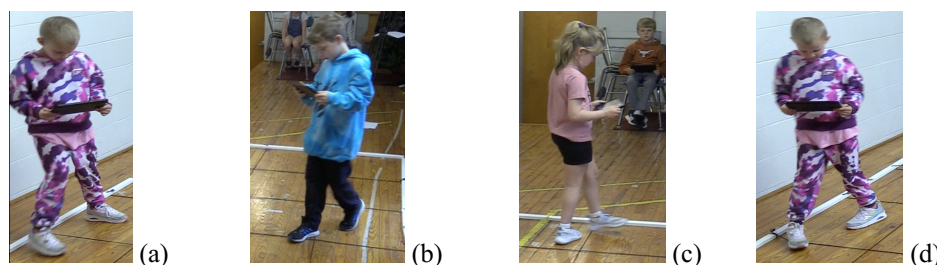


Figure 4. Incongruent embodiments: moving sideways (a), diagonal movement (b), and combining multiple steps into one (c and d).

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 the majority of 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 interesting 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 in situations where students felt unsure or perceived a need for increased safety. This tendency 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 tangible 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, indicated by the increase in the standard deviation from the first to the second test. This variation suggests that while the embodied learning experiences might be effective for some students, they might not address the learning needs or styles of all students 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

In this study, we 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 to associate their actions with abstract ideas of symbols and sequences. By situating abstract concepts of CT in a concrete context of task-finding with AR, students gained a deeper understanding. 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, it is critical for educators to 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).

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