

Towards Embodied Wearable Intelligent Tutoring Systems

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Abstract. Embodied cognition posits that human-environment interaction positively impacts thinking and learning, making it a valuable pedagogical tool. Technology in teaching and learning has seen tremendous maturation, such as the development of Intelligent Tutoring Systems (ITS). However, most ITS provide static learning experiences that do not incorporate embodiment, movement, and interaction with the space around the learner. This paper examines the results of using an embodied tutoring system across three case studies with different dimensions of embodiment. In all cases, we found trends highlighting how embodied tutoring systems can support learning. We also discuss different ways to incorporate embodiment into future research on ITS.

Keywords: Embodied Cognition · Intelligent Tutoring Systems · Math

1 Introduction & Motivation

Embodied learning has emerged as a powerful pedagogical approach for mathematics education, with mounting evidence about its essential role in developing and strengthening mathematical thinking skills [2, 7, 10]. At the core of embodied learning is the notion of *embodied cognition*, which asserts that knowledge develops from our understanding of the interactions between ourselves, our environment, and elements within the environment. This suggests that incorporating sensorimotor processes in learning activities can strengthen learning through learners’ use of their bodies, reflection, and social interaction [7, 16].

Intelligent Tutoring Systems (ITS), however, particularly within mathematics education, have traditionally been screen-based (i.e., students use a computer and answer math problems on screen—e.g., MathSpring [4, 11]) and do not support learners in engaging in embodied learning practices. As new theories of learning evolve, with more significant evidence supporting the incorporation of embodiment, there is also a need for ITS to adapt. For example, ITS that can be accessed through mobile devices, enabling movement and exploration within physical environments, is one way of re-imagining embodied ITS. Developing technologies that support mathematics learning through environments that enable embodied interactions is thus a key area for future development [1, 6].

We present three case studies that analyze the effectiveness of embodiment in tutoring systems. We explore different kinds of embodied interaction in digital

learning environments by comparing traditional tutoring systems with a tutoring system that incorporates embodiment.

2 Related Work

Embodied Cognition and Pedagogy. *Embodied cognition* is the idea that perception of the environment, and the body’s interactions with elements within it, influence cognition [2, 16]. *Embodied learning* emphasizes that learning is supported and bolstered when the deep connection between the mind and the body [12] is employed as a pedagogical tool [16]. A key aspect of embodied cognition is *spatial cognition*, the cognitive process involved in spatial reasoning and problem-solving. Spatial cognition is significant to STEM pedagogy because concepts in mathematics and science incorporate ideas from the physical world around us, such as position, direction, relative speed, and spatial perception, among others. Prior research has shown gains in STEM performance when leveraging spatial cognition as a pedagogical tool [14, 16], which supports the case for instruction that incorporates spatial cognition, such as visuospatial skills (the ability to recognize visual and spatial relationships among objects [16]), as a means to improve conceptual understanding in STEM education.

Making the Abstract Concrete. The potential of embodied learning leads to the question: *how can embodiment be incorporated into ITS effectively to support STEM learning?* Weisberg and Newcombe [16] presented a framework that outlines mechanisms through which this is possible: (a) linking sensorimotor information with abstract concepts, (b) using gestures as a cognitive tool, (c) developing cognitive skills such as spatial cognition, (d) offloading onto the body/environment to free up cognitive processing, and (e) creating and understanding visual representations. *Offloading* refers to storing information in the environment/body without further burdening their mental resources, focusing cognitive capacity on problem-solving, inference-making, and communicating ideas [16]. An example is a student offloading a shape’s mental rotation onto a physical object’s rotation to retain a visual representation of its direction and orientation, enabling them to move on to another part of the problem. Creating visual representations is also critical in communicating ideas and seeing the bigger picture while problem-solving. Additionally, analogy-building between sensorimotor and abstract concepts (such as moving along a number line while adding numbers; a number line does not concretely exist in the natural world) and visual representations (i.e., a number line drawn on the floor) supports the learning of abstract concepts, using the physical world around learners [10, 16].

Embodiment as Support for Mathematical Ideas. Tools and manipulatives can illustrate, communicate, and test concepts and serve as testing grounds for emerging mathematical ideas, where the mind can impose mathematical relationships on the objects [15]. According to Walle, there are five ways to represent mathematical ideas: (1) manipulative models, (2) pictures, (3) real-world situations, (4) written symbols, and (5) translations between and within representations. These representations help develop new mathematical concepts [15].

Prior research suggests that mathematics learning is embodied, based on perception and action, grounded in the physical environment and that different gestures suggest different types of thinking [6,10]. Gestures with hands and body, which are “inherently spatial” because they are expressed in the space that a person occupies/perceives [16], become mechanisms through which cognition is communicated and information is encoded [2]. Prior work suggests that gestures are evidence of involvement in mathematical thinking [2] and may be a vital aspect of learning as students work with their peers and around physical objects.

Intelligent Tutoring Systems and Embodied Cognition. Given the impact of embodied pedagogy on STEM learning, designing ITS to incorporate embodiment is a good path forward for improving ITS [6,7]. Technology that can support and enhance active learning environments has been studied previously, with increased learning gains compared to control groups [7]. However, most ITS are currently largely screen-based and do not incorporate movement. The ones that do often focus heavily on gesture-based movements rather than engaging the entire body [7]. It is crucial to re-conceptualize how ITS can provide embodied pedagogical support for STEM classrooms.

3 The WearableLearning Platform and Embodied Games

Our team developed WL¹, a web-based platform that enables users to play physically active, embodied, educational math games using mobile devices that students carry [3]. Thus, WL games can be situated within physical classrooms and incorporate movement, physical manipulations, and teamwork. Within the WL interface (Figure 1), students can input answers to question prompts to receive feedback, request hints, and proceed through the game. Students can be organized into multiplayer teams, with each member taking on a specific role throughout the game, which may be complementary to other team members.

3.1 WearableLearning Case Studies

Case 1: WL Games. Three teacher-created games, "Integer Hopscotch", "Let's Shop", and "What's my Line?", were played with groups of 49 (6th grade), 84 (7th grade), and 102 (8th grade) students, respectively. These games focused on concepts of integer addition/subtraction operations, price percentage calculations, and graphs. *Integer Hopscotch* uses word problems on addition/subtraction of integers to prompt students to walk along a 20-foot number line to find the correct answer. *Let's Shop* uses word problems based on shopping scenarios, where students need to find the correct price or discount for shopping items (e.g., tips, final sale price, amount of tax, see Figure 1). Teams calculate the answer and locate it on color-coded cards scattered in the classroom, like a scavenger hunt. *What's My Line?* is a slope-equation and graph-matching game that involves the slope-intercept form of equations to challenge students to read

¹ *WearableLearning*: <http://wearablelearning.org/>

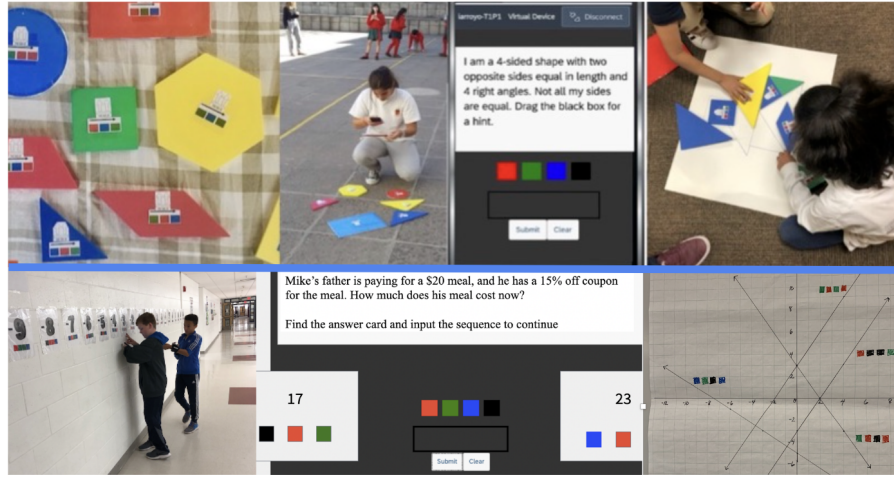


Fig. 1. (Top) *Tangrams Race*: shapes with color combination codes; a student retrieving a piece guided by WL on a phone; a math question in *Tangrams Race*; students building a *Tangrams* puzzle with retrieved pieces. (Bottom) Left: *Integer Hopscotch*; Middle: screenshot of the *Let's Shop* game; Right: a *What's my Line?* game object.

and interpret equations. Teams match equations in WL with the corresponding line on a paper graph, with several other lines drawn as distractions (see Figure 1), at one of seven different stations. Students race through all stations to correctly match each equation to its line graph and draw the correct lines.

Data Collection. Pre- and post-tests assessed student content knowledge. Students playing *Integer Hopscotch* were tested on integer addition and subtraction. Students playing *Let's Shop* were tested on percentages. Students playing *What's my Line?* were tested on equations.

Results. For *Integer Hopscotch*, students improved *significantly* from pre-test ($M=.62$, $SD=.26$) to post-test ($M=.79$, $SD=.17$), $t=6.39$, $p<.001$, after one class period. For *Let's Shop*, students improved *significantly* from pre-test ($M=.57$, $SD=.22$) to post-test ($M=.67$, $SD=.18$), $t=3.12$, $p=.002$, after one class period. For *What's My Line*, students improved *significantly* from pretest ($M=.48$, $SD=.27$) to posttest ($M=.77$, $SD=.27$), $t=7.15$, $p<.001$, after one class period.

Findings. All games led to statistically significant learning gains, and while this study did not have a control condition, the results suggest that even a short exposure to embodied learning experiences may yield promising learning gains. The embodied learning experiences in these experiments provided support for teaching abstract ideas through offloading onto physical representations; for example, in *Integer Hopscotch*, the abstract number line is physically represented and students hop and count a certain number of steps to get to the correct answer. In *What's My Line?*, students worked on visual representations by plotting lines for equations. The students used abstract concepts, such as operations on negative numbers; we suspect that perhaps embodying the concept helped

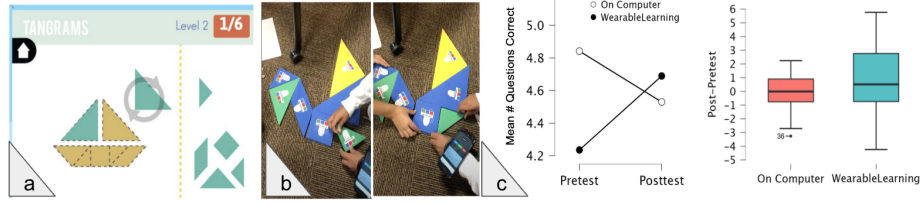


Fig. 2. (a) Control condition: Virtual manipulation of Tangrams pieces; (b) Embodied condition: Physical manipulation of Tangrams pieces by hand; (c) Mean change from students' pre- to post-tests in embodied vs. control.

them visualize more concretely through a spatial representation (e.g., why the subtraction of two negative numbers may yield a negative number) rather than rote-learn sign conventions without developing meaningful understanding.

Case 2: Tangrams Race. *Tangrams Race* is a geometry-puzzle game focusing on classification based on angles/sides and parallel/perpendicular lines. In WL, it is played as a relay race for multiple three-player teams that requires each team to acquire the correct tangram pieces to create a specific shape arrangement. To acquire the pieces, student teams are positioned on one end of a room and each team player takes turns running to the opposite end of the room to retrieve tangram pieces from a container based on a prompt shown on the WL interface (e.g., "What is a shape with three sides?"). The prompts are mathematical descriptions of the desired tangram pieces (e.g., Figure 1), that match math common core skills that students need to practice. Each piece has a color code that students enter into the WL interface (Figure 1), which provides feedback.

Third to fifth-grade students were randomly assigned to one of two game conditions: (1) *Physical* — physically played tangrams (using WL and physical pieces, 54 students) or (2) *Digital* (control, 21 students) — digitally played tangrams. Both groups received equivalent instruction (similar math problems, help, hints, and time). The control group used a digital tutoring system where students answered problems through multiple choice or short answers. They can also ask for hints and construct the same puzzles virtually on the screen through a 'virtual Tangrams' website that allows rotating/dragging/dropping tangram pieces to form the puzzle (Fig. 2). An advantage to the control condition was that all math problems were available to students. In contrast, in the embodied condition, only a third of the problems were available to each player because of their complementary roles (i.e., each player looked for a specific tangram piece).

Data Collection. Pre- and post-tests assessed students' learning gains, using the pre-test as a baseline measure for students' content knowledge. The assessments contained the same ten content-related questions from the Massachusetts Comprehensive Assessment System (MCAS) 4th-grade math standardized exam.

Results. From pre- to post-test, *Embodied* condition students increased by 14.7% and *Digital* condition students decreased by 4.1%. Even though the learn-

ing gain of students in the Digital condition was the lowest (-0.31 learning gain for the Digital group versus 0.45 for the Embodied group), there was no significant effect for condition ($F=0.638$, $p=0.42$), however, Figure 2c shows a trend, highlighting how students in the *Embodied* condition improved on average in comparison to students in the *Digital* condition.

Findings. Tangrams Race, as designed on WL, has many embodied affordances such as: physically manipulating pieces, constructing visual imagery, collaborative manipulation, and gesturing (Figure 1). Before students run to the container of tangram shapes, they are given a description of the shape from the WL interface on their phones, enabling students to conduct visual imagery by visually hypothesizing in their minds what the shape could look like. If a student gets stuck and the hints are not helping, a teacher may help by gesturing to show clues, such as what parallel or perpendicular lines look like. The WL Tangrams Race game is structured to provide support for embodied learning, so it was surprising that the results we obtained were marginally significant trends.

We do not think that students "unlearned" in the *Digital* condition, but instead believe that the post-test scores in both groups in general are deflated, because, in our experience, students do not want to take post-tests, while they are very focused during pre-test time, due to the novelty of the situation.

Despite the advantage of more content, the control condition fared worse than the experimental condition, on average. In contrast, despite exposure to lesser content, the students from the *Physical* condition improved more in comparison.

Case 3: EstimateIt! *EstimateIt!* is a scavenger hunt where student teams search for volumes described in WL (e.g., the mobile device could show: “*Look for a sphere with a 6” radius*” or hints, see Figure 3). Students are provided an unmarked 12-inch ruler for measurement estimations. Objects have a color code; after finding the correct object, the code is input into WL, to get feedback.

Data Collection. 49 students in an afterschool program participated. The experimental condition received hints with images of hand gestures that students should enact (Figure 3); the control condition received textual hints that described ways to estimate. Pre- and Post- tests were conducted with both groups.

Results. Experimental condition students improved more ($M=0.64$, $SD=0.16$ on pre-test; $M=0.68$, $SD=0.17$ on post-test, n.s.) than those in the control condition ($M=0.67$, $SD=0.12$ on pre-test; $M=0.68$, $SD=0.11$ on post-test, n.s.).

Findings. Students in the experimental condition showed a trend of improvement, while those in the control condition did not improve. This trend suggests that incorporating aspects of embodiment, such as gestures, may be an effective way for tutoring systems to use embodiment to support learning. Students used gestures to denote relative and absolute size for measurement and estimation when discussing with their teammates. Using an embodied mode of communication for mathematical concepts may support students’ analogy-building and gesturing, enriching their problem-solving and communicating strategies.

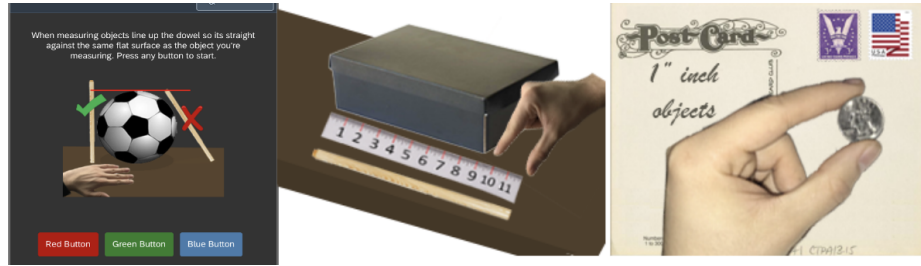


Fig. 3. Examples of hints using hand gestures, Part-Part Whole, and size of an inch.

4 Conclusion

We presented three cases of how digital versus physical games in mathematics education can potentially impact student learning, and how a game-based tutor that uses mobile devices can leverage embodiment for learning. The first case showed that playing active games for different math concepts consistently had a positive impact on math learning, despite short exposure time. In the second and third case, the controlled studies revealed non-significant trends that favored embodied conditions, where the experimental condition was more "embodied". As the pre- and post-tests were given immediately before and after the games, their learning gains and trends of improvement suggest that the embodied-technology activities likely contributed to students' improvement.

Limitations. One limitation is that the case studies showed trends but non-significant effects. We suspect that the non-significant effects may be due to assessment instruments being paper & pencil (as opposed to having an embodied activity that reflects their learning through the game), failing to capture deeper modes of embodied thinking that are not necessarily reflected on multiple choice questions. For instance, if we assessed students' knowledge of triangles through an embodied activity of cutting a right triangle with scissors and paper, this could potentially provide more meaningful insight into students' conceptual understanding. We aim to find ways to capture such differences in engagement in the future. Another limitation is that exposure time to the intervention was short, thereby constraining the impact that the activities could have brought about. Lastly, the experiments were deployed in after-school programs instead of math classes in formal classrooms. After-school environments are noisy due to looser student attendance regulations than in formal classrooms. Ideally, the intervention could have been deployed in schools led by math teachers within a math class, as this would be more suitable context than an after-school program.

Future Implications: Embodied & Game-based ITS. WearableLearning is not an ITS in a traditional sense yet, as it does not incorporate AI nor personalize instruction. Based on our work, we believe the following should be characteristics of embodied intelligent tutoring systems:

Assessing Student Knowledge in Embodied ITS. Students progress through WL games by finding, arranging, or manipulating physical objects in the envi-

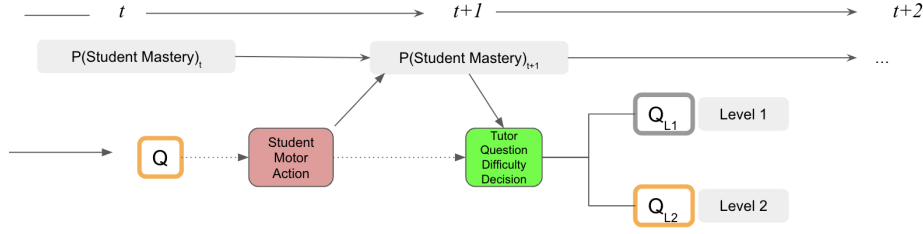


Fig. 4. An embodied ITS can work similarly to a non-embodied ITS, only that the questions (Q) are embodied quests that require motor action.

ronment and submitting answers into WL. Behind the scenes, each question has associated meta-data, such as the mathematics skill (standard) associated with a question. Success or failure at completing math tasks provides some evidence of students’ math knowledge. Therefore, a traditional Bayesian Estimation of students’ knowledge based on correctness, errors, and hint requests can be computed [5]; this is however dependent on students being exposed to enough questions regarding the same math skill (e.g., same Math Common Core standard).

Changing Item Difficulty in Embodied Intelligent Games. Lester et al. [9] described how, in Crystal Island, a Dynamic Decision Network can negotiate the narrative state of the game, the story world state, and the student user state. We envision a similar way of modeling students’ knowledge and adjusting items in the games to satisfy the game narrative’s requirements and constraints and the level of difficulty for each student player (Figure 4). While the game continues to flow temporally in a horizontal direction, the intelligent game engine can update estimates of mastery, and make decisions in a vertical direction, making choices between questions or items of various difficulties (e.g., easy, medium, and hard) for the same “meta-level” math standard involved in the question.

Embodied Hints and Support. Teachers naturally incorporate gestures for illustrating and visualizing concepts as they communicate mathematical ideas [2]. Given the embodied nature of these learning tasks, gesture-based hints should be incorporated into embodied ITS. Underlying Case 3 described above is the work of Harrison et al. [8], who performed a deep cognitive task analysis of children’s gestures and actions during measurement tasks. Using data collected from this study, Valente [13] created hints aimed at conveying motor strategies observed in college students and described the most common mistakes of elementary students during measurement tasks. Providing embodied hints introduces students to motor strategies to deploy during problem-solving (Figure 3).

Future work will involve bringing WL to more math classrooms, creating more games aligned to mathematics standards, refining existing games, refining our assessments for capturing math learning, and further analyzing the importance of motion, gesture, and action by collecting data on learners’ movements.

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