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Implementing WearableLearning in the Math Classroom: An Exploration into the Affordances of Embodied Learning through Game-Play Compared to Traditional Learning Technologies

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Abstract: This article reports findings of implementing a novel learning technology called WearableLearning to teach geometry transformations in a math classroom. The paper aims to answer RQ1) To what extent do students learn math with embodied games facilitated by WearableLearning? and RQ2) How do students learn math differently with embodied games enabled by WearableLearning, compared to traditional learning technology? Quantitative results indicate a trend of improvement from pre-test to post-test ($t = 1.5$, $p < 0.1$). Qualitative results indicate that games through WearableLearning increase the opportunities for mathematical thinking between students, physical objects, and the learning environment. Qualitative results also indicate that students benefit from additional affordances of support when utilizing WearableLearning compared to traditional learning technologies.

Introduction

Within recent work, embodied learning has emerged as a powerful pedagogical approach to introduce and develop mathematical thinking skills, with mounting evidence that indicates its essential role in developing and strengthening mathematical thinking skills (Alibali & Nathan, 2012; Link et al., 2013; Georgiou & Ioannou, 2019). At the core of embodied learning, the notion of *embodied cognition* asserts that knowledge is built from a continuum between mind, body, and the physical world around us. This suggests that incorporating sensorimotor processes in lessons will strengthen learning–through the learners' use of their bodies, reflection, and social interaction (Georgiou & Ioannou, 2019; Weisberg & Newcombe, 2017).

Yet, Intelligent Tutoring Systems (ITS) for mathematics have traditionally been screen-based, with students sitting down in front of a computer (e.g. MathSpring, Algebra Tutor, etc.) and do not allow learners to engage in embodied learning practices naturally (See left-side of Figure 4). As new theories of learning continue to evolve, with greater evidence supporting the need for incorporating embodiment into pedagogy, there is also a need for ITS to embrace new ideas of learning and enable ways to support learners through embodiment. Even if collaboration is in-built into ITS, the collaboration is generally accomplished through chat windows. There is great potential to explore the possibility of having students learn with mobile tutoring systems while moving and exploring the physical environment.

The development of technologies that support embodied cognition as a strategy for mathematics education is a key area for future development (Abrahamson et al., 2023). Understanding how embodied learning can aid the development of mathematical thinking is crucial to building effective technologies and providing pedagogical support through embodied-interaction environments. With this in mind, the Advanced Learning Technologies Lab with NSF support developed a novel learning technology called WearableLearning (WearableLearning.org). WearableLearning enables K-12 mathematics thinking and learning *via* physically active and multiplayer math games, using mobile devices (phones or tablets with WIFI connection). Using WearableLearning, we investigate the benefits students gain by participating in embodied learning in a mathematics classroom. We ask:

RQ 1) To what extent do students learn math with embodied games facilitated by WearableLearning?

RQ 2) How do students learn math differently with embodied games enabled by WearableLearning, compared to traditional learning technology?

Background

The Common Core State Standards for Mathematics (CCSSM) and the Standards for Mathematical Practice (SMP) impose high demands on students and teachers that require an alternative approach to teaching mathematics. These standards call for greater coherence, focus, and rigor, and require students to develop not only procedural skills and fluency, but also a deep conceptual understanding and application of mathematical concepts. Rather than memorizing algorithms to correctly solve problems, the focus has shifted towards having students use and discuss different problem-solving approaches, explain their reasoning, and transition fluidly through representations of phenomena and their properties. In order to be successful in mathematics, students need opportunities to transfer knowledge to novel scenarios or contexts, seek multiple methods and pathways to reach solutions, and rely on problem solving skills to find possible solutions. This focus has shifted the way that math teachers are expected to teach and interact with students, requiring them to narrow and deepen the content that they teach. The CCSSM and SMP require a more integral view of learning, and high level of interaction with students, resembling embodied cognition views of learning.

Traditional learning technologies for math generally make students practice problem solving. Some resemble digital worksheets, and some of them involve higher levels of graphics and visualization (e.g. such as interactive math games) yet they require students to sit down and work one-on-one with the computer. Embracing embodied learning implies moving the interface "off the screen", to experience phenomena/relationships, to engage in hands-on and socially-rich activities, and to obtain support during moments of struggle and cognitive conflict.

Embodied cognition and embodied learning posit that sensory-motor action and gestures are essential for teaching and learning, as ideas that are distributed among the mind, the world, and the social context, and that hand gestures support essential communication during learning (Goldin-Meadow et al., 2009; Congdon et al., 2017). Students explore new metaphors by manipulating real objects in the environment and communicating face-to-face with peers/teachers (Georgiou & Ioannou, 2019; Abrahamson, 2023).

Principles of embodied design can be used as a critical lens on how digital resources are created and brought to life into mathematics learning tasks. WearableLearning facilitates the creation of learning activities that implement the themes of embodied interaction design introduced by Klemmer et al. (2006): they involve thinking through doing, where mathematical reasoning uses bodily capacities. In WearableLearning games, bodies matter in performance, as motion and action enable better performance. Playing WearableLearning games in the shared classroom results in high visibility for sharing, where visible mathematical objects/artifacts support synchronous collaboration. Embodied activities in WearableLearning involve risk taking, as a physical action is characterized by risk; choosing an action requires commitment, personal responsibility. This results in high levels of affective engagement with tasks, as opposed to technologies that often strive to minimize or eliminate risk. This framework enables us to interleave: a) researchers' conceptualizations of the body's function in models of thinking, learning and teaching; in dialogue with (b) designers' engineering of digital resources conducive to learners' detection of conceptually meaningful interaction affordances, through sensorimotor exploration.

Some research has explored bringing gesturing into math learning technologies through pedagogical agents (Cook et al., 2016). Yet, this research focused on general gesturing such as pointing, while WearableLearning provides an infrastructure for the creation of embodied activities, which might afford different kinds of gesture, movement and action during math learning. Melcer and Isbister (2016) realized that embodied games and simulations have utilized a large breadth of design approaches that often have resulted in the creation of seemingly unrelated systems. As a consequence, they created a unified design framework that aggregates different conceptual design approaches for embodied learning systems, divided into three areas: 1) kinds of physical interaction, classified into embodied, enacted, manipulated, surrogate, or augmented; 2) kinds of social interactions that the activity requires (e.g., collaborative, competitive and the role of Non-Player-Characters such as supportive teachers); and 3) role of the environment, and the degree of physical/virtual/mixed world that it involves. Games in WearableLearning align to this design framework, ensuring that embodiment creates the foundation of students' mathematical learning.

WearableLearning

WearableLearning is a web-based platform accessed through mobile devices (e.g. smartphones or tablets) that enables the incorporation of developmentally appropriate embodied game play for K-12 students into classrooms, curricula, and standards (Arroyo et al., 2017; Micciolo, 2018). While using WearableLearning, students participate in active and collaborative game-based math activities that emboldens them to explore their physical learning environments, manipulate tools that invoke mathematical thought, interact with their peers and teachers in rich face-to-face discourse, and internalize their mathematical learning through embodiment. Lightweight and portable mobile devices which can be worn on the lower arm or carried, become "virtual assistants," providing students with direction and feedback as they navigate their mathematical learning through physical spaces, interacting with physical objects and peers.

Math game playing and creation with WearableLearning has been implemented with roughly 500 elementary, middle, and high school students, as well as 25 math teachers, who also have created a variety of games for students to play as part of an eight-hour teacher professional development program (Arroyo et al., 2020; Rasul et al., 2023a). These games were designed and implemented in WearableLearning's Game Editor, and are deployed with WearableLearning's Game Player, developed to target the range of standards set by the CCSSM, concretely for areas 3.G, 3.NF, 4.MD, 4.NF, 5.NF, 6.NS, 7.NS., 7.RP, 8.G and 8.EE. A math games library is accessible from WearableLearning.org.

In previous studies, these embodied games supported by the WearableLearning Platform were implemented in both math classrooms and afterschool programs to determine how game play impacted student math performance. Pre- and post- tests showed improvement in math problem solving across different areas of math and grade levels, even after short 30-40 minute exposures (Arroyo et al., 2021). All games led to learning gains, and students were observed to be incredibly engaged while playing these games. Yet the question remains regarding how physical actions in each game mediates student learning and the affordances of the materials, objects, space, and human interactions, as mediators of math learning.

Methodology

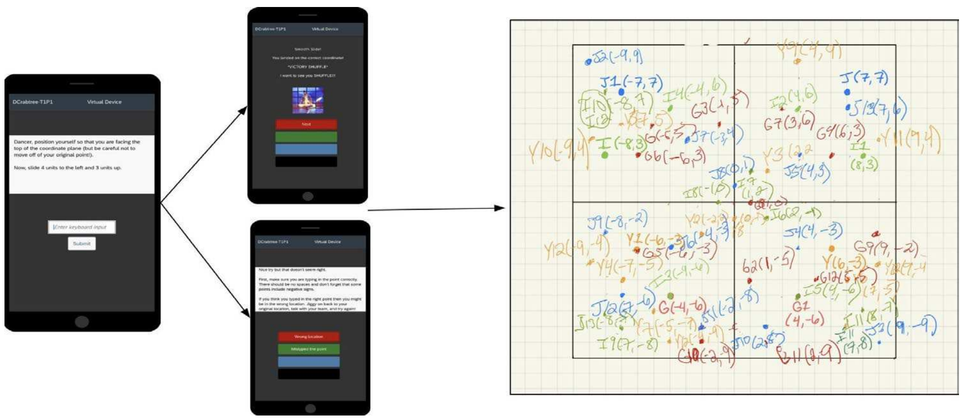
Using a quantitative approach, we address RQ1: To what extent do students learn math with embodied games facilitated by WearableLearning? Additionally, using a qualitative approach, we address RQ2: How do students learn math differently with embodied games enabled by WearableLearning, compared to traditional learning technology?

WearableLearning: Flip, Slide, Turn

To simplify the context of this research, we intentionally chose to investigate the affordances gained by students using one WearableLearning game called Flip, Slide, Turn. Flip, Slide, Turn is a geometry-based game designed using Melcer and Isbister (2016) embodied- game design framework. In this game, students work as a team to reflect (flip), translate (slide), and rotate (turn) a team member who is representing a single point on a large-scale coordinate plane. Teams are prompted by the mobile devices to move their team member from one coordinate to the next, requiring the team to physically enact each transformation. Additionally, after each transformation, teams are required to input their new position on the coordinate plane into the mobile device. If the team inputs the correct coordinate, they are rewarded with an encouraging visual then prompted with the next transformation. If the team inputs the incorrect coordinate, the team is encouraged to start back at the previous point and try again, this time using patty paper and paper-sized scale of the coordinate plane. Each team goes through a total of fourteen transformations before ending at the origin (See Figure 1).

Figure 1

The WearableLearning Platform Utilizes Mobile Devices to Provide Teams with Immediate Feedback as They Perform Fourteen Embodied Transformations in the Game Flip, Slide, Turn



Participants

The study participants were ten students from Grade 9 and Grade 10 in two sections of a summer camp in Western Massachusetts. These students belonged to low-socioeconomic backgrounds and historically minority communities, with regional demographics being 47.5 % Hispanic, 28.9% White, and 18.2% Black. Students received a stipend and on-campus accommodations. The focus of the summer camp curriculum was geometry in order to prepare them for the upcoming school year.

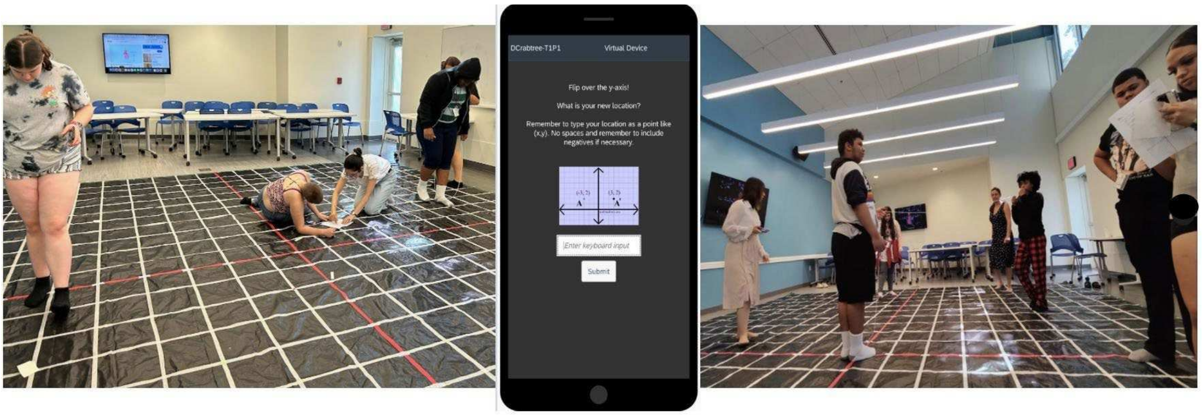
Students spent three weeks studying and revising the geometry concepts of reflection, translation, and rotation using a public curriculum called Open Up Resources (openupresources.org) before their exposure to the embodied WearableLearning game.

Procedure

Students took a pre-test before they played the game and concluded with a post-test. The distribution of the pre-post tests were counterbalanced --group A's pre-test was group B's post-test, and vice versa. Counterbalancing ensured that if one of the tests was unintentionally more difficult than the other, the difference would cancel out, and our measure of learning would not be biased.

Students had a 20-foot by 20-foot tarp that had been marked with tape to create a coordinate plane on the floor (See Figure 2). Students worked in teams of two, using their hand-held devices to play the game and orient themselves as they transformed the points on the coordinate plane. Each team had a unique starting point (in different quadrants) and a unique game trajectory (similar transformations) that took them through every quadrant. For rotations, students were given a string that one team member held down at the origin, and the other team member held the string taut on the floor and rotated the point about the origin. They also had grid and patty paper to work out and double-check their point transformations. Students put down markers at the coordinate points they got correctly before they moved; in case they had miscalculated, it would allow them to return and recalculate. All students completed their game trajectories in time.

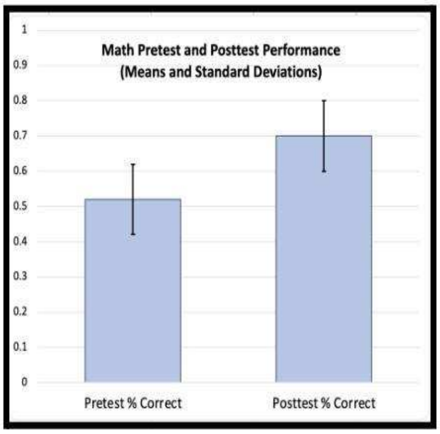
Figure 2
Students Participating in the WearableLearning Game, Flip, Slide, Turn, Using Mobile Devices



Results: Quantitative (RQ1)

Figure 3 shows the change in test scores and the results of a two-tailed paired-samples t-test (significance level set at alpha = 0.05).“Pre-test % Correct” and “Post-test % Correct” refer to a normalized score as the tests were scored and scaled to 1. The difference in test scores shows a trend of improvement from pre-test to post-test ($t = 1.5$, $p < 0.1$), resulting in a medium effect size measured through Cohen’s d of 0.48, which indicates the strength of the relationship between exposure to the intervention and positive change in test scores.

Figure 3
Math Performance Gains from Pre-Test to Post-Test, after Playing Flip, Slide, Turn.



Paired Samples T-Test

Measure 1		Measure 2	t	df	p	Cohen's d	SE Cohen's d
PreTest % Correct	-	PostTest % Correct	−1.524	9	0.081	−0.482	0.429

Note. For all tests, the alternative hypothesis specifies that PreTest % Correct is less than PostTest % Correct.
Note. Student's t-test.

Descriptives ▼

Descriptives

	N	Mean	SD	SE	Coefficient of variation
PreTest % Correct	10	0.520	0.343	0.108	0.659
PostTest % Correct	10	0.700	0.221	0.070	0.316

Results: Qualitative (RQ2)

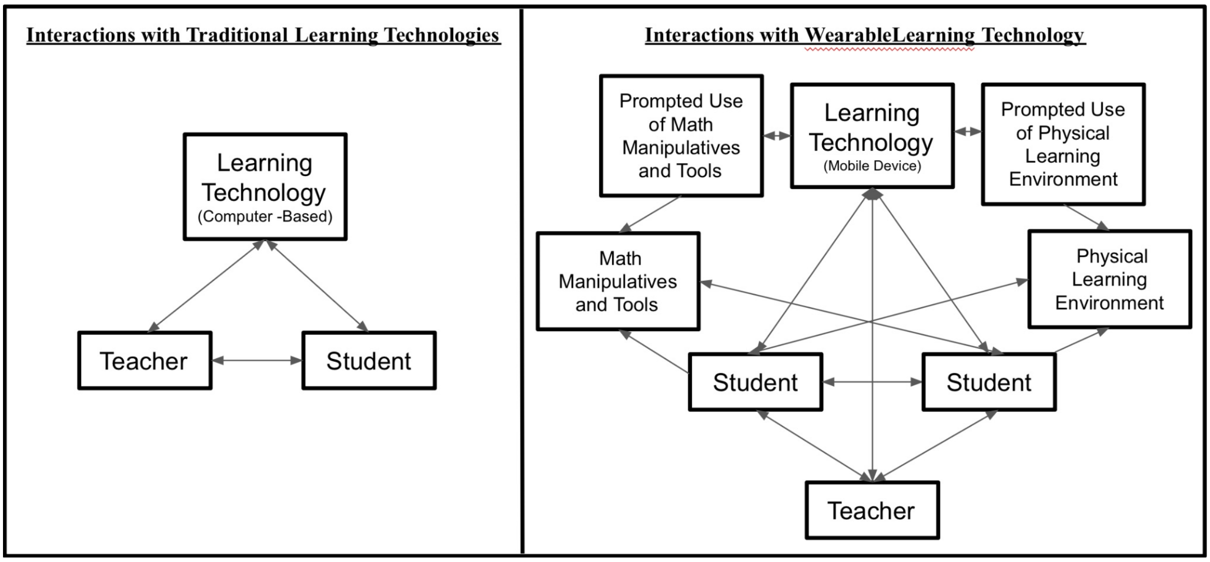
Data sources for the qualitative analysis of Flip, Slide, Turn included researcher logs, video and photos.

Interactions

Figure 4 shows the differences in interactions between traditional learning technologies and WearableLearning. Traditional learning technologies restrict students to only two interactions: the teacher and the computer-based learning technology. This is due to the fact that the computer-based learning technology requires the student to remain seated.

In contrast, WearableLearning utilizes hand-held devices that allow students to be mobile. This increased the number of interactions a student encounters while learning. Students using WearableLearning were observed interacting with other students, the teacher, the learning technology on the mobile device, math manipulatives/tools (i.e. string to conduct rotations, patty paper, paper coordinate plane), and the physical learning environment (i.e. the coordinate plane tarp, the floor, the television).

Figure 4
The Difference in Observable Interactions between Traditional Learning Technologies and Interactions Observed in the WearableLearning Game Flip, Slide, Turn



Affordances

In general, the affordances of learning technologies for mathematics are well known: a) *immediate feedback* when students solve problems and enter correct/incorrect answers (Razzaq et al., 2020); b) detailed *support* when students make mistakes (help provision) or when they seek help during cognitive conflict (Aleven, 2013); c) use teacher *formative assessments* created from detailed student logs from student interaction with the computer to provide formative assessments to teachers even within educational games, without stopping to test (Wang et al., 2015, Shute & Ventura, 2013); and d) allowing students *personal pacing* of their problem solving work, with students working at their own pace with a computer that resembles a more knowledgeable other, enabling, to some extent, the replication of a reasonable form of a teacher/tutor, albeit a digital tutor that supports students as they learn individually (Woolf, 2010; Arroyo et al., 2014). For this analysis, affordances were extended using more discriminatory details, particularly for the affordances of support and assessment (See Table 1).

Table 1 shows a comparison between the affordances provided to students using traditional learning technologies versus the observed affordances students received by participating in Flip, Slide, Turn. In addition to the affordances of traditional learning technologies, students who participated in Flip, Slide, Turn also received tangible support through the use of mathematical manipulatives, tools, and gesturing, peer support from other students also participating in Flip, Slide, Turn, and the benefits of cooperative/ collaborative learning as they worked with their team.

Table 1
The Affordances of Ttraditional Computer-Based Learning Technologies Versus the Affordances of Flip, Slide, Turn.

Affordance	Description of Affordance	Traditional Learning Technologies (Computer-Based)	WearableLearning Technology (Flip, Slide, Turn)
Alignment to Math Curriculums and State Standards	Problems and activities within the learning technology align to	Yes	Yes
Immediate Feedback	Students are instantly informed if their response is correct or incorrect	Yes	Yes
Digital Support (Support Extension)	Digital Tutors, Problem Hints, Virtual Manipulatives	Yes	Yes
Tangible Support (Support Extension)	Math Manipulatives, Math Tools, Mathematical Gesturing	No	Yes
Teacher Support (Support Extension)	Support from a teacher, either virtually or face-to-face	Yes	Yes
Peer Support (Support Extension)	Support from one other student, either virtually or face-to-face	No	Yes
Cooperative/ Collaborative Learning (Support Extension)	Support from two or more students, either virtually or face-to-face	No	Yes
Personal Pacing	Students are able to move through learning tasks at their own pace	Yes	Yes
Assessment	Teachers are able to assess students without having to stop to test	Yes	Yes
Mastery Approach to Learning (Assessment Extension)	Students need to master concepts before moving forward with their learning	Yes	Yes

Discussion

This article reports the findings of implementing a novel learning technology called WearableLearning into a math classroom. In this study, students played a game called Flip, Slide, Turn to embody the geometry-based concept of transformations. Our goal was to determine 1) to what extent students learn math through embodied games facilitated by WearableLearning (RQ1) and 2) how students learn math differently with embodied games enabled by WearableLearning, compared to traditional learning technology (RQ2).

In response to our first inquiry, with a sample of ten students, there was a mean difference of +.18 and a standard deviation of -.12 from the pre-test to the post-test. This result indicates that students scored higher and with less variance on the post-test compared to the pre-test, indicating marginal significance in a paired-sample t-test. Since no other teaching occurred between the pre-test and the post-test, this suggests that the improvement of students' mathematical understanding of transformations was due to their participation in the WearableLearning game Flip, Slide, Turn.

Further, the consistency in the modality of teaching and prompts presented in this study also suggests that students learned math through embodiment. The curriculum used prior to the study was paper-based, as were the pre-test and post-test. Additionally, the transformation prompts used in the pre-test and post-test directly align to the transformation prompts in Flip, Slide, Turn. Participating in Flip, Slide, Turn was the only time students embodied the concept of transformations, physically acting as a point on the coordinate plane. With the modality of teaching and question prompts being consistent, the difference in the pre-test scores and post-test scores indicates a positive influence of embodiment on students' math learning. However, in order for this to be investigated further, a controlled study would need to be conducted.

In response to our second inquiry, our study revealed two main points of difference in *observable* ways students learn math through WearableLearning compared to traditional learning technologies. The first difference is the type of interactions students encounter while learning (See Figure 4). With traditional learning technologies, students are often confined to a seat, immobilized by the fact that the technology itself is stationary. With this restriction, student interactions are limited to the teacher (if they raise their hand for assistance) and to the learning technology. Contrarily, WearableLearning is a mobile learning technology, significantly increasing the number of possible interactions students are able to encounter while learning. Mobilization assists and encourages students to interact with the teacher *and* other students in the classroom, prompting face-to-face discussions that enrich mathematical learning. Additionally, unlike traditional learning technologies, WearableLearning deliberately incorporates math manipulatives, math tools, and the physical learning environment into the students' learning. Compelling interactions outside of the learning technology lowers students' reliance on the learning technology itself and increases the opportunities students have to think mathematically through other means. This supports Abrahamson et. al's (2023) ecological dynamics, grounding new concepts in perceived affordances of physical mathematical objects and movement.

The second difference is in the kind and amount of support that students receive from traditional learning technologies compared to WearableLearning. As stated previously, the affordances of traditional learning technologies are well known and include immediate feedback, support, assessment data for teachers, and personal pacing. Though both traditional learning technologies and WearableLearning attend to these affordances, a deeper observation into the details of how students receive support revealed a distinction between the support afforded by traditional learning technologies and WearableLearning. Since WearableLearning increases the number of interactions a student may encounter (see Figure 4), the support received is extended beyond teachers and the digital. More specifically, students who participate in WearableLearning are able to receive face-to-face support from their teachers (Teacher Support), peers (Peer Support) and teams of their peers (Cooperative/ Collaborative Learning). Additionally, students who learn math through WearableLearning receive the benefits of tangible support, with external support coming from physical objects, as well as internal support coming from gesturing and embodying the mathematical concept. We claim that these differences between traditional learning technologies and WearableLearning account for the differences in quantitative gains in learning, but also in qualitative observations on how students are *seen* learning math. Yet, further investigation is required to determine *how* these differences in the received support impact student learning.

Conclusion

WearableLearning is a novel technology that engages students in embodiment through game-based learning. Unlike traditional learning technologies that are stationary, WearableLearning utilizes mobility to change the way students access, engage, and discuss their mathematical thinking. Results from this study indicate that embodied games implemented through WearableLearning, like Flip, Slide, Turn, have a positive impact on student learning, improving test scores while deepening students' understanding of mathematical concepts. Further research with larger sample sizes is necessary to investigate the full potential of WearableLearning. As this study shows, WearableLearning already extends the possibilities presented by current traditional learning technologies, and we envision bringing the benefits of ITS to make them even more effective (Rasul et al., 2023b).

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