# Comparing the Effectiveness of Digital Game-Based Learning and Embodied Learning

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**Abstract.** This research project proposes to investigate the comparative effectiveness of digital game-based learning (DGBL) and embodied learning in mathematics education. It will address a gap in the literature by directly comparing a digital learning game, *Decimal Point*, to its embodied counterpart developed using the WearableLearning platform. The research aims to assess differences in learning outcomes and student affect in the embodied and DGBL conditions. Furthermore, it will examine how gender and prior knowledge influence learning outcomes in both the DGBL and embodied learning contexts, following up on a previously observed gender effect in *Decimal Point*. The project will also explore the potential of large language models (LLMs) to translate and design embodied learning activities from a digital learning game. The expected contributions include insights into the specific benefits and limitations of each approach, guidance for designing more equitable educational technologies, and a novel methodology for leveraging AI in educational design. In short, this research bridges learning science, game design, and artificial intelligence to advance the understanding of active learning in mathematics.

**Keywords:** Digital Game-Based Learning · Embodied Learning · Large Language Models

## 1 Introduction

Digital game-based learning (DGBL) and embodied learning are both methods of active learning that are effective in increasing learning, as well as motivating and engaging students [5, 6, 16, 19]. Both methods have been studied in the context of math education, but there is limited research that uses empirical methods to compare the effectiveness of a digital learning game to an equivalent embodied learning activity. Since DGBL and embodied learning have similarities as forms of active learning, comparing the two methods can provide insights into what aspects of these learning methods make them effective. In this project, we aim to create an embodied version of the digital learning game, *Decimal Point* [8], to directly compare differences in student learning between DGBL and embodied learning.

Embodied learning methods have been compared to traditional learning [5, 13, 16] but not to digital game-based learning. It would be interesting and novel to create an


A. I. Cristea et al. (Eds.): AIED 2025, CCIS 2590, pp. 409–414, 2025.
https://doi.org/10.1007/978-3-031-99261-2_45

embodied version of *Decimal Point* and see how learning gains compare between the game and its embodied version. If there are differences in how students learn with *Decimal Point* and an embodied version of the game, the findings would contribute to our understanding of why these active learning methods are effective and how they benefit students differently. By identifying differences in how students internalize decimal concepts, we can offer design principles for choosing when and for which audiences each method is most effective—especially with respect to learner characteristics such as gender and prior knowledge.

Furthermore, previous studies with *Decimal Point* have revealed a consistent gender effect where girls demonstrate greater learning gains than boys [11]. This finding raises important questions about how different learning approaches might benefit diverse learner populations. By examining potential differences in learning outcomes and engagement across gender and prior knowledge levels, this project aims to contribute to our understanding of how to design more equitable and effective educational technologies.

During the design phase, we also plan to evaluate the effectiveness of LLMs in helping to create embodied learning activities. Therefore, our research questions are the following: (**RQ1)** How do student learning outcomes and engagement differ between a digital learning game and an embodied version of the same math content? **(RQ2**) How do gender and prior knowledge moderate the effects of digital game-based vs embodied learning? (**RQ3)** Can LLMs effectively support the translation of digital learning games into embodied learning activities?

## 2 Background

### 2.1 Digital Game-Based Learning and *Decimal Point*

DGBL is a form of instruction that takes advantage of students' natural interest in video games. A well-designed learning game can intrinsically motivate students through elements of fantasy, challenge, and curiosity [7] and lead to greater learning gains when compared to traditional methods of instruction [6, 16]. One example of a successful digital learning game for math is *Decimal Point*, a game that teaches decimal concepts [8]. *Decimal Point* uses an amusement park metaphor (see Fig. 1, left) where students play various themed mini-games designed to target common decimal misconceptions. Students work through 24 mini-games [8] with a variety of problem types. For example, there are number line problems where students must place a decimal on the appropriate spot on a number line (Fig. 1, right). A particularly interesting finding across multiple studies with *Decimal Point* is a consistent gender effect, with girls demonstrating greater learning gains from the game than boys [11]. This finding raises important questions about how different interactive learning approaches might benefit diverse learner populations and suggests that educational technologies might help address persistent gender gaps in STEM education.

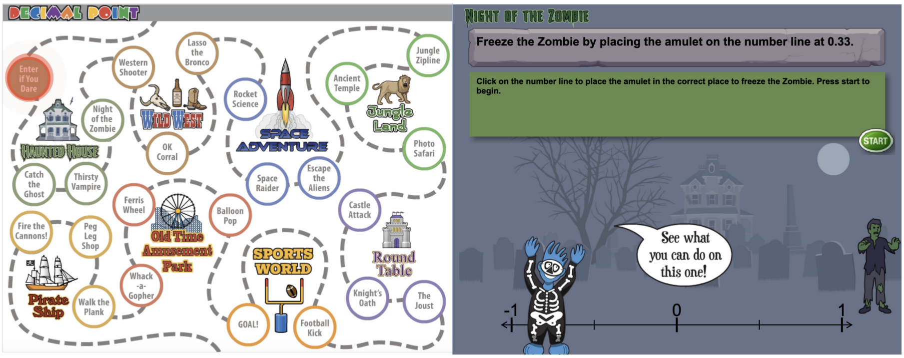


**Fig. 1.** *Decimal Point* game map (left) and example number-line mini-game problem (right)

### 2.2 Embodied Learning

Theories of embodied learning suggest that cognition is fundamentally linked to motor and sensory experiences [1], as brain regions involved in movement are closely connected to those responsible for learning [10, 18]. Engaging students in physical movement can therefore enhance learning. One example of successful embodied learning technology is the Mathematical Imagery Trainer for Proportion (MIT-P) [1]. The system has students move their hands up and down, maintaining a specific ratio to keep the screen green. This direct physical experience helps students internalize the concept of proportions without initially relying on numerical representations [1].

An important insight from embodied learning research is that the types of physical movement that students are doing should have meaning in the educational context [14]. Conceptually relevant actions show more benefits in performance, mathematical intuition, insight, proof production, problem-solving, and learning [1]. A study by Nathan et al. [10] found that using their arms to create triangles on a whiteboard helped participants understand the triangle inequality theorem. Similarly, tapping between two points to simulate gears helped participants grasp the concept of alternating directions in a gear chain, demonstrating that embodied interactions can support key mathematical insights.

## 3 Methods and Current Progress

**Development of Embodied *Decimal Point*.** To ensure that the comparison between the two versions of *Decimal Point* is fair and valid, it is important to create an embodied version that keeps the same content and context while only varying the platform of the game. Therefore, we propose to use the WearableLearning platform [2] as a basis for the embodied version of *Decimal Point*. WearableLearning is a platform that allows for the development of multi-player, interactive, embodied activities for the classroom. Students read instructions for each problem on a mobile device, engage in the embodied activity, and then enter their answers into the device, where they can receive feedback and move on [2]. This will help control for teacher variability in the embodied condition, as all embodied activities will use scripted instructions and be facilitated by the researchers.

In designing the embodied activities for *Decimal Point*, we will use Melcer & Isbister's [9] framework, which categorizes different types of physical interaction in embodied learning. For example, consider an activity where students sort decimals as greater or less than a given threshold. In an embodied version of this activity, students would be given a physical clothesline and "ghosts" with decimals written on them. The students would then pin the ghosts on the clothesline, representing their values relative to the threshold. This type of interaction aligns with the "manipulation" category, as students are directly using tangible objects to embody the abstract concept of decimal magnitude.

Part of the development phase will also involve answering RQ3. Specifically, we want to determine whether or not LLMs can create an equivalent embodied learning activity (or at least a starting point) for each of the *Decimal Point* mini-games, and if there are differences in effectiveness between LLM models. Preliminary experimentation with ChatGPT-4 has shown promising results. When asked to provide ten ideas for converting the number-line problem from Fig. 1 into an embodied activity, ChatGPT-4 suggested multiple ideas involving students embodying the decimal and walking along a physical number line (Fig. 2). While this problem type lends itself easily to physical movement, it remains to be seen whether LLMs can produce similar results for more abstract problems.

**1. Human Number Line Walk**

- Lay a long rope or tape on the floor as a number line (0 to 1 marked with tenths and optional finer divisions).
- Call out a decimal (e.g., 0.33), and students walk to the estimated position.
- Freeze the "zombie" (a student acting as one) by standing in the correct spot.

**2. Giant Number Line Jump**

- Mark a number line on the ground.
- A student starts at 0 and jumps forward in tenths to estimate 0.33.
- If they land close, they "freeze the zombie" (a student moving toward them).

**Fig. 2.** Two of the ChatGPT-4 suggestions for embodying number-line problems

While LLMs can quickly generate embodied activity ideas based on a digital game, a critical research question is how to systematically evaluate the quality and educational value of these outputs. Our approach will include rubric and expert-based evaluation. Outputs will be evaluated using a structured rubric including dimensions such as conceptual alignment (how well the activity targets the intended math concept), physical mapping (how meaningfully movement is tied to the idea), feasibility in classroom contexts, clarity of instructions, and creativity or engagement potential. Each activity will be rated independently by experts in learning sciences, math education, or educational technology, and we will calculate interrater reliability to ensure consistency across evaluations.

**Comparing Digital and Embodied *Decimal Point*.** After the embodied version of *Decimal Point* has been developed, we will conduct comparative studies. Participants would be fifth and sixth-graders since the content of the game is most suitable for this age group. To test for learning gains, we will use the existing *Decimal Point* pretest, post-test, and delayed post-tests [8].

To test for differences in affect, students will take a post-game questionnaire evaluating their sense of motivation, engagement, perception of mastery, and enjoyment. For motivation in mathematics, we will use the traditional Eccles & Wigfield expectancy-value theory assessment instrument, which divides motivation into self-concept, liking, and value of mathematics [17]. To measure enjoyment in mathematics, we will use the same items that Frenzel et al. [4] used to measure enjoyment for mathematics in students, which correspond to class-related enjoyment items of the Achievement Emotions Questionnaire for Mathematics [3] to assess students' enjoyment during mathematics classes. To measure mastery vs. performance goal orientation, we will use selected items from Pintrich's [12] motivated strategies for learning questionnaire. Finally, students will take a demographic questionnaire with binary and multi-dimensional aspects of gender [15].

## 4 Expected Contributions

This proposed project addresses a gap in prior research by directly comparing digital and embodied learning approaches using identical math content. Past research has studied these methods separately or compared them to traditional instruction, but never against each other. Our proposed study provides an opportunity to examine which modality supports better learning outcomes overall, and how each fosters engagement, conceptual understanding, and transfer differently. This work aims to uncover the mechanisms that drive learning in each modality. For instance, embodied learning may promote deeper conceptual grounding by leveraging sensorimotor experiences and spatial reasoning, while DGBL may enhance learning through structured interactivity, narrative engagement, and immediate feedback.

By investigating how gender and prior knowledge interact with learning modality, we may also reveal important insights about inclusive design for educational technologies. For example, if the embodied version shows different patterns of effectiveness across gender or prior knowledge levels, this could suggest important design considerations for creating more equitable learning technologies.

This project also opens possibilities for exploring how large language models (LLMs) might assist in the creative design process of translating digital games into embodied learning activities. As an extension of this work, we plan to investigate how well LLMs can generate designs for embodied versions of the *Decimal Point* mini-games based on the digital game specifications. This could potentially establish a new methodological approach for efficiently creating embodied learning activities from existing digital content, thus expanding the repertoire of AI applications in educational design.

In summary, this research sits at the intersection of learning sciences, game design, and artificial intelligence. Beyond advancing our theoretical understanding of embodied cognition and active learning in mathematics, this project offers practical insights for developing technologies that engage the whole student—mind and body—in the learning process.

**Acknowledgments.** Thank you to Zitao Liu for his helpful comments as part of the AIED Doctoral Consortium. ChatGPT was used to revise this paper.

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