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Assessing Impact of Tablet-Based Digital Games on Mathematics Learning Performance †

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Abstract: The popularity of digital games offers new-generation students an effective mathematics learning approach. In this study, a digital game intervention is used to enhance the learning of school mathematics for primary school students. The participants were first-grade children identified by the school as having difficulties in mathematics. The students were assigned to interact with the game implemented as a parallel part of normally scheduled class activities for one semester. The results revealed that using digital games for cognitive engagement with the regular mathematical content being taught in a classroom increased students' learning potential.

Keywords: digital game; cognitive training; mathematical disabilities; mathematics learning; numeracy training

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1. Introduction

Sources contributing to mathematical achievement include numerical knowledge and underlying general cognitive processing. Mathematical skills also are an integral component of basic literacy. Improving students' proficiency in mathematics plays a key role in many countries' education strategies [1,2]. Despite the importance of mathematics, the majority of students in K-12 education regard mathematics unfavorably and recognize it as a frustrating and difficult subject that causes learning fatigue, pressure, and anxiety [3–7]. Therefore, mathematics shows the highest student failure rate [8]. Scholars have pointed out that the traditional teaching method deserves criticism and leads to learning problems. For example, students' exposure to complex problems is very limited. Hence, the traditional method does not advance the development of students' problem-solving skills, conceptual understanding, or critical analysis [9,10].

Due to substantial technological developments during the past decade, many researchers and educators are incorporating technology into education [11,12]. Among the various technology-supported learning methods, digital game-based learning (DGBL) is perceived as an effective way to learn mathematics because digital games are powerful in presenting complex mathematical concepts as they provide an alternative media where the interaction and exploration of the content are inherent. For instance, it was indicated that using DGBL applications in mathematics promotes students' perseverance and improves their engagement in learning [13,14]. Thus, gaming could contribute to young learners' cognitive development [15]. Researchers also found that numerous technology-based games improved students' numerical magnitude knowledge by training domain-specific and domain-general skills and improving mathematical learning performance. For example, playing adaptive and computerized number games involves numerical magnitude comparisons using dots, numbers, or arithmetic problems and improves preschool- and kindergarten-age children's numerical magnitude knowledge [16,17]. However, most research has been focused on improving mathematics learning of children with a disease that

causes learning difficulty in mathematics. Mathematics learning disabilities (MLD) are used broadly to describe difficulty with a variety of math skills that cannot be explained by a lack of intelligence, neurological abnormalities, or insufficient teaching [18]. Currently, studies on mathematics learning examine working memory and numeracy training programs for children with math learning difficulties.

Early numeracy skills training may impact children's math achievement more than other programs for domain-general mathematics skills. However, there are still gaps in the literature for a better understanding of the phenomena, which needs further study. Based on the literature review, we hypothesized that playing a mathematics-based game would improve the numerical fluency, mathematical fluency, and mathematics learning achievement of children with mathematical learning disabilities. Thus, we investigated the effectiveness of a tablet-based game intervention in mathematics learning to answer the following research questions.

- Do MLD students who use tablet-based digital game intervention demonstrate greater mathematical fluency?
- Do MLD students who use tablet-based digital game intervention demonstrate greater mathematics learning achievement?

2. Literature Review

2.1. DGBL

Learning during playing games on a digital platform is called DGBL learning. DGBL transforms digital games into educational tools [19]. Multiple studies have indicated that game-based learning has numerous benefits, including allowing students to enjoy learning [20], improving their engagement, and motivating them to explore the unknown [21,22]. Digital game-based learning is an interactive experience that integrates educational content into gaming activities and is relevant to almost all subjects [12,23]. Digital game-based learning attracts students' attention, fosters a positive attitude toward learning, heightens their interest and engagement, and contributes to the growth of problem-solving-related critical thinking skills [20,22].

2.2. DGBL for Mathematics Learning

Mathematics is fundamental for developing human cognition and advancing many other disciplines [12]. Children in the 21st century must be capable of logical, creative, critical, and rational thoughts and ideas [23]. Nevertheless, many elementary and high school students find mathematics discouraging. Specifically, students often dislike mathematics because they believe it to be tedious, difficult, and irrelevant [6]. Therefore, it is essential to establish effective strategies for arousing students' interest in mathematics, enhancing their conceptual understanding, and supporting them in acquiring arithmetic skills [24].

In mathematics education, DGBL is regarded as a learning tool that helps students acquire conceptual knowledge [25], practice arithmetic skills [26], and increase classroom engagement [25]. For several decades, the pedagogical potential of DGBL has been widely recognized [26,27]. Students will learn mathematics effectively when they can independently and productively generate mathematical concepts. Therefore, using DGBL to teach and study mathematics helps students develop self-awareness [28]. In addition to other fundamental skills such as reading and problem-solving, children can master fundamental mathematics concepts and skills while they play the game and complete the tasks. These interactions assist in learning and acquiring abilities [29], suggesting that DGBL assists pupils in enhancing their mathematical performance.

3. Tablet-Based Digital Game Intervention

In Ref. [18], a brain training program was created based on computer games (Figure 1). We translated the game content into the Thai language version. This tablet game provides narratives and themes to simulate a video game environment. Each game features twelve minigames that vary in game design, topic, necessary action, and types of inputs. Within

each minigame, the level of difficulty increases proportionally to the number of stimuli that were recalled depending on the working memory capacity and numerical factors. After completing each assignment, the player receives a gift, and their development through each mission was awarded with badges that increased their learning status.

Figure 1. Screenshots of the tablet-based game intervention.

4. Research Methodology

4.1. Participants

In total, 10 first graders (5 females and 5 males) from two classes in a municipal primary school in the northeastern area of Thailand were recruited, considering mathematical fluency and prior mathematics knowledge assessments. The students had a limited capacity for working memory and scored at or below the 20th percentile on the tests in the two classes. Their abilities were different in participating in the game in the experiment.

4.2. Training Intervention

Participants were exposed to the gaming intervention for 16 weeks, one regular semester. The training games were played on 7-inch touchscreen tablets, which recorded the children's reactions, too. During the semester, we offered the intervention twice or thrice per week for 20 min every session in a total of 800 min of training.

4.3. Research Instruments

A multiple-choice questionnaire with 25 items was used as a research tool for evaluating the mathematics learning achievement of the students. Surveys were conducted before and after the game intervention. The maximum possible score on this assessment was 25. A correct response scored one point, while an incorrect one scored zero. Mathematical fluency was evaluated using a "Math Fluency" examination. Participants were given one minute to execute as many arithmetic operations as possible in each set. The raw score was determined by how many additional problems were completed successfully within the allocated time.

4.4. Data Collection and Analysis

All the students experienced the game intervention for 800 min for 16 weeks. They spent 31 min completing the mathematics learning achievement questionnaire as a post-test. The obtained data from questionnaire surveys were analyzed for descriptive statistics such as arithmetic mean, standard deviation, frequency, and ratio. Individual actual gains were calculated as the percentage of the absolute gain.

$$\text{Gain (individual)} = (\text{post-test score} - \text{pre-test score})/\text{pre-test score} \times 100\ (\%) \quad (1)$$

The use of the single student's gain and its related calculations was used as an empirical justification of course effectiveness.

5. Results and Discussions

5.1. Research Question 1

For research question 1, descriptive statistics and individual normalized learning gain were analyzed. The descriptive statistics of the students' pre- and post-test mathematical fluency scores are presented in Table 1.

Table 1. Descriptive statistics on students' mathematical fluency.

Measurement	Mathematical Fluency			
	Mean	Standard Deviation (SD)	Maximum Score	Minimum Score
Pre-test	1.50	1.43	5	0
Post-test	16.60	5.23	26	11

Table 1 shows that the students' mathematical fluency scores after receiving the tablet-based game intervention (mean = 16.60, SD = 5.23) were higher than those before the intervention (mean = 1.50, SD = 1.43). Figure 2 shows the normalized gains ranked from 0.20 to 0.45 and from low to medium levels.

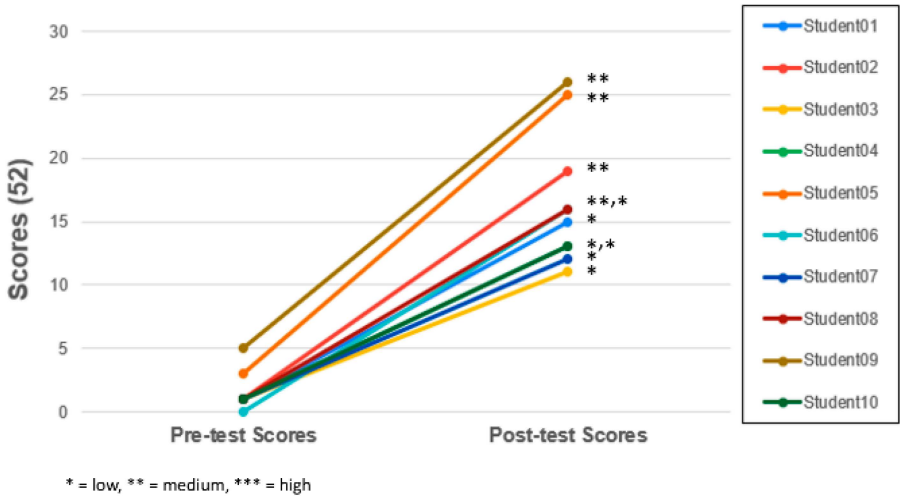

Figure 2. Results on mathematical fluency for individual students.

These results indicate that students improved mathematical fluency with the proposed tablet-based digital game intervention. These findings correspond to the results of Refs. [18,30] and show that numeric training benefits children at risk of mathematical learning disabilities to a larger extent.

5.2. Research Question 2

For research question 2, individual normalized learning gain and descriptive statistics were analyzed. Table 2 shows the descriptive statistics for the students' pre-and post-test scores on mathematics learning achievement.

Table 2. Descriptive statistics on students' mathematics learning achievement.

Measurement	Mathematical Learning Achievement			
	Mean	Standard Deviation (SD)	Maximum Score	Minimum Score
Pre-test	12.50	2.59	17	7
Post-test	17.40	2.88	23	14

Table 2 shows that the students' mathematics learning achievement scores after receiving the game intervention (mean = 17.40, SD = 2.88) were higher than those before the intervention (mean = 12.50, SD = 2.59). Figure 3 shows the ranking of the single-student normalized gains from 0.08 to 0.83, with the ranking of their size effects from low to high levels.

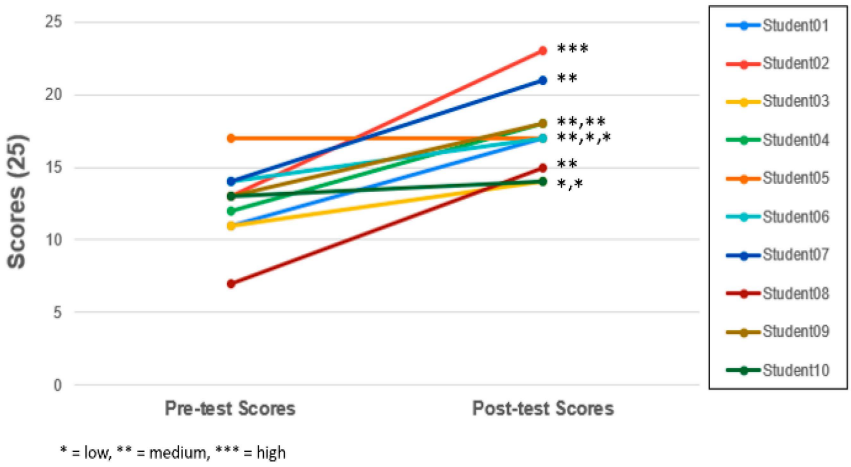

Figure 3. Results on mathematics learning achievement for individual students.

Intervention effects were observed in other mathematics performance training for students' mathematics development, as those who finished the numerical training enhanced mathematics learning performance [16].

6. Conclusions

Even though the number of studies on working memory and numeracy training has increased significantly over the past decade, it is still necessary to determine whether children with math learning impairments can benefit from them [18]. Thus, we researched if tablet-based digital game interventions allowed mathematics learning gains by measuring learning achievement and mathematical fluency for primary school students with mathematical challenges. The results revealed that the tablet-based digital game intervention had significantly favorable effects on the enhancement of students' mathematical fluency. In addition, primary school students with mathematical difficulties enhanced their mathematics learning performance considerably.

This study has limitations, such as a small sample size and short intervention periods. These necessitate a study with a larger number of students and a longer period to explore a long-term impact. The short period could alter the students' interaction with the games and the extent of the observed effects. In addition, future research with game interventions and training studies with other teaching aids and strategies are also required to find a way to overcome the inherent limits in actual classroom settings.

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