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Effects of Integrating Brain Training Digital Game for Improving Learning Gains †

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Abstract: Mathematics is a fundamental subject for learning at all levels of education. Thus, developing effective methods for increasing children's learning performance in mathematics is important. In this study, first graders who were identified to have difficulties with mathematics experienced a digital game-based intervention as a parallel part of normally scheduled class activities for one semester. The results revealed that the students showed positive results in their mathematical learning and numerical fluency after receiving the game intervention.

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

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1. Introduction

One of the core subjects in schools is mathematics, as it offers helpful knowledge for everyday life and is crucial for personal growth [1,2]. However, many students in basic and secondary education consider mathematics to be depressing. For example, it was demonstrated that students frequently categorized mathematics as a disliked course because they thought it was boring, challenging, and pointless [3]. Those who struggle to master mathematics may have lower aspirations for their professional futures [4]. Therefore, it is crucial to develop effective teaching strategies to increase students' interest in math, enhance their conceptual comprehension, and develop their arithmetic skills [4,5]. To address the problem, Muñez et al. proposed a digital game-based intervention to facilitate students' mathematics learning performance [6]. The present study was conducted based on the guidelines of Ref. [6] to see if students could successfully improve their mathematical learning using the proposed digital game-based intervention. The result was discussed to answer the following research questions.

- Do students with mathematical disabilities demonstrate better mathematical fluency with digital game-based intervention?
- Do students with mathematical disabilities demonstrate better mathematics learning achievement with digital game-based intervention?

2. Literature Review

2.1. Digital Game-Based Learning (DGBL)

Recently, much research has been done in the context of DGBL as an enjoyable environment that helps students in education. Considering this, Prensky underlined that merging serious learning with interactive entertainment is the primary characteristic of DGBL environments [7]. Digital games make learning enjoyable, facilitate task-focused attention [8], encourage learning, boost success [9], and influence behavior and attitude [10]. These findings suggest that instructional video games ought to have a set of features that must not be created at random. However, different scholars have different ideas about what characteristics of a digital game are needed to be instructive.

2.2. DGBL in Mathematics Learning

The educational potential of digital games has been generally acknowledged for a while [11–13]. Digital games provide delight and pleasure for children to progress in their learning and performance in mathematics by reducing their stress and frustration [4,5,11,14,15]. Digital games offer students numerous options for learning, such as repeating activities to not make the same mistakes [16]. They are not just for enjoying [12,15,17], but for allowing students to participate and explore mathematical knowledge [18,19]. Digital game-based learning creates such an environment that fosters students' learning interest [12,20], learning confidence [15], and eagerness to learn [5,12,19].

3. Brain Training with Digital Game Intervention

Muñez et al. developed a computerized game-based brain training program in which the game intervention was translated into the Thai language, as shown in Figure 1 [6]. This tablet game uses narratives and themes to simulate a video game environment. There are twelve minigames in each game, and each one has a different game concept, theme, action required, and type of stimuli. The difficulty of each minigame increases as a function of the number of stimuli, working memory capacity, and numerical aspects. Each completed task gives rewards, and progressing through the missions earns the player badges to upgrade the player's status.

Figure 1. A screenshot of the game intervention.

3.1. Participants

A total of 10 first-grade students were recruited from 67 students as participants in this study. They were screened for mathematics fluency and prior mathematics knowledge from the students of two classes in a public primary school in Thailand's northeast. The selected students had poorer working memory and performed at or below the 20th percentile on the aforementioned exams in the same age group of the two classes. The participants had satisfactory skills in using a tablet and had yet to experience using it in mathematics classes. The group of participants was heterogeneous in terms of their backgrounds in mathematics before interacting with the game intervention in the experimental study.

3.2. Training Intervention

The game intervention was given to the participants for 16 weeks, which was a whole regular semester. Children participated in the training games on similar 7-inch touchscreen tablets and recorded their responses. During 16 weeks of the intervention, the participants spent 800 training minutes in total, experiencing the intervention for 20 min twice or three times a week.

3.3. Questionnaire Survey

Each participant's mathematics learning achievement was measured through a questionnaire survey with 25 items using a multiple-choice method. Surveys were conducted before and after the game intervention. In addition, a math fluency test consisting of 52 arithmetic addition problems was used to measure their mathematical fluency. The participants finished as many calculations in each set as they could in one minute. The total number of correct calculations within the allotted time was their raw scores.

3.4. Data Collection and Analysis

Before having the game intervention, the participants were pre-tested for mathematics learning achievement and math fluency for 31 min. For the post-test, the same test was conducted. The results from pre- and post-tests were analyzed to obtain descriptive statistics including arithmetic mean, standard deviation, frequency, and ratios. Individual actual gains were calculated as the percent absolute gain as follows.

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

This is the actual gain divided by the maximum gain achievable by an individual participant. The participant's gain is used to understand course effectiveness.

4. Results

4.1. Mathematical Fluency

The descriptive statistics of the pre-test and post-test mathematical fluency scores of the participants are presented in Table 1. The mathematical fluency scores after experiencing the game intervention (mean = 13.11, standard deviation (SD) = 7.08) were considerably higher than those before the intervention (mean = 1.44, SD = 1.33). (The total score of the mathematical fluency test was 52). All participants' scores for pre- and post-tests are shown in Figure 2. The participants' scores were significantly increased.

Table 1. Descriptive statics on students' mathematical fluency.

Test	Mathematical Fluency Score			
	Mean	**SD**	**Highest**	**Lowest**
Pre-test	1.44	1.33	3	0
Post-test	13.11	7.08	22	4

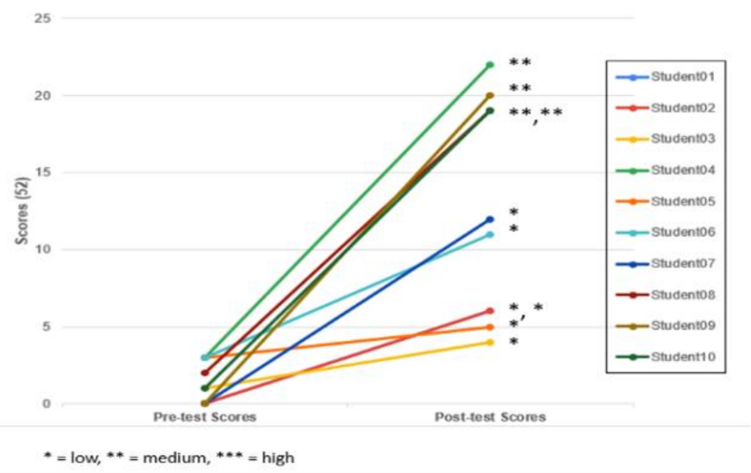

Figure 2. Improvement in the mathematical fluency test score for participants.

4.2. Mathematics Learning Achievement

The descriptive statistics of the scores of the mathematics learning achievement in the pre- and post-tests are presented in Table 2. The mathematical fluency scores of the participants after the game intervention (mean = 20.00, SD = 2.62) were significantly higher than before the intervention (mean = 9.80, SD = 5.39). (The total score is 25). The pre- and post-test scores of all participants are shown in Figure 3, showing considerable improvement in test scores.

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

Test	Mathematics Learning Achievement			
	Mean	SD	Highest	Lowest
Pre-test	9.80	5.39	17	2
Post-test	20.00	2.62	23	15

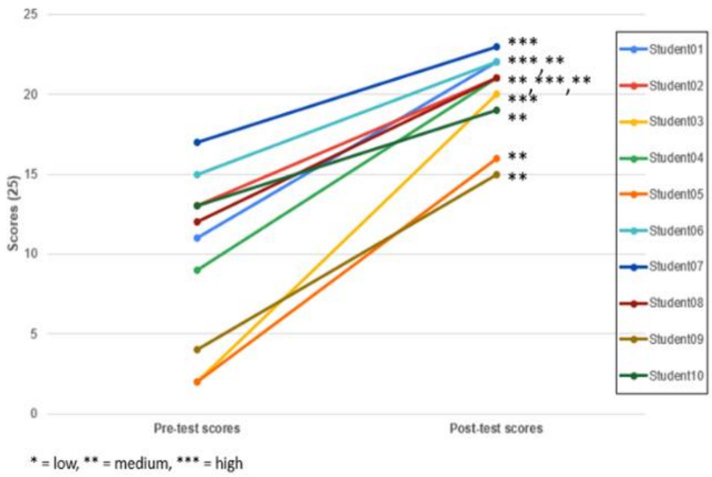

Figure 3. Improvement in the mathematics learning achievement test score for participants.

5. Discussions and Conclusions

Although studies on working memory and numeracy training have been carried out over the past ten years, it has been unclear whether the training helps children with learning impairments in mathematics [6]. The purpose of the present study was to confirm the effect of the digital game intervention on the increase in mathematics learning in terms of learning achievement and mathematical fluency for primary school students with mathematical disabilities.

Our first research question was whether digital game-based intervention enhances the mathematical fluency of students with mathematical disabilities. The findings of the present study showed the positive effects of the game intervention on enhancing mathematical fluency. For the second research question, whether mathematics learning gains are modified by the digital game-based intervention, the findings proved that students with mathematical disabilities improved their mathematics learning achievements. These findings coincided with the results of Refs. [6,21] which stated that such instruction had a positive impact on children with math learning problems. The training effects on mathematics performance have been confirmed as children who underwent the numerical training demonstrated improvements in their aptitude for learning mathematics [22,23].

Considering the limitation of the small number of participants and the short intervention period, further study is required with a large number of participants and a longer intervention period than 16 weeks. The students' experiences with the games and the scope of the impacts in this study may be also limited by their limited gaming times. However, the findings of the present study are the basis for research on how to design interventions and training programs to enhance instructional efforts and overcome the inherent constraints of real classroom environments.

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