

The Effects of Mini-Games on Students' Confidence and Performance in Mental Calculation

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Abstract: Low confidence toward mathematics is one of the critical issues that diminish students' will to learn mathematics. Several studies indicated that game-based learning (GBL) might be a potential approach to address this issue. In addition, mental calculation, a fundamental mathematical skill, was considered to be a potential skill that may build students' confidence toward mathematics. Thus, this study attempted to promote students' mathematical confidence by incorporating mini-games, a sub-genre of games, into mental calculation learning. A preliminary study was conducted to investigate how students reacted to learn mental calculation in a mini-game environment. The results of the preliminary study suggested that the mini-game-based approach was popular to students. However, it was observed that students' with different levels of academic ability might benefit diversely from the mini-game environment. Thus, an experiment was conducted to investigate how students with different levels of academic ability react to learn mental calculation with mini-games, in terms of two important aspects of learning, i.e., performance and confidence. A control group participated in a paper-based learning approach to provide a baseline of comparison. The results indicated that The mini-games helped both high- and low-ability students gain significant improvement on their mathematical confidence. In addition, the low-ability students learned with mini-games gained more improvement on mental calculation than their paper-based peers did.

Keywords: mini-games, confidence, math learning, mental calculation, learning performance

1. Introduction

Mathematics is an important and fundamental skill taught in schools. However, it is also a difficult subject in students' mind (Stodolsky, Salk, & Glaessner, 1991). Such a negative perception may result from students' low confidence toward mathematics, which, in turn, may diminish students' will to learn mathematics (Brown, Brown, & Bibby, 2008). The importance of self-confidence can be seen in many aspects (Linnenbrink & Pintrich, 2003; Maclellan, 2014). For example, a person's self-confidence toward a subject can predict not only how much effort he/she will pay to learn the subject but also his/her expectation of learning outcomes (Schunk, 1990). In addition, high self-confidence may lead students to engage in a learning task actively (Gushue, Scanlan, Pantzer, & Clarke, 2006) and attain better learning outcome (Kleitman, Stankov, Allwood, Young, & Mak, 2013). Thus, helping students to build their confidence toward mathematics is an urgent issue.

Digital games, as an alternative learning approach, may be a possible solution to the problem of students' low confidence toward mathematics. There have been a number of studies reporting the positive effects of GBL (Pivec, 2007; Chang, Wu, Weng, & Sung, 2012), such as enhancing students' learning motivation (Klawe, 1998; Nussbaum, 2007) and improving students' learning performance (Girard, Ecalle, & Magnan, 2012). Importantly, several studies indicated that GBL might enhance students' confidence (Cunningham, 1994; Radford, 2000). On the other hand, mental calculation, a relatively basic mathematical skill, may also help students shape their confidence toward learning mathematics (Rubenstein, 2001).

To this end, this study aims at investigating whether embedding learning content in digital games can enhance students' confidence and performance in mental calculation, especially for low confident students. Among various genres of digital games, mini-games are chosen as the learning environments in this research due to their simplicity. Regarding learning material, mental calculation was chosen as the learning content for its importance to mathematics. In addition, how students with different levels of ability react to the mini-games-based learning approach was also examined, because the issue of individual difference is more and more important to the design of digital learning. Thus, the research questions of this study are: (1) Can embedding mental calculation learning in mini-games enhances students' confidence and learning performance toward mental calculation and their future math learning? (2) Do students with different levels of academic ability react similarly to mini-game-based learning?

2. Related Work

2.1 Mathematical Confidence

Confidence influences students' performance (Al-Hebaish, 2012) and effort (Bandura, 1982; Tschannen-Moran, Woolfolk Hoy, & Hoy, 1998). For example, confidence was also found to affects one's math performance (Stankov, Lee, Luo, & Hogan, 2012). Besides, it also affects students' will to enroll mathematics courses (Metie, Frank, & Croft, 2007).

On the other hand, the recent reports of the Trends in International Mathematics and Science Study (TIMSS) indicated that there were a large proportion of Asian students possessing low confidence toward learning mathematics (Mullis, Martin, Gonzalez, & Chrostowski, 2004; Mullis, Martin, & Foy, 2008). Such a phenomenon was getting more and more serious with the students' age. This is a critical issue that needs to be noticed because low confidence may make students feel mathematics difficult (Brown, Brown, & Bibby, 2008), which, in turn, may make student avoid facing mathematics. Thus, there is a need to help students build up their mathematical confidence.

2.2 Game-based Learning

Past studies on GBL revealed many positive effects brought by applying digital games to learning environments. For example, GBL enhanced students' learning motivation (Dickey, 2007) and improved students' engagement in learning (Huizenga, Admiraal, Akkerman, & ten Dam, 2009). In addition, digital games were found to have the potential to enhance students' confidence (Cunningham, 1994). For example, Straker et al. (2011) investigated whether playing virtual reality (VR) electronic games helped children with developmental coordination disorder (DCD) gain motor confidence. Their results indicated that playing VR electronic games enhanced DCD children's confidence in performing motor skills. Such research demonstrated that digital games might have the potential to help students build their confidence toward the course that they are learning. In this vein, digital games may be a possible solution to address the issue of students' low confidence toward learning mathematics. Therefore, embedding math learning into digital games may be a possible solution to enhance students' self-confidence toward learning mathematics.

2.2.1 Mini-games

Among various game genres, a mini-game (causal game) is a kind of relatively simple games designed for players who do not want to spend much time and effort on playing games. The main purpose of mini-games is providing people a period of relaxation time between two formal tasks. In contrast with large-scale games, mini-games are simpler and easier to be operate. Even so, they still possess the characteristics of a game. In most computer games, players have to devote significant attention on playing games. However, in mini-games, players can keep more concentration on learning tasks rather than playing games; games are just assistants that engage students in learning tasks. On the other hand, because mental calculation requires a high level of concentration for students to produce an answer, there is a need to reduce students' cognitive load. To this end, mini-game is adopted as the design of the

games with exchangeable learning materials for this study. More specifically, mini-games were adopted majorly due to their simplicity, which might cause less cognitive load for learners than complex games did. Additionally, mini-games are content-independent, which makes it possible for the mini-games to be associated with different learning materials.

3. Research Design

Two studies were conducted to investigate the effects of mini-games on students' confidence and performance in mental calculation. In addition, a framework is presented to illustrate the relationship between the two studies.

3.1 Preliminary Study

Since not all GBL produced positive results in past studies, there is a need to examine whether such a pedagogy is beneficial for building students' confidence toward mental calculation and enhancing their performance. Thus, a preliminary study was conducted to examine whether learning in mini-game environments brings positive effects on students' confidence and performance in mental calculation. The purposes of the preliminary study included the following aspects:

- 1) Examining the effects of mini-game-based mental calculation learning. If students' attitude and performance on mental calculation were improved due to the intervention of mini-game-based learning (mGBL), a study with experimental design would be conducted to investigate how the mGBL approach builds students' confidence and meanwhile enhances their performance subsequently.
- 2) Collecting students' learning behavior. Students' reactions to the mini-game-based mental calculation learning will be analyzed to serve as the design principles for improving the game design in the subsequent study.

3.2 Main Study

Based on the results of the preliminary study, a main study was designed and conducted to verify whether the game-based approach significantly build students' confidence toward learning mental calculation and improve their mental calculation performance. Importantly, the main study further investigates whether the mini-game-based approach brings different learning effects on students with different levels of learning ability.

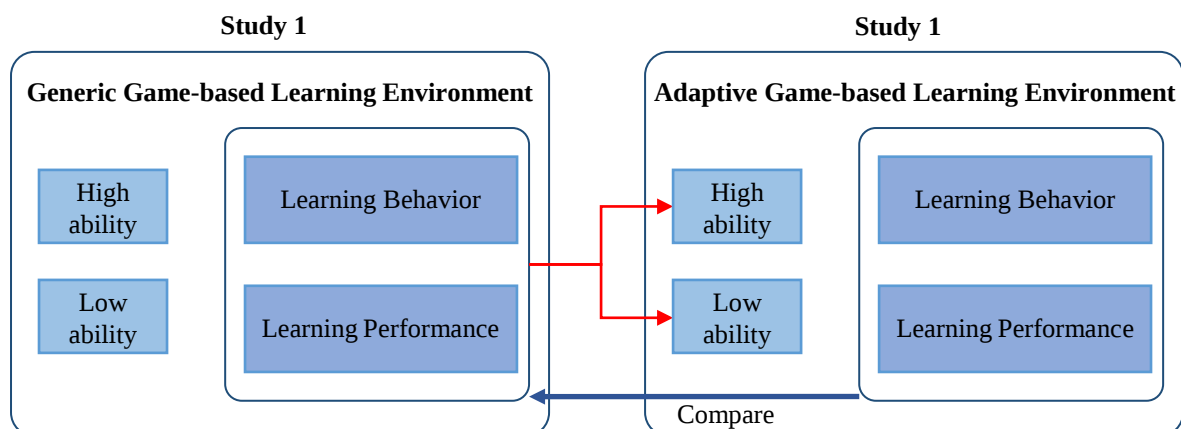


Figure 1. The relationship between Study 1 & Study 2.

3.3 Research Framework

Figure 1 illustrates the relationship between the preliminary and the main studies. The preliminary study explored the possible effects of game-based mental calculation learning while the main study further investigated how the effects were produce and whether the effects acted equally on students with different levels of ability.

4. Study One: Preliminary Study

4.1 Participants

The participants of the preliminary study were fourth grade students from an elementary school in northern Taiwan. Students in the school were normally distributed to the classes of the school based on their academic performance. Thus, a class with 28 students was randomly selected to participate in the preliminary study.

4.2 Instruments

4.2.1 Mini-games

Four mini-games (Fig. 2) were developed as the learning environments for students to learn the mental calculation skills.



Figure 2. Screenshots of mini-games

The four mini-games were designed as two multiple choice questions games (A & B) and fill-in questions (C & D). The detail descriptions of the mini-games are shown in Table 1.

Table 1: The descriptions of the mini-games.

Game	Name	Description
A	Space Traveler	Problems are shown at the top of game screen. Students have to shoot the asteroid with correct answer. Otherwise, their spacecraft will crash.
B	Forest Protector	Students have to shoot the invader who holds the correct answer to the question displayed at the top of game screen.
C	Light City	Students have to enter the correct answer to the question shown at the bottom of game screen to prevent the bomb cart from exploding.
D	Panda Math	Students have to help the panda in the screen answer the question thrown by the enemy before the question block hit the panda.

4.2.2 Materials

In order to prevent the interference from regular math courses, this study adopted mental calculation, which was not taught in regular math courses, as students' learning materials.

There are thousands of mental calculation strategies to simplify computational problems. In addition, students can also invent their own strategies. In this study, several patterns of mental calculation skills were selected according to students' prior knowledge. The goal of this study is helping students gain more "number sense", so that they might get more sense of analyzing numbers and consequently formulate an algorithm to simplify the problem they met.

4.3 Procedures

In order to investigate students' reactions to learning mental calculation within the mini-games, a set of instruction was delivered to the participants twice a week. The set of instruction lasted for nine weeks. The Procedures of each session are depicted in Figure 3. In the beginning of each session, the teacher conducted a mini lecture to introduce a mental calculation skill for five minutes. Then, the teacher used five minutes to ensure whether students understood the content of the mini lecture. Finally, students practice in mini-games for 20 minutes.

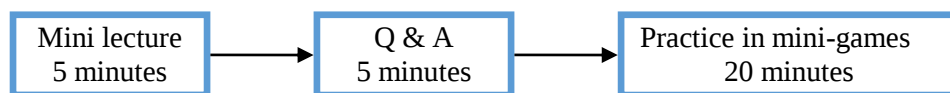


Figure 3. The procedures of a session

4.4 Results and Discussion

According to students' math scores of their school exam, students were divided into high- and low-ability groups (Table 2) to investigate whether they react differently to the intervention of mini-game-based learning. In order to investigate the impact of the mini-games in this study, the accuracy of students with different math abilities and the response time (RT) of students with different math abilities were analyzed.

Table 2: The numbers of the participants in the low and high ability groups.

High ability	Low ability	Total
13	15	28

4.4.1 Accuracy



Figure 4. The change of accuracy

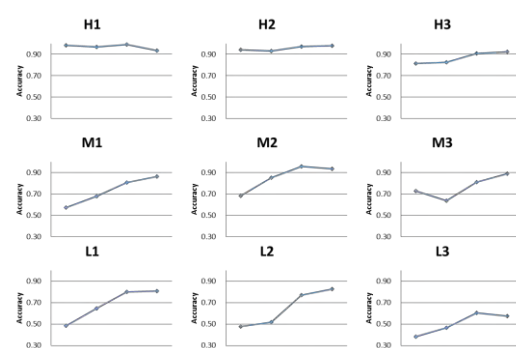


Figure 5. The average accuracy of students

The result of the Mann-Whitney test revealed a significant difference of the gain score of accuracy between the high- and the low-ability students ($U = 52.000$, $p = .036$). Such a result may imply that the low-ability students gained more improvement than high-ability students in terms accuracy (Figure 4).

Furthermore, according to students' mathematical achievements, the learning profile of the first three, the middle three, and the last three students were chosen to be analyzed. Figure 5 illustrates the average accuracy of the nine students. High math achievement students gained little improvement in

accuracy; they performed very well from the beginning of the learning sessions. The middle and left-behind group students gained quite steady improvement on the accuracy of answering questions.

4.4.2 Response Time

Students' change of response time is shown in Figure 6. The result of the Mann-Whitney test indicated that no significant difference of the gain score of response time was found between the high- and the low-ability students ($U = 76.000$, $p = .322$).

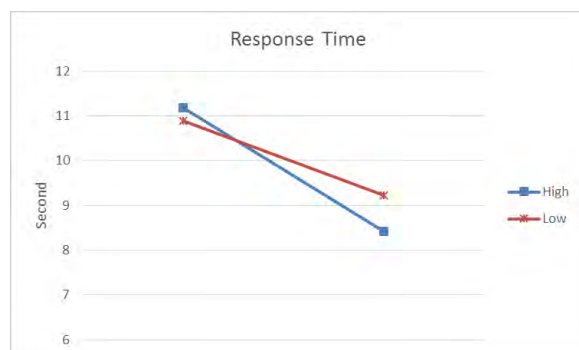


Figure 6. The change of response time

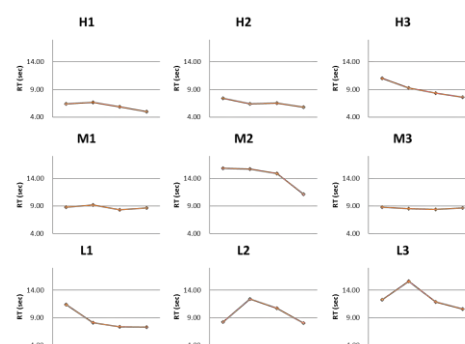


Figure 7. The average response time of students

However, when looking into the response time of the first three, the middle three, and the last three students, we can find that students showed quite different patterns of the change of response time. Figure 7 depicts students' RT. In the high achievement group, all the three students gained improvement in RT steadily. In the middle and the left-behind groups, the improvement seemed unstable. The differences among all sessions were large. Sometimes they may performed very well in a session but very poor in the next time. Maybe it was due to the fact that the learned skills in left-behind student were not consolidated enough; thus, those student performed quite unstable in their response time on answering questions.

Although several positive effects were obtained in this study, an important issue emerged with the conduction of this preliminary study should be further investigated: students with various abilities demonstrated different levels of improvement in mental calculation skills. A further study needs to be done to investigate whether such a result was caused by GBL.

5. Study Two: Main Study

The main study was conduct to investigate the ability issue raised in the preliminary study. More specifically, since individual difference is a key factor when designing individual learning environments, this study further investigates how students with different levels of academic ability react to mGBL on mental calculation in terms of two important aspects of learning, i.e., performance and confidence.

5.1 Experimental Design

A quasi-experiment was conducted to examine the effects of mGBL. Participants were fourth-grade elementary school students from Northern Taiwan. The participants were 59 students ($N=59$), aged 10-11 years old. Two classes of students were randomly selected and then assigned as an Experimental Group (EG, 14 males and 17 females) and a Control Group (CG, 12 males and 16 females). The experimental group received computer game-based learning, while the control group received paper-based learning.

In addition, students in both groups were further divided into two subgroups—high achievement and low achievement—to investigate the effects of mGBL on high and low achievement students.

5.2 Instruments

The learning materials used in the main study were the same as those in the preliminary study. Students in the EG learned in mini-game environments while CG students learned with paper handouts and worksheets.

5.2.1 Mini-games (EG)

Two mini-games were adopted as the learning environments for EG students to interact with learning materials. The two mini-games were implemented as a board game and a sports game (Fig. 4). The rules of both games are simple so that players can get started with the games without difficulty. Students learned and practiced in the mini-game environments. Students can replay the electronic learning materials at any time.



Figure 4. The board game and the sports game

5.2.2 Paper Handouts and Worksheets (CG)

Every student in the CG received a copy of learning materials printed on A4 paper. After receiving a short instruction from their teacher, students were asked to practice the newly learned mental calculation strategies with their worksheets. They could review the learning material whenever they have problems during practice. They could also ask their teacher to explain the mental calculation strategy individually. The teacher can pause students' practice and re-explain the strategy to the whole class if he found too many students encountered the same problem.

5.3 Procedures

The procedure of this study is presented in Figure 5. The pretest was administered a week before the experimental intervention. The posttest was administered a week after the last session of the experimental intervention. During the experiment, nine learning sessions were conducted for five consecutive weeks; each session lasted for 25 minutes. In each session, the teachers in both groups taught students the key features of a new strategy or reviewed previous strategies for five minutes. Students then preceded individual learning for 20 minutes.

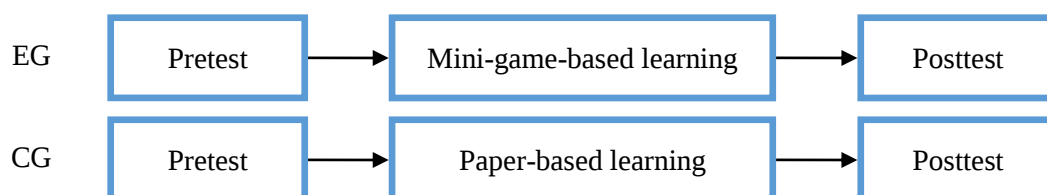


Figure 5. The procedures of a session

5.4 Results and Discussion

In order to examine whether students with different levels of ability benefited equally from the mini-game-based approach, participants were divided into four sub-groups in terms of their academic abilities (Table 3).

Table 3: The numbers of students grouped by their math ability.

	EG	CG
High ability	14	12
Low ability	12	13

5.4.1 Confidence

As shown in Table 4, low-ability CG students demonstrated a negative trend of confidence change, while the other three sub-groups demonstrated a positive change of confidence. In other words, low-ability CG students' confidence dropped after experiment.

Table 4: The mean scores of confidence toward mathematics grouped by ability.

	Ability	Pretest		Posttest	
		Mean	SD	Mean	SD
CG	Low	3.19	0.57	2.75	0.76
	High	3.55	0.67	3.69	0.88
EG	Low	3.14	0.48	3.45	0.56
	High	3.57	0.54	3.86	0.81

Regarding the mini-game-based (EG) condition, the Wilcoxon's matched-pairs signed-ranks tests revealed that both high- ($Z = 2.165$, $p = .030$) and low-ability ($Z = 2.156$, $p = .031$) students gained significant improvement on confidence. In addition the Mann-Whitney test indicated no significant difference of the gain score of confidence between the two sub-groups ($U = 81.000$, $p = .876$). Conversely, both high- and low-ability CG groups did not demonstrate significant improvement on their confidence.

For low-ability students, such a result may be caused by the positive feedback (scores, reward, and correct signs) provided by mini-games. Frequently receiving a message about completing a learning task successfully may encourage low-ability students to build their confidence toward similar tasks in the future (Pajares, 2006).

As for the high-ability EG students, there may be another source for their improvement of confidence—challenge. High-ability students may tend to expect challenge (Jones & Spooner, 2006). When completing challenging tasks, students may obtain a sense of achievement (Dickey, 2007), which, in turn, may enhance their confidence (Hammond, 2004). The mini-games adjust the game challenge dynamically; thus, high ability students can always receive adequate challenge during gameplay.

5.4.2 Mental Calculation Performance

Table 5 presents students' mental calculation performance. The Wilcoxon's matched-pairs signed-ranks tests indicated that students in each sub-group gained significant improvement of their mental calculation performance.

Table 5: The mean scores of confidence toward mathematics grouped by ability.

	Ability	Pretest		Posttest		Z	P
		Mean	SD	Mean	SD		
CG	Low	10.85	2.94	36.08	20.89	2.971	.003
	High	33.58	25.29	76.08	25.49	3.061	.002
EG	Low	18.58	9.92	62.75	24.63	3.061	.002
	High	24.64	22.20	75.21	22.08	3.297	.001

For the CG students, as expected, the result of the Mann-Whitney test demonstrated a significant difference of the gain score of mental calculation performance between the high-ability and the low-ability students ($U = 40.000$, $p = .039$). In other words, the high-ability students in the CG gained more improvement than their low ability peers in the same setting.

On the other hand, although the high-ability EG students did not performed as well as their high-ability CG peers, they attained a comparable level of performance in the posttest. As for low-ability students, the result of the Mann-Whitney tests demonstrated a significant difference of the gain score between the EG low-ability and the CG low-ability students ($U = 38.500$, $p = .032$) while the difference of pretest between the EG low-ability and the CG low-ability students was not found ($U = 46.500$, $p = .085$). This result might imply that the low-ability EG students gained more improvement than those in the CG.

The results demonstrated in this section indicated that the mini-game-based learning might provide greater benefit to low-ability students in terms of the learning gain. Such a result might be caused by the immediate feedback for error correction in the mini-games, which helped learner consolidate knowledge (McDaniel, Roediger, & McDermott, 2007).

6. Conclusions

Confidence plays an important role in students' learning process. However, a lack of confidence toward mathematics is many students' common problem, which prevents them from pursuing advanced mathematical knowledge. This research introduced mini-games as an approach to motivate students to learn a fundamental mathematical skill, mental calculation and investigated whether such an approach can enhance students' confidence toward mathematics.

The results from both the preliminary and the main studies indicate that students' confidence and performance in mental calculation were improved after receiving a mini-game-based mental calculation course. Furthermore, the experimental results obtained from the main study indicate that students with the mini-game-based environment gained significant improvement on confidence toward mathematics; both high and low ability students gained significant improvement on their mathematical confidence. In contrast, students learned with the paper-based setting did not demonstrate similar change on their mathematical confidence. On the other hand, students in all conditions gained significant improvement for mental calculation performance. Importantly, the EG students gained more improvement than their CG peers.

Acknowledgements

The authors would like to thank the National Science Council of the Republic of China, Taiwan, for financially supporting this study under contract numbers NSC 100-2511-S-008-014-MY3 and NSC 100-2511-S-008-013-MY3.

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