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REGULAR ARTICLE

# Using Game-Based Learning to Support Learning Science: A Study with Middle School Students

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**Abstract** Game-based learning refers to establishing learning environments that involve digital or non-digital games to enhance students' knowledge and skill acquisition. Previous studies indicated that game-based learning is superior to the conventional instructional method, but few compared the differences between different game types. This study examined the effects of game-based learning on Chinese middle school students' learning of science and their self-efficacy. We implemented an experiment to compare the effects between digital and non-digital game-based learning. Our results showed that students in game-based learning groups performed significantly better in the content knowledge assessment and reported higher self-efficacy than the traditional lecture group. No significant difference was found between the digital and non-digital game groups when considering science learning performance, but students of the digital game group showed significantly higher self-efficacy than those of the non-digital game group. Implications of the findings for future research and practice of game-based learning are discussed.

**Keywords** Science education · Digital game-based learning · Non-digital game-based learning · Self-efficacy · Chinese middle school students

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## Introduction

Game-based learning refers to a type of learning environment that involves game content and game play to enhance knowledge and skill acquisition (Qian and Clark 2016). Typically, game-based learning includes game activities regarding problem solving and offers challenges to learners with a sense of achievement. Well-designed educational games show great potential to enhance teaching and learning. In science education, game-based learning is an effective method to support students' learning of scientific knowledge. Prior studies have reported that game-based learning not only have positive effects on students' learning but also can enhance their self-efficacy (Meluso et al. 2012; Sung and Hwang 2013; Hung et al. 2014). With these merits, more and more researchers and educators start to pay attention to integrating game-based learning into science classrooms.

In China, there is a growing interest in STEM education, especially in science education (Zhao and Thomas 2016; Liang et al. 2017). Natural science is a required subject for students in the 9-year compulsory education. Scientific literacy is also considered a core literacy of all students (Chen et al. 2009; Gao et al. 2016). However, in most science classrooms, teacher-centered lecturing is still the dominant instructional method. What's more, Chinese students have shown better response to traditional lecture styles relative to western students (Dahlin and Watkins 2000; Cheng and Wan 2016). Game-based learning is a method that shows the potential to transform the teaching and learning of science (Hamari et al. 2016; Khan et al. 2017; Cardinot and Fairfield 2019), but is it applicable for Chinese students? Further study is needed to answer this question. Moreover, there exist at least two types of educational games: digital and non-digital games. However,

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few studies have compared the effects of game-based learning on students' learning and self-efficacy between the two types of games. Previous research is mostly based on digital games, and non-digital games have received less attention (Naik 2014). Some digital game-based learning proponents presumed that digital media had certain hidden qualities compared to non-digital media as concerns learning (Prensky 2001; Tapscott 1998). While non-digital game-based learning proponents believed that non-digital games had many advantages over digital games (von Gillem and Alaswad 2016). Echoing Berland et al. (2011) argued that the transparency of the rules of non-digital games was an important element of their enjoyment. Thus, investigating and comparing effects of digital and non-digital games on students' learning is important. The goal of this study was to examine the effects of game-based learning on Chinese middle school students' learning of science and their self-efficacy in learning. We implemented an experiment to compare the effects between digital and non-digital game-based learning. The following research questions guided the study:

1. Whether digital games have better effects on students' learning of science than non-digital games?
2. Whether students who play digital games show better self-efficacy than students who play non-digital games when learning science knowledge?

## Literature Review

### Game-Based Learning

The major characteristic of game-based learning is integrating games into instruction to promote knowledge and skill acquisition (Qian and Clark 2016). During the gameplay, students need to solve problems and complete challenges that are relevant to the course content. Previous studies have reported positive effects of using game-based learning in science education (Yien et al. 2011; Lin et al. 2013). In general, researchers have examined two types of games: digital and non-digital games. A digital game refers to a game played using electronic devices such as computers, mobile devices, and so forth. Prior studies have found that digital games are effective to improve students' learning of science knowledge. For instance, Sung and Hwang (2013) conducted an experiment of integrating educational computer games into elementary school science courses and found that students' learning achievements were improved. In another study of fifth graders who played a computer game called *Crystal Island* to learn science, Meluso et al. (2012) indicated that students showed significant increases in science content knowledge in both collaborative and single game player conditions.

Non-digital games refer to any board-, card-, or other type of games that can be played in physical environments (Uzun et al. 2013). Different from digital games, non-digital games do not need electronic devices and can be implemented in different scenarios. Thus, non-digital games are widely used in STEM education and have been found to be effective in enhancing learning (Mustafa et al. 2011; Liu and Chen 2013). For example, by integrating a role-playing game into chemistry classes, Cook (2014) concluded that game participation helped to facilitate students' learning of science knowledge about the chemistry of plastics. In another study using Lego bricks to teach elementary school students science concepts, researchers noted that playing games with Lego improved both students' knowledge and problem-solving ability (Li et al. 2016). Card games are another choice. Morris (2011) conducted a study to use a card game to help students learn chemical formulas and found that the card game effectively promoted learning.

While previous research has investigated the effectiveness of using educational games to support learning, few studies have compared the effects on learning between digital and non-digital games. Some researchers compared game-based learning with conventional instructional method (Brom et al. 2011; McLaren et al. 2017). Within one game type such as digital games, prior studies also compared the effects of the single game player condition with the collaborative condition (Chen et al. 2015; Chen and Law 2016). However, little empirical research has been conducted to examine the differences in effects on learning between digital and non-digital games. One goal of our study was to investigate whether digital games have better effects on students' learning of science than non-digital games (RQ1).

### Self-efficacy and Game-Based Learning

An effective educational game should include appropriate challenges that can make students experience a feeling of self-efficacy (Johnson and Mayer 2010). In other words, successful game-based learning should consider learners' self-efficacy. Self-efficacy refers to an individual's belief in his or her innate ability to achieve goals (Bandura 1982, 1994). It reflects students' confidence in their capabilities to exert control over their own emotion, motivation, and behavior in the course of learning. These cognitive self-evaluations influence various aspects of students' learning experience, including the goals for which they strive, the amount of time and effort involved in achieving the goals, and the likelihood of reaching specific levels of learning performance. Studies have shown that students

with high self-efficacy achieved better learning results (Yusuf 2011; Safaria and Ahmad 2013).

Many researchers have explored the effects of game-based learning on students' self-efficacy (Meluso et al. 2012; Leonard et al. 2016; Lu and Lien 2019). For instance, by integrating computer games into elementary school science classes, Sung and Hwang (2013) noted that computer games improved students' self-efficacy of using computers to learn. In a study of nursing students using classroom simulation, Goldenberg et al. (2005) found that role-playing games enhanced students' self-efficacy in performing health teaching. According to Hung et al. (2014), game-based learning can effectively improve students' self-efficacy in learning compared to traditional teacher-directed lecture method. Hence, successful integration of educational games into instruction can benefit students in both learning performance and self-efficacy.

Prior studies provide evidence that game-based learning increases students' self-efficacy in learning, compared to traditional lecture method. This can be great merit of using educational games in instruction. However, few studies focused on comparing the effects of digital and non-digital games on learners' self-efficacy. While both digital and non-digital games can be used to implement game-based learning approach, gameplay and game experience of the two types of games are very different. Thus, it is important to examine students' self-efficacy when playing different types of games. This was our second research question (RQ2).

## Summary

Game-based learning is to establish learning environments that involve digital or non-digital games to enhance students' knowledge and skill acquisition. Previous research reported that game-based learning showed positive effects on students' learning performance. Researchers also found that game-based learning could improve students' self-efficacy in learning. Majority of prior studies investigated the effects of using game-based learning compared to conventional instructional method, either using digital games or non-digital games. Few have made the comparison between the two types of games. This study explored the effects of game-based learning on Chinese middle school students' learning of science and their self-efficacy in learning. We implemented an experiment to compare the effects between digital and non-digital game-based learning.

## Methods

### Participants

The participants of this study were three groups of 7th graders from a city in Central China. In this middle school, the 7th graders were divided into 12 classes. In this study, we randomly selected three classes as the research subjects, each class had about 31 students (see Table 1). The average age of students was about 12.6 years old. They all had some prior experience of game-based learning (about once or twice per term). In this study, the scientific concept taught to students was the reflection of light, which includes the four major parts: (1) objects that emit light are called light sources, (2) light travels in a straight path in a uniform medium, (3) light reflects from a smooth surface at the same angle as it hits the surface, (4) the path of light is reversible.

## Research Design and Procedures

This study used an experimental design. Students of the three classes used different instructional approaches (see Table 1). Students of class A used a digital game while students of class B used a non-digital game. Class C was the control group and used the traditional lecture method. All the three classes were taught by the same teacher.

The digital game used by class A was called *Lazors*. It is a free Android app and can be downloaded from app stores such as Google Play. In essence, Lazors is a puzzle game of lasers. To complete challenges in the game, players have to use mirrors and move the blocks to reflect the laser to hit the target. Figure 1 presents several screen shots of Lazors. In this study, students of class A played this game in a computer lab using the BlueStacks App Player, which is designed to run Android games on computers (see Fig. 2).

The non-digital game used by class B was *Laser Maze* from the American company ThinkFun. This game also requires using mirrors and other game tokens to direct the laser through a series of mind-challenging mazes and hit the target (see Fig. 3). Figure 4 shows a picture of a student who were playing Laser Maze. The key ideas of this game are similar to the digital game Lazors. The major game blocks of Lazors and the game tokens of Laser Maze are

**Table 1** Groups and interventions

| Natural class | Class A | Class B | Class C |
|---|---|---|---|
| Number of students | 31 | 30 | 32 |
| Type of game | Digital | Non-digital | None |

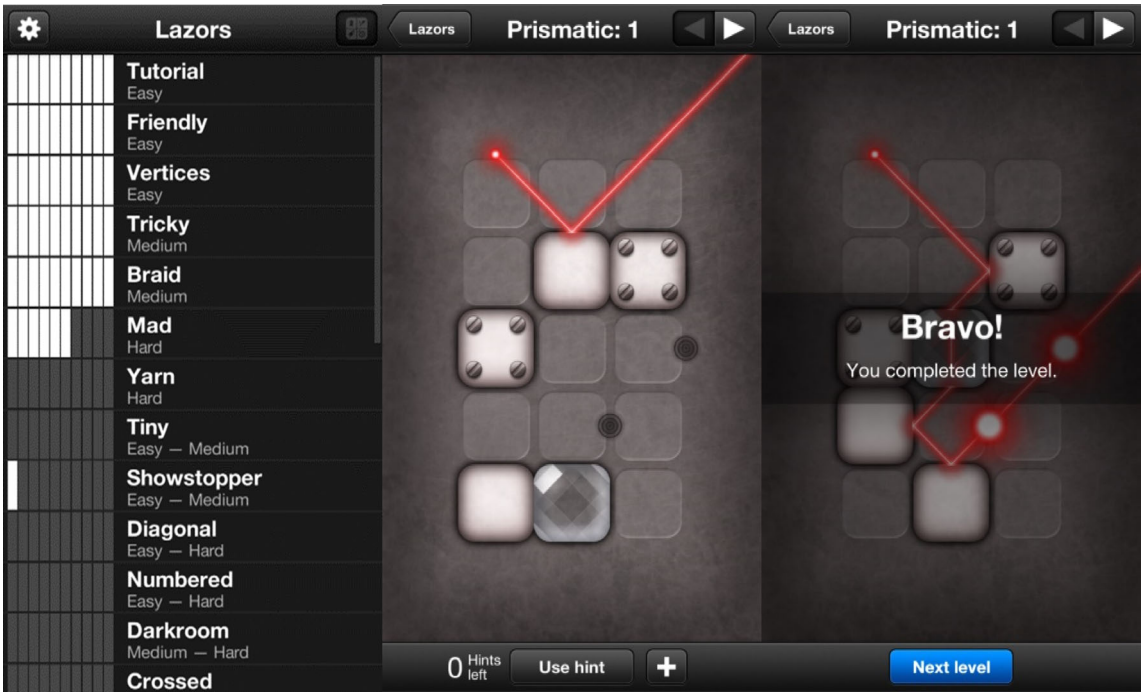



**Fig. 1** Screen shots of lazors



**Fig. 2** Students playing lazors

almost identical. The two games both have light sources, reflectors, obstacles, and so on. The main idea of the two games is similar: the player needs to use game blocks/tokens (e.g., a mirror) to direct a laser to hit targets. They both are good games for teaching scientific knowledge about optics such the reflection of light. The major difference between the two games is the rule of choosing challenges. The non-digital game Laser Maze allows players to choose challenges freely, while the digital game Lazors requires completing challenges from the easy ones to the difficult ones.

There was also a control group who learned the reflection of light using the traditional lecture method. All the three groups of students took a 50-min class about the reflection of light taught by the same teacher. Figure 5 presents the overall procedures. First, students took the pre-test before the class. Second, students started to take the class. For the two game-based learning groups, the teacher first spent about 15 min introducing the topic, learning objectives, learning tasks, and rules of playing the game. Next, students started to play the game and investigate the reflection of light. They had to complete specified learning tasks of different difficulty levels. During the game period, the teacher provided support as needed. After about 25-min game play, the teacher discussed what they had learned from the game with the students and summarized the course content. For the control group (the traditional lecture group), the teacher also spent about 15 min introducing the topic, learning objectives, learning tasks, and experiments about the reflection of light. Next, the teacher did several experiments and provided some examples to demonstrate the reflection of light. The experiments involved the rectilinear propagation of light, the law of reflection, and the principle of reversibility. During the experiments, students had to observe the phenomena and record the results. Finally, the teacher spent about 10 min discussing the reflection phenomenon with students and summarized the course content. After the class, students took the post-test and the self-efficacy survey.

## Measurements

The pre/post-test used in this study was an assessment tool provided by the school's assessment department. This assessment was based on the national assessment question



**Fig. 3** The principle of laser maze

pool for middle school physics. As this study only focused on one science concept the reflection of light, the assessment tool only consisted of the questions relevant to the concept. It included eight multiple choice questions, five Fill in the Blank questions, and ten True or False questions. The total of possible points were 36.

To measure students' self-efficacy, we used the New General Self-Efficacy Scale (NGSE), which was designed and developed by Chen et al. (2001). It is a validated assessment of self-efficacy and has high validity and reliability. NGSE has eight five-point Likert items. One is the lowest score, and five is the highest. The higher score indicates higher self-efficacy. To assess the internal consistency, reliability analysis was conducted, and the Cronbach's alpha was 0.91. In other words, this scale was reliable.

### Data Analysis

To answer RQ1, we analyzed students' performance in the content knowledge assessment. First, we used an analysis of variance (ANOVA) to compare the three groups' performance in the pre-test to see whether significant differences existed among groups before the experiment. Next, we used an analysis of covariance (ACNOVA) to analyze the effects of using the proposed approach on students' science learning achievements. Tukey's honest significant difference (HSD) post hoc tests were used for pair-wise comparisons. To answer RQ2, we analyzed students' self-efficacy scores in the NGSE scale. We also used the ANOVA technique to compare the differences between the three groups. For the post hoc tests, we used Tukey's HSD. All the statistical analyses were done using SPSS V22.0. All statistically significant results were reported at $p < .05$ level, unless specified otherwise.

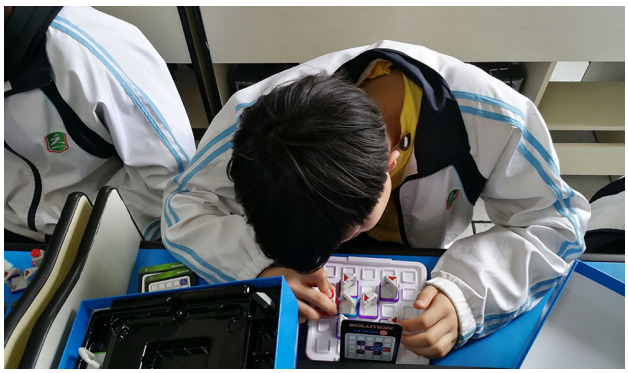


**Fig. 4** A student playing laser maze

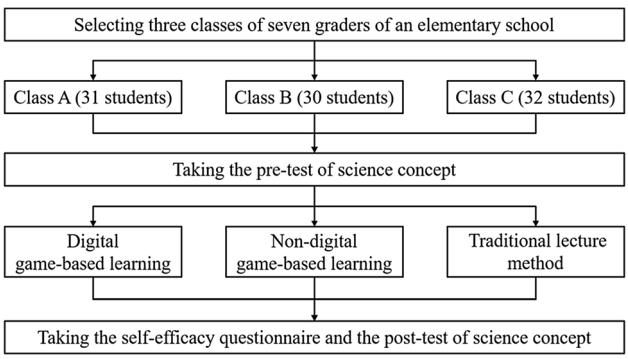



**Fig. 5** Experimental design for the learning activities

## Results

### RQ1: Whether Digital Games have Better Effects on Learning Science Concepts than Non-digital Games?

Table 2 shows the descriptive statistics of students' pre-test and post-test scores. Students' performance in the pre-test was similar. Class A (the digital game group) had the

**Table 2** Descriptive statistics of students' pre-test scores and post-test scores

| | Mean (SD) | | |
|---|---|---|---|
| Group | Class A ($n$ = 31) | Class B ($n$ = 30) | Class C ($n$ = 32) |
| Pre-test score | 19.87 (4.32) | 20.70 (4.13) | 20.12 (4.39) |
| Post-test score | 28.48 (4.73) | 29.83 (3.27) | 25.90 (5.13) |

lowest mean score in the pre-test, and class B (the non-digital game group) had the highest mean score. The ANOVA test results indicated that the difference of the pre-test scores among the three groups was not significant ($F(2, 90) = 0.299$, $p > 0.05$). In other words, students of the three groups had similar knowledge background about the reflection of light before the experiment.

This study conducted an analysis of covariance (ANCOVA) using the students' pre-test scores as the covariate to exclude the impact of the pre-test on their science learning. After conducting the experiment, ANCOVA was performed on the post-test scores, in which the pre-test was the covariant, the post-test scores were the dependent variable and the "different instructional methods (three groups)" were the control variable, to examine the relationships among the post-test results of the three groups. As shown in Table 3, the ANCOVA results showed that the variance between the three groups is significant ($F = 6.864$, $p < 0.01$). In other words, the post-test scores were significantly different due to the different instructional methods. Furthermore, post hoc analysis was performed to examine specific differences in achievement between the groups. A Tukey's HSD post hoc test revealed that the scores of Class A were significantly higher than those of Class C, comparing the adjusted mean of 28.64 for the Class A with the Class C score of 25.95 ($p < 0.01$). In addition, scores of Class B (adjusted mean = 29.62) were also significantly higher than those of Class C ($p < 0.01$). No significant difference was found between Class A and Class B.

Therefore, compared to the traditional lecture approach, the game-based learning approaches showed better effects on students' learning of science concepts. Our results also imply that digital and non-digital games have similar positive effects when students learn science concepts.

## RQ2: Whether Students Who Play Digital Games Show Better Self-efficacy than Students Who Play Non-digital Games When Learning Science Knowledge?

Table 4 presents the descriptive statistics of students' self-efficacy. Students of class A reported the highest self-efficacy, $M = 4.55$, SD = 0.48, while students of class C showed the lowest self-efficacy, $M = 3.58$, SD = 0.68. The results of the ANOVA test found that significant differences in students' self-efficacy existed among the three groups, $F(2, 90) = 22.488$, $p < 0.01$. The results of the post hoc Tukey HSD tests indicated that students of class A ($M = 4.55$ SD = 0.48) showed a significantly higher self-efficacy than students of other two classes. In addition, students of class B ($M = 4.24$, SD = 0.61) showed a significantly higher self-efficacy than students of class C ($M = 3.58$, SD = 0.68). Our results suggest that by using a game-based learning approach, students tend to have higher self-efficacy than those in a traditional lecture class when learning science. Our results also indicate that digital games may bring students higher self-efficacy than non-digital games.

**Table 3** The ANCOVA result of students' post-test scores for the three groups

| Variable | Group | $N$ | Mean | SD | Adjusted mean | $F(2, 89)$ | Post hoc |
|---|---|---|---|---|---|---|---|
| Post-test score | Class A | 31 | 28.48 | 4.73 | 28.64 | 6.864* | Class A > Class C |
| | Class B | 30 | 29.83 | 3.27 | 29.62 | | Class B > Class C |
| | Class C | 32 | 25.90 | 5.13 | 25.95 | | |

*$p < 0.01$

**Table 4** Descriptive statistics and the ANOVA result of students' self-efficacy

| Variable | Group | $N$ | $M$ | SD | $F(2, 90)$ | Post hoc |
|---|---|---|---|---|---|---|
| Self-efficacy | Class A | 31 | 4.55 | 0.48 | 22.488* | Class A > Class C |
| | Class B | 30 | 4.24 | 0.61 | | Class B > Class C |
| | Class C | 32 | 3.58 | 0.64 | | Class A > Class B |

*$p < 0.01$

## Discussion

### Game-Based Learning and Learning Achievement

Our results showed that the two game-based groups performed better than the traditional lecture group. This is consistent with previous studies. Many empirical studies have found that students in a game-based learning class show better learning performance than those in a traditional lecturing class (McLaren et al. 2017; Wang et al. 2018). According to constructivism, effective learning requires learners' active construction of new knowledge, rather than passive receiving (Amineh and Asl 2015). From this point of view, game-based learning creates a learning environment that allows students to actively construct the meaning of scientific knowledge. When playing games, students have to solve problems and complete challenges using the knowledge they learn. In contrast, during a traditional lecturing class, students are usually passive learners and do not have to apply the new knowledge to problem solving. Therefore, it is not so surprising that the traditional lecture group showed the lowest learning achievement.

Our results also showed that the digital game group and the non-digital game group had no significant differences in students' learning of science. The results suggest that digital and non-digital games have similar positive effects when students learn science knowledge. The key difference between digital and non-digital games is whether games are played using electronic devices. The game content and rules can be identical for a digital educational game and a non-digital educational game. In our study, the digital game *Lazors* and the non-digital game *Laser Maze* are very similar in game content, rules, blocks, and so on. Hence, it is possible that for learning the science concept the reflection of light, the two games are both sufficient to help students understand the concept and facilitate learning. In this scenario, the effectiveness of using digital and non-digital games is similar.

### Digital Games and Self-efficacy

For self-efficacy, the results of our study indicate that by using a game-based learning approach, students tend to have higher self-efficacy than those in a traditional lecture class. According to previous studies, game-based learning can effectively improve students' self-efficacy, compared to traditional instructional method (Hung et al. 2014; Yükseltürk et al. 2018). Our results confirm this argument. Among the three groups, students of the lecturing group showed the significant lower self-efficacy than the gaming groups. Johnson and Mayer (2010) pointed out that game-based learning environments provide appropriate challenges for learners so that they can experience a feeling of self-efficacy. In our study, both digital and non-digital games included game challenges with clear goals, instant feedback, and proper difficulty levels. Thus, students may feel they are capable to complete the challenges. On the contrary, during the lecture, students may not clearly see the learning goals and progress. Without challenges of different levels, students could not get enough feedback especially positive feedback, which made it difficult for them to get a sense of achievement in science learning. Therefore, students may show lower self-efficacy.

A key finding of our study is that students playing digital games reported higher self-efficacy than those playing non-digital games. As the two games are similar in game content, rules, and blocks, the different effects on students' self-efficacy are surprising. However, during the experiment, we noticed important differences between the two games, which may explain our results. In the digital game, students can easily identify the gap between their current status and the goal required by the challenge. For a digital game, this is a built-in functionality and visible on the screen. However, for the non-digital game, students have to figure out this gap by themselves. In addition, when playing the non-digital game, students need to place those game blocks on the game board and adjust the blocks to complete the challenge by hands. In contrast, the actions to play the digital game are easier. Students only need to use the mouse and sometimes the keyboard as well to play the game. To some extent, the digital game simplifies the difficulty of the gameplay and requires simpler skills. Thus, both the two features of the digital game might have improved our students' self-efficacy.

There is an interesting Dunning Kruger effect (Dunning 2011) in this study. The students in Class A (digital game) had the highest self-efficacy score, but they actually had lower learning achievement than students in Class B (non-digital game). It might be because non-digital game could better promote students' reflection. Digital game might give students a more explicit and more direct feedback than non-digital game, which made it easier for them to overcome the difficulty in accomplishing tasks and achieving goals. However, the quick hit of success also brought a problem that students had no time to reflect on what kind of knowledge they had used during the task. While, non-digital game's feedback was more implicit because the light beam was invisible, students needed to check their plans again and again, which helped them to establish connections between knowledge and behaviors. It is important to provide appropriate feedback to help learners self-explain their learning process (Tan et al. 2007), and studies showed that reflection combined with feedback enhanced performance better than feedback alone (Anseel et al. 2009). The reflective observation of the feedback

might lead to the construction of schemata (Kiili 2005). To some extent, non-digital game had a better effect on stimulating deeper learning.

### Implications

Based on our findings, we make two recommendations for researchers and educators who are interested in game-based learning. First, because of the merits of digital games, we recommend that researchers and developers of educational games design and develop more digital games that can support teaching science knowledge. Nowadays, digital devices are accessible to students and teachers. As digital natives, students are familiar with the use of digital devices. Our findings indicate that digital games can benefit both learning performance and self-efficacy of students. Therefore, we believe that developing more digital games for teaching science can enhance the quality of science education. According to our results, we make two suggestions for developing digital games for learning. First, it is important to provide immediate feedback for students so that they can quickly reflect on their game play and learning. Second, digital games should integrate automatic data collection and analysis components to enable teachers to track students' learning progress in real time. We believe that with those features digital games can better support teaching and learning of science classes.

Second, we recommend developing professional development programs focusing on integrating educational games into instruction. Compared to traditional lecturing, game-based learning has its merits including enhancing students' self-efficacy, improving learning performance, and so forth. However, teachers may not own the knowledge of implementing game-based learning in their instruction. Integrating educational games into instruction is not easy, because it requires not only the content knowledge of subject matter but also the knowledge of games and game integration. Therefore, we believe that professional development programs about game-based learning are vital to teachers who would like to use educational games. We recommend that more future professional development programs focus on game-based learning to help teachers build their knowledge of and develop their skills for effectively integrating educational games into instruction.

### Limitations and Future Research Directions

This study has several limitations. First of all, our sample size was relatively small. On average, we had 31 students in each group. While such a sample size was sufficient for our study, the generalizability of our results can be limited. In the future, we will replicate our experiment in more schools with more students.

Second, our experiment only focused on one scientific concept and did not explore the long-term effects of different types of games. In this study, we investigated students learning of the reflection of light and assessed their learning performance using pre- and post-tests. However, if game-based learning is used in teaching several scientific concepts or used for a whole semester, the two types of games may show different effects. Our next step is to design several units of a middle school science course using game-based learning and to examine the effects of digital and non-digital games in students' learning of science.

Finally, in this study, we only collected quantitative data to compare students' learning performance and self-efficacy in different settings. However, with only quantitative data, it is hard to understand why students reported higher self-efficacy when playing digital games. Future research should use mixed methods collecting both quantitative and qualitative data (e.g., interviews, class observations, etc.) to study the effects of different types of game-based learning.

## Conclusions

Game-based learning shows great potential to support teaching science knowledge and facilitating students' learning. While previous studies reported that game-based learning showed positive effects on students' learning performance and self-efficacy compared to conventional instructional method, few studies have investigated the different effects between digital and non-digital games. This study examined the effects of game-based learning on Chinese middle school students' learning of science and their self-efficacy in learning. We implemented an experiment to compare the effects between digital and non-digital game-based learning. Our results showed that students in game-based learning groups (both digital and non-digital game groups) performed significantly better in the content knowledge assessment and reported higher self-efficacy than the traditional lecture group. No significant difference was found between the digital game group and the non-digital game group when considering science learning performance, but students of the digital game group showed significantly higher self-efficacy than those of the non-digital game group.

According to our findings, we recommend that researchers and developers of educational games design and develop more digital games that can support teaching science knowledge. Meanwhile, we suggest developing professional development programs focusing on integrating educational games into instruction. While game-based

learning has advantages over the conventional instructional method when teaching science, without appropriate educational games and sufficient professional development about game-based learning, teachers may not able to effectively use educational games in science classroom. We believe in the future, there will be more and more quality teachers who can effectively implement game-based learning if we provide more effective educational games and relevant professional development programs.

## References


Amineh, R. J., & Asl, H. D. (2015). Review of constructivism and social constructivism. *Journal of Social Sciences, Literature and Languages, 1*(1), 9–16.

Anseel, F., Lievens, F., & Schollaert, E. (2009). Reflection as a strategy to enhance task performance after feedback. *Organizational Behavior and Human Decision Processes, 110*(1), 23–35. https://doi.org/10.1016/j.obhdp.2009.05.003.

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist, 37*, 122–147. https://doi.org/10.1037/0003-066X.37.2.122.

Bandura, A. (1994). Self-efficacy. In V. S. Ramachandran (Ed.), *Encyclopedia of human behavior* (Vol. 4, pp. 71–81). New York: Academic Press.

Berland, M. (2011). Understanding strategic boardgames as computational-thinking training machines. *Tabletop analog game design* (pp. 167–173). Pittsburgh: ETC Press.

Brom, C., Preuss, M., & Klement, D. (2011). Are educational computer micro-games engaging and effective for knowledge acquisition at high-schools? *A quasi-experimental study. Computers & Education*, *57*(3), 1971–1988. https://doi.org/10.1016/j.compedu.2011.04.007.

Cardinot, A., & Fairfield, J. A. (2019). Game-based learning to engage students with physics and astronomy using a board game. *International Journal of Game-Based Learning, 9*(1), 42–57. https://doi.org/10.4018/IJGBL.2019010104.

Chen, G., Gully, S. M., & Eden, D. (2001). Validation of a new general self-efficacy scale. *Organizational Research Methods, 4*(1), 62–83. https://doi.org/10.1177/109442810141004.

Chen, C. H., & Law, V. (2016). Scaffolding individual and collaborative game-based learning in learning performance and intrinsic motivation. *Computers in Human Behavior, 55*, 1201–1212. https://doi.org/10.1016/j.chb.2015.03.010.

Chen, F., Shi, Y., & Xu, F. (2009). An analysis of the Public Scientific Literacy study in China. *Public Understanding of Science, 18*(5), 607–616. https://doi.org/10.1177/0963662508093089.

Chen, C.-H., Wang, K.-C., & Lin, Y.-H. (2015). The comparison of solitary and collaborative modes of game-based learning on students' science learning and motivation. *Educational Technology & Society, 18*(2), 237–248.

Cheng, M. H. M., & Wan, Z. H. (2016). Unpacking the paradox of Chinese science learners: Insights from research into Asian Chinese school students' attitudes towards learning science, science learning strategies, and scientific epistemological views. *Studies in Science Education, 52*(1), 29–62. https://doi.org/10.1080/03057267.2015.1112471.

Cook, D. H. (2014). Conflicts in chemistry: The case of plastics, a role-playing game for high school chemistry students. *Journal of Chemical Education, 91*(10), 1580–1586. https://doi.org/10.1021/ed4007277.

Dahlin, B., & Watkins, D. (2000). The role of repetition in the processes of memorising and understanding: A comparison of the views of German and Chinese secondary school students in Hong Kong. *British Journal of Educational Psychology, 70*(1), 65–84. https://doi.org/10.1348/000709900157976.

Dunning, D. (2011). The Dunning–Kruger effect: On being ignorant of one's own ignorance. In *Advances in experimental social psychology* (Vol. 44, pp. 247–296). New York: Academic Press.

Gao, H., He, W., Zhang, C., & Ren, L. (2016). Building scientific literacy in China: Achievements and prospects. *Science Bulletin, 61*(11), 871–874. https://doi.org/10.1007/s11434-016-1076-0.

Goldenberg, D., Andrusyszyn, M.-A., & Iwasiw, C. (2005). The effect of classroom simulation on nursing students' self-efficacy related to health teaching. *Journal of Nursing Education, 44*(7), 310.

Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in Human Behavior, 54*, 170–179. https://doi.org/10.1016/j.chb.2015.07.045.

Hung, C. M., Huang, I., & Hwang, G. J. (2014). Effects of digital game-based learning on students' self-efficacy, motivation, anxiety, and achievements in learning mathematics. *Journal of Computers in Education, 1*(2–3), 151–166. https://doi.org/10.1007/s40692-014-0008-8.

Johnson, C. I., & Mayer, R. E. (2010). Applying the self-explanation principle to multimedia learning in a computer-based game-like environment. *Computers in Human Behavior, 26*(6), 1246–1252. https://doi.org/10.1016/j.chb.2010.03.025.

Khan, A., Ahmad, F. H., & Malik, M. M. (2017). Use of digital game based learning and gamification in secondary school science: The effect on student engagement, learning and gender difference. *Education and Information Technologies, 22*(6), 2767–2804. https://doi.org/10.1007/s10639-017-9622-1.

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *The Internet and Higher Education, 8*(1), 13–24. https://doi.org/10.1016/j.iheduc.2004.12.001.

Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O. S., Hubert, T., et al. (2016). Using robotics and game design to enhance children's self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology, 25*(6), 860–876. https://doi.org/10.1007/s10956-016-9628-2.

Li, Y., Huang, Z., Jiang, M., & Ting-Wen, C. (2016). The effect on pupils' science performance and problem-solving ability through Lego: An engineering design-based modeling approach. *Journal of Educational Technology & Society, 19*(3), 143–156.

Liang, L. L., Liu, X., & Fulmer, G. W. (Eds.). (2017). *Chinese science education in the 21st century: Policy, practice, and research*. Dordrecht: Springer. https://doi.org/10.1007/978-94-017-9864-8

Lin, C. H., Liu, E. Z. F., Chen, Y. L., Liou, P. Y., Chang, M., Wu, C. H., et al. (2013). Game-based remedial instruction in mastery learning for upper-primary school students. *Journal of Educational Technology & Society, 16*(2), 271–281.

Liu, E. Z. F., & Chen, P. K. (2013). The effect of game-based learning on students' learning performance in science learning-A case of "conveyance go". *Procedia-Social and Behavioral Sciences, 103*, 1044–1051. https://doi.org/10.1016/j.sbspro.2013.10.430.

Lu, Y. L., & Lien, C. J. (2019). Are they learning or playing? Students' perception traits and their learning self-efficacy in a game-based learning environment. *Journal of Educational Computing Research*. https://doi.org/10.1177/0735633118820684.

McLaren, B. M., Adams, D. M., Mayer, R. E., & Forlizzi, J. (2017). A computer-based game that promotes mathematics learning more than a conventional approach. *International Journal of Game-*

*Based Learning (IJGBL), 7*(1), 36–56. https://doi.org/10.4018/IJGBL.2017010103.

Meluso, A., Zheng, M., Spires, H. A., & Lester, J. (2012). Enhancing 5th graders' science content knowledge and self-efficacy through game-based learning. *Computers & Education, 59*(2), 497–504. https://doi.org/10.1016/j.compedu.2011.12.019.

Morris, T. A. (2011). Go chemistry: A card game to help students learn chemical formulas. *Journal of Chemical Education, 88*(10), 1397–1399. https://doi.org/10.1021/ed100661c.

Mustafa, J., Khan, A., & Ullah, A. (2011). Investigating student's achievement in mathematics through non technological game based teaching. *International Journal of Scientific Research in Education, 4*(3–4), 151–164.

Naik, N. (2014). A comparative evaluation of game-based learning: Digital or non-digital games?. In *European Conference on Games Based Learning* (Vol. 2, p. 437). Academic Conferences International Limited.

Prensky, M. (2001). *Digital game-based learning*. New York: McGraw-Hill. https://doi.org/10.1145/950566.950567.

Qian, M., & Clark, K. R. (2016). Game-based learning and 21st century skills: A review of recent research. *Computers in Human Behavior, 63*, 50–58. https://doi.org/10.1016/j.chb.2016.05.023.

Safaria, T., & Ahmad, A. (2013). Effects of self-efficacy on students academic performance. *Journal of Educational, Health and Community Psychology, 2*(1), 22–29. https://doi.org/10.12928/jehcp.v2i1.3740.

Sung, H. Y., & Hwang, G. J. (2013). A collaborative game-based learning approach to improving students' learning performance in science courses. *Computers & Education, 63*, 43–51. https://doi.org/10.1016/j.compedu.2012.11.019.

Tan, P. H., Ling, S. W., & Ting, C. Y. (2007). Adaptive digital game-based learning framework. In *Proceedings of the 2nd international conference on Digital interactive media in entertainment and arts* (pp. 142–146). ACM.

Tapscott, D. (1998). *Growing Up Digital: The Rise of the Net Generation*. New York: McGraw-Hill.

Uzun, L., Çetinavci, U. R., Korkmaz, S., & Salihoglu, U. M. (2013). Developing and applying a foreign language vocabulary learning and practicing game: The effect of VocaWord. *Digital Culture & Education, 5*(1), 50–70.

von Gillem, S., & Alaswad, Z. (2016). Games and game-based learning in instructional design. *International Journal of Technologies in Learning, 23*(4), 1–7. https://doi.org/10.18848/2327-0144/CGP/v23i04/1-7.

Wang, S. Y., Chang, S. C., Hwang, G. J., & Chen, P. Y. (2018). A microworld-based role-playing game development approach to engaging students in interactive, enjoyable, and effective mathematics learning. *Interactive Learning Environments, 26*(3), 411–423. https://doi.org/10.1080/10494820.2017.1337038.

Yien, J. M., Hung, C. M., Hwang, G. J., & Lin, Y. C. (2011). A game-based learning approach to improving students' learning achievements in a nutrition course. *Turkish Online Journal of Educational Technology-TOJET, 10*(2), 1–10.

Yükseltürk, E., Altıok, S., & Başer, Z. (2018). Using game-based learning with kinect technology in foreign language education course. *Journal of Educational Technology & Society, 21*(3), 159–173.

Yusuf, M. (2011). The impact of self-efficacy, achievement motivation, and self-regulated learning strategies on students' academic achievement. *Procedia-Social and Behavioral Sciences, 15*, 2623–2626. https://doi.org/10.1016/j.sbspro.2011.04.158.

Zhao, Z., & Thomas, G. P. (2016). Mainland Chinese students conceptions of learning science: A phenomenographic study in Hebei and Shandong Provinces. *International Journal of Educational Research, 75*, 76–87. https://doi.org/10.1016/j.ijer.2015.11.008.

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