Sun-Lin, H.-Z., & Chiou, G.-F. (2019). Effects of Gamified Comparison on Sixth Graders' Algebra Word Problem Solving and Learning Attitude. Educational Technology & Society, 22 (1), 120–130.

# Effects of Gamified Comparison on Sixth Graders' Algebra Word Problem Solving and Learning Attitude

**Hong-Zheng Sun-Lin* and Guey-Fa Chiou**
Graduate Institute of Information and Computer Education, National Taiwan Normal University, Taipei City, Taiwan // hzsunlin@gmail.com // gueyfa@ntnu.edu.tw
*Corresponding author

(Submitted September 15, 2016; Revised June 18, 2017; Accepted August 8, 2017)

**ABSTRACT**

This study examined effects of gamified comparison on sixth graders' performance of algebra word problem solving and attitude toward algebra learning. Seventy-two sixth graders were invited to participate in a four-week experimental instruction and assigned to three groups: gamified comparison, comparison, and control. The results showed (1) a significant effect on solving similar problems: the gamified comparison group performed significantly better than the comparison group and the control group respectively, and the comparison group performed significantly better than the control group; (2) a significant effect on solving transfer problems: the gamified comparison group gained significantly higher scores than the comparison group and the control group respectively, and the comparison group gained significantly higher scores than the control group; (3) a significant effect on students' learning attitude: while no significant differences found on students' confidence, the gamified comparison group made significantly more positive responses than the comparison group and the control group in terms of enjoyment, motivation, and perceived value. This study proposed a feasible combination of game rule and comparison strategy, as well as exploring implications for teachers' teaching design and students' gamified learning activities.

**Keywords**

Gamification, Comparison, Algebra word problem solving, Learning attitude

## Introduction

### Algebra word problem solving

Algebra plays an important role in mathematics learning, and the success in algebra learning is necessary to access to higher mathematics (Adelman, 2006; National Mathematics Advisory Panel, 2008). Many students, however, struggle with algebra that normally is the first unit in mathematics where they usually find the abstraction and symbolisation difficult to understand (Star et al., 2015; National Research Council, 2001). In algebra learning, solving word problems presents a challenge to middle graders (Bush & Karp, 2013; Carpraro & Joffrion, 2006; MacGregor & Stacey, 1998). It is probably because many learners, especially novice learners, are unable to recognise a similar problem type across a variety of cover stories/contexts, and apply what they have learnt to different problem types as well (Bush & Karp, 2013; Reed, 1987; Reed, Dempster, & Ettinger, 1985).

Transfer has been considered as an important ability for algebra word problem solving because it enables students to apply gained knowledge to build an understanding of a new concept. It also makes appropriate connections between various concepts within a domain based on the understanding of shared structural similarity between problems (Bush & Karp, 2013; Ngu & Yeung, 2012). In algebra learning, transfer ability prompts students to apply a learnt problem-solving technique to another context to solve novel problems (Rittle-Johnson & Star, 2007, 2009). To develop the transfer ability, previous studies suggested that teachers can encourage students to solve similar problems with different methods first (Richland, Holyoak, & Stigler, 2010; Richland & McDonough, 2010). For example, Rittle-Johnson and Star (2007) found that seventh graders who compared two contrasting step-by-step procedures outperformed those who studied one example with one solution at a time in problem solving. They attributed the learning effect to the benefit of allowing students to explore knowledge and flexibility in their problem-solving process. In their subsequent study, Rittle-Johnson and Star (2009) further stated that students' knowledge and ability to solve similar algebra problems was the essential pre-requisites to ensure effects of transfer when solving novel problems. According to above-mentioned studies, practising similar problems with different stories/contexts is beneficial for students' ability to solving transfer problems. However, research focusing on related teaching strategies to develop students' problem solving ability is still scarce.

As to mathematics learning, topics regarding students' learning attitude have also received considerable attention (Lim & Chapman, 2013; Zan, Brown, Evans, & Hannula, 2006). Several studies have noted that learning attitude would affect students' learning performance, and strategies to encourage students' learning behaviour should be emphasised in teaching design(Bouchey & Harter, 2005; Samuelsson & Granstrom, 2007). To be specific, Zakaria and Nordin (2008) proposed four favourable affective dimensions, including enjoyment of mathematics, general motivation of learning mathematics, confidence in solving mathematics problems, and perception on value of mathematics that would affect students' learning achievement. These aspects of learning attitude should also be measured for further exploration when exploring students' mathematics learning achievement.

**Comparison strategy**

Comparing problems and their solutions has been considered as an effective learning strategy in mathematics (National Council of Teachers of Mathematics, 2000). Numerous studies have investigated effects of differentiating similarities and differences between problems and solutions on students' mathematics problem solving by fostering students' reflection (Silver, Ghousseini, Gosen, Charalambous, & Strawhun, 2005; Ziegler & Stern, 2014, 2016). Some scholars further noted that comparing side-by-side examples can effectively help students understand important features of a problem as well as solving novel problems based on what they have learnt (Gentner, Loewenstein, & Thompson, 2003; Sidney, Hattikudur, & Alibali, 2015). To enhance the learning effects, the importance of systematic guidance and coherent structure have also been highlighted (Star et al., 2015; Ziegler & Stern, 2016). Alfieri, Nokes, and Schunn (2013) mentioned that guiding prompts could play an important role in students' comparison activities. However, the benefits of comparisons might be limited when students merely read or solve given examples (Ziegler & Stern, 2016). According to studies of Sweller and Chandler (1994) and Sweller, Merrienboer, and Paas (1998), guiding prompts could encourage students to familiarise themselves with similar examples and realise the features of problems, thereby gaining a better understanding of certain problem types and possible problem-solving techniques. This probably implies that precise and explicit guiding prompts could be necessary and essential to students' comparison activities. For example, asking students to directly describe similarities and differences of given examples (Mason, 2004; Ziegler & Stern, 2014) or respond specific comparison questions (Gadgil, Nokes, & Chi, 2012; Ziegler & Stern, 2016).

A review of numerous empirical studies in a practice guide proposed by the US Department of Education identified comparison as one of recommendations to enhance grade 4-8 students' mathematical problem-solving abilities (e.g., Guo & Pang, 2011; Rittle-Johnson & Star, 2007, 2009; Rittle-Johnson, Star, & Durkin, 2012; Woodward et al., 2012). Each of reviewed studies generally covered two common features of comparison strategy: the use of examples and the use of prompts. According to the conclusion, students who were shown and compared two side-by-side examples performed significantly better than those who did not receive such materials. Although positive learning effects of comparison on student's mathematics learning (e.g., arithmetic) were reported, few studies have been done specifically on middle graders' algebra word problem solving, especially their transfer performance.

One problem usually occurs when students compare examples: high learning effort (Ziegler & Stern, 2016). It may make learning tasks challenging and have a negative effect on students' learning attitude, especially for those who are not fairly familiar with given concepts and the process of comparison. For example, in Ziegler and Stern's study (2014), they provided some algebra principles and problems for sixth graders who were assigned to one of two groups: contrast or sequential group. In the contrast group, algebra problems were presented in juxtaposition; in the sequential group, the problems were presented in sequence. The results showed that not only could the contrast group distinguish between examples but also apply the algebra principles in the long run; however, the contrast group performed worse on immediate learning measures than the sequential group. The authors explained that the requirement of comparison may make the learning tasks more difficult for students to accomplish. To be specific, juxtaposition of examples could help students benefit from the process of comparison, but at the same time they probably increase students' cognitive load that might negatively affect learning attitude.

**Gamified learning**

Gamified learning is defined as a strategy to employ game elements (e.g., points, levels, and challenges) in learning contexts to promote students' learning (Domínguez, et al., 2013; Landers, 2014). For example, in gamified learning activities, students earn experience points after successfully accomplishing certain tasks by themselves. Villagrasa, Fonseca, Redondo, and Duran (2014) stated that gamification is not just about gaming, it is also about ensuring that students are motivated to complete learning tasks. To develop a gamified learning system, ways of using game elements in learning activities that make digital games attractive to students should be carefully considered (Buckley & Doyle, 2014; Domínguez, et al., 2013). For examples, points could be regarded as rewards after completing a challenge (Attali & Arieli-Attali, 2015; Sun-Lin & Chiou, 2017b), level-ups could be used to unlock new challenges after meeting certain requirements (Buckley & Doyle, 2014; Sun-Lin & Chiou, 2017a), and records of challenges could be employed to keep students' engagement in tasks (Domínguez, et al., 2013). Additionally, several studies showed that when fun from gamified content impregnates the learning process, students' learning motivation would increase and the stress would be reduced (Koster, 2004; Villagrá-Arnedo, Gallego-Durán, Molina-Carmona, & Llorens-Largo, 2016). This kind of gamification design would facilitate students' learning because game elements encourage students to engage in learning tasks, perceive what they experience, and decide what to do in learning process (Mora, Riera, González, & Arnedo-Moreno, 2015).

However, studies on gamification have not always reported positive results. Here is a common problem: students may pay too much attention to where game elements are added. For example, Attali and Arieli-Attali (2015) conducted two studies to examine effects of points on students' learning performance. In their first study, students were rewarded by points for their performance including correctness of answers and speed of answering when in assessment. In the second study, all the participants were required to express their enjoyment of the achievement test gamified by points. The results showed that while the students gave positive feedback on the gamified assessment, they did not report an entirely positive attitude toward the learning activity. Moreover, although students' speed of answering significantly increased, the correctness did not. This is probably because they knew they would be rewarded by quick responding and thus focused more on improving speed of responses rather than correctness of answers.

Another issue is that students' experience of gamified learning remains on the surface. In many gamified activities, students just received a layer of standardised game elements such as points and levels; however, in a gamified context, the connection between gaming process and learning process that guides students to learn certain content has not yet been much explored (Landers, 2014; Mora et al., 2015; Sun-Lin & Chiou, 2017a). For example, Villagrá-Arnedo et al. (2016) proposed an idea that adapting game rule/procedure of a famous game Pac-Man to facilitate students' problem solving, and in which students would experience the problem-solving process through gaming process, and vice versa. Teachers could also design and present instructional materials more effectively. To date, however, few empirical studies have been done on combination of the processes.

Overall, although algebra word problem solving has been considered an important and challenging field for students, little research has been done on related innovative strategies such as gamification. In addition, many studies reported positive effects of comparison strategy on mathematics learning achievement, and it requires higher cognitive effort that may negatively affect students' learning attitude. Feasible applications still need to be explored further. Despite the growing awareness of the educational potential of gamification, empirical studies on its applications in algebra word problem solving are scarce. The present study, therefore, seeks to fill the gap by examining effects of gamified comparison on sixth graders' algebra word problem solving and their learning attitude through investigating the following research questions:

- What are the effects of gamified comparison, comparison, and direct practice activities on students' performance on solving similar algebra word problems??
- What are the effects of gamified comparison, comparison, and direct practice activities on students' performance on solving transfer algebra word problems?
- What are the effects of gamified comparison, comparison, and direct practice activities on students' learning attitude toward algebra word problem solving?

## Method

This study adopted a quasi-experimental design with learning activities as the independent variable. To be specific, students who were asked to compare the correct/incorrect examples in gamified tasks were considered as the gamified comparison group (the GC group). Students who were asked to compare the correct/incorrect examples in general tasks were considered as the comparison group (the CO group). The other participants who read all the learning material and did not receive any gamification elements and comparison tasks were considered as the control group (the C group).

The dependent variables were students' learning achievement of algebra word problem solving and learning attitude. The learning achievement referred to the learning outcomes including (1) test scores for solving similar problems, and (2) test scores for solving transfer problems. The learning attitude referred to students' perception of algebra learning after completing learning tasks, including four dimensions: enjoyment, motivation, confidence, and perceived value.

### Participants

Seventy-two sixth graders (39 females and 33 males, 12-13 years old) participated in this instructional experiment. They were randomly and evenly assigned to one of groups, meaning there were 24 students in the GC, the CO, and the C group respectively. All the participants had learnt basic algebra concepts (e.g., know how to use symbols to present unknown values) and had basic algebra arithmetic ability (e.g., know how to simplify an algebraic expression).

To minimise the possible influence of The Hawthorne Effect, the students attended learning activities as invited participants not subjects of an experiment. All of them were protected by replacing their personal information with serial numbers. They were informed that the participation was voluntary and would not affect the grade of the course and they could withdraw from the study at any time.

### The learning system

To explore combination effects of gamification and comparison strategy, the researchers developed a mini learning system by using software Construct 2. The participants were asked to accomplish four tasks by studying four examples and solving four practice problems with guidance provided by the system, as described below.

#### *The learning content*

To develop the learning content properly, one middle-school mathematics teacher, an author of K-9 mathematics reference books with more than 13-year teaching experience, and two primary-school mathematics teachers with five-year teaching experience were invited. They reviewed sixth-grade mathematics instructional materials and drafted four types of algebra word problems that commonly confuse students. Examples in each learning task were designed based on these problem types, as shown in Table 1. The guiding prompts, designed for facilitating students' comparison, were also reviewed by the invited teachers, as listed below.

- What are the similarities between the two solutions in this example?
- What are the differences between the two solutions in this example?
- Which one is incorrect (choose one of examples)? Why (your explanation for the answer)?

*Table 1.* Examples of problem types for sixth graders

| Type | Example |
|---|---|
| Addition/subtraction | Peter has a pen and so does his sister Amy. Amy's pen is 4 cm longer than Peter's. The sum of their pens' lengths is 20 cm. What is length of Peter's pen? What is length of Amy's pen? |
| Sum of differences | There are 500 packages in Warehouse A and 300 packages in Warehouse B. If employees take out 15 packages from Warehouse A and 5 ones from Warehouse B per day. How many days later will the number of packages in Warehouse A be equal to the number of packages in Warehouse B? |
| Multiple | A commander is 58 years old and you are 28 years old. When will the commander's age be two times yours? |
| Remainder/shortage | There are many apples that will be distributed to children in a classroom. If we distribute 5 apples to each child, we will need 12 more apples. If we distribute 3 apples to each child, there will be no remainder. How many children are there? |

#### *The GC group*

Students in this group learnt to solve algebra word problems through accomplishing four gamified comparison tasks. Each task consisted of three sections: a description of four types of algebra word problems, four example problems with correct and incorrect step-by-step solutions, and four practice problems.

The design of tasks was an adaption of a famous game Photo Hunt in which in each level players would receive two side-by-side photos and be asked to find out differences between them. The students compared the correct and the incorrect examples that were juxtaposed, then responded prompts by their own explanations. They could go back to previous pages for review if necessary (see Figure 1). This juxtaposed examples were developed based on the features of effective comparison strategy, i.e., to differentiate two cases easily on a single page. The step-by-step prompts with specific statements were used to guide and encourage students to reflect on the techniques of problem solving and accomplish learning tasks more effectively instead of extremely-high cognitive effort.

In gamified tasks, students played defenders to protect the Earth from the unknown attack from the space and were required to get their aircrafts ready by solving a series of word problems. There were two solutions in each example associating with an issue of the aircraft and the contingent. For example, defenders were asked to solve a Sum of Differences problem to predict how many day(s) later there will be no aircraft fuel left in two warehouses at the same time. Before solving problems, players had to study all the examples, but they could decide whether to solve the four challenging problems or not for practice. If they practised solving the challenging problems and answered correctly, they would earn faster level-up opportunities for a better aircraft. Once all the problems in a task were solved, the levels of defenders would go up and the aircraft would be significantly upgraded.

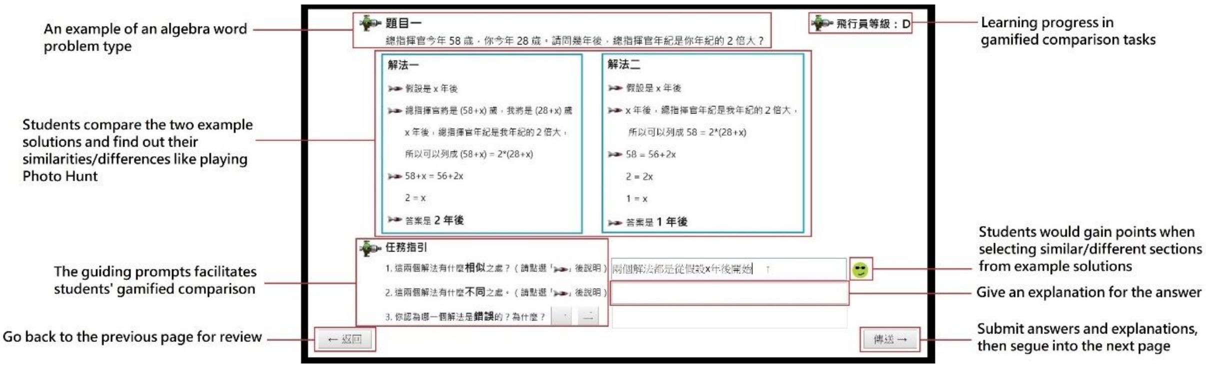

*Figure 1.* A screenshot of a gamified comparison task

*The CO group*

Students in this group learnt how to solve algebra word problems through accomplishing four comparison tasks. They were asked to compare correct and incorrect examples, then respond the prompts by their own expressions. However, these participants did not receive game elements during the process. Similarly, the students could decide whether to solve the four challenging problems and go back to previous pages for review if necessary.

*The C group*

The students learnt to solve algebra word problems via studying given learning materials. They read all the four examples, decided whether to solve the four practice word problems, and reviewed previous pages if necessary. All the examples were presented page by page that could be reviewed unlimitedly during the period.

**Instruments**

*Algebra word problem tests*

The achievement tests were reviewed by three primary-school mathematics teachers with over five-year teaching experience. The review suggested the content validity. Two tests were created: a similar-problem test and a transfer-problem test. Both of them consisted of eight problems. Problems in the similar-problem test were similar to practice problems presented in the system, and problems in the transfer-problem test were slightly different from the practice problems. Here are some examples:

- A practice problem: A commander is 58 years old and you are 28 years old. When will the commander's age be two times yours?

- A similar problem: You are 50 years old and your nephew is 10 years old. In how many years will your age be three times your nephew's age?
- A transfer problem: John has worked for 25 years and Mary has worked for 9 years in a company. How many years ago was John's work year three times Mary's?

To further ensure the quality of the measurement, 96 sixth graders who did not participate in the instructional experiment were invited to complete the tests for pilot study. The reliability of tests was estimated based on Cronbach's $\alpha$ measure for the pre-test $\alpha$ = .864 and for the post-test $\alpha$ = .888, and there was a strong positive correlation between the pre-test and the post-test ($r$ = .821, $p$ =.000). Additionally, the tests showed significant positive correlations with a regular school mathematics examination in algebra word problem solving: between the examination and the pre-test, $r$ = .797, $p$ = .000; between the examination and the post-test, $r$ = .752, $p$ = .000. The results indicated good criterion-related validity of the tests.

*Algebra learning attitude scale*

The scale for students' algebra learning attitude covering enjoyment, motivation, self-confidence, and perceived value, was modified from an inventory developed by Lim and Chapman (2013). It comprised 19 items using a four-point Likert rating schema. Here are examples of the items:

- I like solving algebra word problems.
- I am confident that I can solve more challenging algebra word problems.
- I am not stressed when solving algebra word problems.
- The ability of solving algebra word problems is important.

To ensure appropriateness of the scale, the three invited teachers reviewed all the scale items, and the 96 sixth graders were also invited to complete the survey to help the researchers examine the reliability. The Cronbach's $\alpha$ value for the enjoyment was .909, for motivation was .929, for confidence was .901, for perceived value was .923, and for the entire scale was .938, showing excellent internal consistency.

### Procedure

The experimental instruction took about 265 minutes in four weeks. First, the researchers introduced the system and invited the participants to experience the learning activities (5 minutes), after which students finished the pre-test of learning achievement (35 minutes) and the pre-survey of learning attitude (15 minutes). During the learning activities, all students learnt how to solve algebra word problems through accomplishing different learning tasks (i.e., gamified comparison, comparison, and read-and-practice) in 160 minutes. After that, all groups answered the post-test of learning achievement (35 minutes) and responded the post-survey of learning attitude (15 minutes).

## Results

### Student performance on solving similar problems

This study employed covariate of analysis (ANCOVA) to examine the sixth graders' performance of algebra word problem solving on the similar-problem test. As presented in Table 2, the results showed a significant difference among the three groups, with $F$ = 29.615 ($p$ < .05), meaning the post-hoc comparison was needed. The result of post-hoc comparison further indicated that the GC group (adjusted $M$ = 9.960, $SE$ = .487) gained significantly higher scores than the CO group (the adjusted $M$ = 7.707, $SE$ = .495) and the C group (the adjusted $M$ = 4.834, $SE$ = .469) respectively, and the CO group gained significantly better scores than the C group. According to the definition of effect size proposed by Cohen (1988), the partial eta squared ($\eta^2$) of the analysis results indicated a strong effect ($\eta^2$ = .466 > .139).

*Table 2.* ANCOVA results of student performance on the similar-problem test

| Source of variance | *SS* | *df* | *MS* | *F* | *Sig.* | Post-hoc |
|---|---|---|---|---|---|---|
| Prior knowledge | 244.126 | 1 | 244.126 | $46.354^{***}$ | .000 | |
| Group | 311.933 | 2 | 155.967 | $29.615^{***}$ | .000 | GC > CO, GC > C, CO > C |
| Error | 358.124 | 68 | 5.267 | | | |

*Note.* $^{***}p$ < .000.

**Student performance on solving transfer problems**

The ANCOVA results, as presented in Table 3, indicated a significant difference among the three groups, with $F = 47.235$ ($p < .05$). The result of the post-hoc comparison indicated that the GC group (adjusted $M = 4.735$, $SE = .353$) acquired significantly better scores than the CO group (the adjusted $M = 3.336$, $SE = .358$) and the C group (the adjusted $M = .179$, $SE = .339$) respectively, and the CO group performed significantly better than the C group. The partial eta squared ($\eta^2$) of the analysis results represented a strong effect size ($\eta^2 = .581 > .139$).

*Table 3.* ANCOVA results of student performance on the transfer-problem test

| Source of variance | *SS* | *df* | *MS* | *F* | Sig. | Post-hoc |
|---|---|---|---|---|---|---|
| Prior knowledge | 44.382 | 1 | 44.382 | $16.107^{***}$ | .000 | |
| Group | 260.305 | 2 | 130.152 | $47.235^{***}$ | .000 | GC > CO, GC > C, CO > C |
| Error | 187.368 | 68 | 2.755 | | | |

*Note.* $^{**}p < .01$; $^{***}p < .000$.

**Students' learning attitude toward algebra word problem solving**

MANCOVA was used to examine the sixth graders' learning attitude. The results showed that there was a statistically significant difference in students' attitude toward algebra word problem solving based on learning tasks (*Wilks' Lambda* = .504, $p = .000$, $\eta^2 = .290$). After that, ANCOVA was employed to explore the differences in each dimension. Although there was no significant difference on students' confidence ($F = 1.670$, $p = .196 > .05$), significant differences were found on their enjoyment ($F = 14.425$, $p < .05$), motivation ($F = 24.234$, $p < .05$), and perceived value ($F = 11.742$, $p < .05$), as shown in Table 4. Therefore, the post-hoc comparisons were needed.

The result of the post-hoc comparison showed that on enjoyment, the GC group (adjusted $M = 17.235$, $SE = .469$) gave significantly more positive responses than the CO group (the adjusted $M = 15.840$, $SE = .473$) and the C group (the adjusted $M = 13.675$, $SE = .474$) respectively, and the CO group responded significantly more positively than the C group. The partial eta squared ($\eta^2$) of the analysis results represented a strong effect ($\eta^2 = .298 > .139$).

As to students' motivation, the post-hoc comparison showed that the GC group (adjusted $M = 14.917$, $SE = .387$) made significantly more positive responses than the CO group (the adjusted $M = 12.624$, $SE = .388$) and the C group (the adjusted $M = 11.194$, $SE = .391$) respectively. The partial eta squared ($\eta^2$) of the analysis results indicated a strong effect ($\eta^2 = .416 > .139$).

As for the perceived value, the post-hoc comparison indicated that the GC group (adjusted $M = 17.945$, $SE = .433$) had significantly more positive responses than the CO group (the adjusted $M = 15.981$, $SE = .445$) and the C group (the adjusted $M = 14.824$, $SE = .483$) respectively. The partial eta squared ($\eta^2$) of the analysis results represented a strong effect ($\eta^2 = .257 > .139$).

*Table 4.* ANCOVA results of learning attitude

| Source of variance | Dimension | *SS* | *df* | *MS* | *F* | Sig. | Post-hoc |
|---|---|---|---|---|---|---|---|
| Prior attitude | Enjoyment | 104.220 | 1 | 104.220 | $19.767^{***}$ | .000 | |
| | Motivation | 32.630 | 1 | 32.630 | $9.131^{**}$ | .004 | |
| | Confidence | 409.985 | 1 | 409.985 | $76.039^{***}$ | .000 | |
| | Perceived value | 90.429 | 1 | 90.429 | $21.108^{***}$ | .000 | |
| Group | Enjoyment | 152.111 | 2 | 76.055 | $14.425^{***}$ | .000 | GC > CO, GC > C, CO > C |
| | Motivation | 173.198 | 2 | 86.599 | $24.234^{***}$ | .000 | GC > CO, GC > C |
| | Confidence | 18.008 | 2 | 9.004 | 1.670 | .120 | |
| | Perceived value | 100.612 | 2 | 50.306 | $11.742^{***}$ | .000 | GC > CO, GC > C |
| Error | Enjoyment | 358.530 | 68 | 5.272 | | | |
| | Motivation | 242.995 | 68 | 3.573 | | | |
| | Confidence | 366.640 | 68 | 5.392 | | | |
| | Perceived value | 291.321 | 68 | 4.284 | | | |

*Note.* $^{**}p < .01$; $^{***}p < .000$.

## Discussion and conclusions

### A significant effect on solving similar problems

First, the GC group acquired significantly higher scores than the CO group; second, the GC group also gained significantly higher scores than the C group. These results showed that gamified comparison tasks could effectively help students learn to solve algebra word problems. The gamification design played a role in learning effects of the comparison strategy. This is because the game context could effectively immerse students in the learning tasks, thereby encouraging them to concentrate on example studying to learn how to solve certain algebra word problems. Additionally, in gamified tasks, students would not only be engaged but be able to monitor their own learning progress because they could realise their progress while accomplishing each task with game rewards. Their learning achievement on the similar-problem test, therefore, reflected learning effects of the gamified comparison tasks. These results could address the issue proposed by Attali and Arieli-Attali's (2015): gamified group may gain lower scores than the non-gamified group by points. When adapting a game rule from an existing game (e.g., Pac-Man or Photo Hunt) that could combine learning and gaming process, rather than just employing a layer of standardised game elements (e.g., points and levels), the effects of learning gamification would be more significant (Villagrá-Arnedo et al., 2016).

Third, the CO group acquired significantly higher scores than the C group. The results obviously showed that the comparison strategy was effective in students' learning of algebra word problem solving. The comparison process could encourage students to reflect on what they learnt and find out their own difficulties when explaining answers by themselves. The result supports findings of numerous previous studies (Rittle-Johnson & Star, 2007, 2009; Star et al., 2015): the use of comparison strategy could improve students' algebra learning. It also addresses the issue proposed by Ziegler and Stern (2014; 2016): the effects of comparing contrasting examples only appeared with delay. However, by using appropriate guiding prompts to facilitate students' comparison, their learning achievement on the follow-up measures can be effectively enhanced.

### A significant effect on solving transfer problems

Firstly, the GC group performed significantly better than the CO group; secondly, the GC group performed significantly better than the C group as well. The results showed that the gamified comparison had significant effects on students' performance on solving transfer problems. The reason may lie in the game rule and the challenges in tasks. The gamified comparison tasks not only motivated students to compare examples to gain effective techniques of algebra word problem solving but also encouraged them to solve the challenging practice problems with giving game rewards and level-up settings. For example, after accomplishing a similar problem following by an example, students received a message that recognised the performance then encouraged them to solve a challenging problem for practice. Such design may help students gain a sense of achievement and motivate them to attempt to practise more related problems, thereby enhancing their transfer ability. Thus, they could score higher on the transfer-problem test because they probably had enough practice to master problem-solving techniques than others students. These results might bridge the gap between gamified meta-cognitive strategy (i.e., comparison) and students' learning performance on solving transfer algebra word problems.

Thirdly, the CO group performed significantly better than the C group. Compared with the C group, even though students in the CO group were not encouraged to solve different algebra word problems, the process of comparison could still guide them to know problem-solving techniques. The comparison activities promoted students to think deeply, reflect on what they already understood, and find out what they still felt confused about. Such process may further encourage students to learn how to analyse and solve a problem from different angles as well as monitoring their own learning progress, thereby improving the performance on solving transfer problems. The result is in accord with research findings from Christianson et al. (2012): comparison could be promising to facilitate students' transfer ability in algebra word problem solving. In addition, as Rittle-Johnson and Star (2007; 2009), and Rittle-Johnson et al. (2012) stated: comparison may not significantly effective without appropriate guiding prompts. Teachers should consider providing clear and understandable guiding prompts to help students develop meta-cognitive ability that usually requires high cognitive load.

### A significant effect on learning attitude

As to students' enjoyment, the GC group responded significantly more positive results than the CO group and the C group respectively, and the CO group gave significantly more positive responses than the C group.

According to the results, the gamification design made learning tasks more interesting to immerse students in learning activities. This echoes the statement from Buckley and Doyle's (2014) and Domínguez et al. (2013) in which game elements used in learning content attracted students' attention and motivate them to complete learning tasks. In addition, the juxtaposed examples and guiding prompts made the algebra word problem solving interesting because students might reckon that they were playing a mini game (similar to Photo Hunt) rather than just solving a problem. Such design may help students engage in the problem-solving process and lead to positive responses. This might address the issue proposed by Hanus and Fox (2015): gamified group may show less satisfaction than the non-gamified group after learning activities because of inappropriate design of learning gamification. By adapting the game rule to present process of comparison, students' learning performance and their attitude toward algebra word problem solving can be enhanced effectively.

As for students' motivation, the GC group reported significantly more positively than the CO group and the C group respectively. The results showed that the gamification design motivated students to learn how to solve algebra word problems. This is in line with previous research findings that game elements encourage students to learn and further increase their learning motivation (Koster, 2004; Villagrá-Arnedo et al., 2016). However, there was no significant difference between the CO group and the C group. This is probably because a comparison task requires more time and effort than students thought. In other words, they were more likely to feel frustrated rather than confident when failing to accomplish assigned tasks. That may make it harder to strengthen learners' motivation.

There was no significant effect on sixth graders' confidence probably because that various problem types and steps of algebra word problem solving make it challenging for students to retrieve appropriate techniques when solving problems by themselves. The results are consistent with findings of Hanus and Fox's study (2015). The difficulty of learning content and requirement of tasks might pose a challenge to students even if guiding prompts and encouragement mechanism are provided. This led them not to respond as positive as on other attitude aspects.

The GC group made significantly more positive responses than the CO group and the C group respectively in terms of perceived value. Comparison activity usually required students to pay more attention to the process and accomplish the tasks (Rittle-Johnson & Star, 2007; Rittle-Johnson & Star, 2009), and the gamification design such as levels and rules provided students with a good opportunity to realise what they had achieved and reflect on what they had learnt (Domínguez et al., 2013). Such combination design could be used to raise learners' awareness of their own learning difficulty and progress, and further help them perceive value of learning tasks and materials.

### Implications

Several implications can be drawn from this study. Firstly, a possible combination of game rule and meta-cognitive strategy was proposed, and it effectively facilitated students' algebra word problem solving. This provides teachers with a better understanding of the connection between learning and gaming process and some ideas of using common game rules in learning activities. Secondly, despite the simplicity of game rule, students' enjoyment, motivation, and perception of learning could be effectively enhanced. It encourages teachers to select and apply some appropriate game rules to classroom activities, thereby improving their students' learning attitude. Thirdly, this study suggests positive learning effects of procedural strategies (i.e., comparison rule and steps) that can be employed in class. However, exploration of possible combined effects and relationships (e.g., between rewards, challenges, rules) is limited in this study. This may point to new possibilities for future study on gamified learning strategies.

### Limitations

Although this study has yielded findings that have both theoretical and instructional implications, its design is not without flaws. The first limitation concerns the Hawthorne effect existed in the study. It may limit the explanations and discussion of the results. The second limitation is rooted in the relatively short time (i.e., 265 minutes in four week) allowed for the intervention. In addition, since this study involved only 24 participants in each group, the generalisation of the results can be limited. The long-term effects of learning gamification on larger and different populations could be explored further in future studies.

## References


Adelman, C. (2006). *The Toolbox revisited: Paths to degree completion from high school though college*. Washington, DC: United States Department of Education.

Alfieri, L., Nokes, T. J., & Schunn, C. D. (2013). Learning through case comparisons: A meta-analytic review. *Educational Psychologist, 48*(2), 87-113. doi:10.1080/00461520.2013.775712

Attali, Y., & Arieli-Attali, M. (2015). Gamification in assessment: Do points affect test performance? *Computers & Education, 83*, 57-63. doi: doi:10.1016/j.compedu.2014.12.012

Bouchey, H. A., & Harter, S. (2005). Reflected appraisals, academic perceptions, and math/science performance during early adolescence. *Journal of Educational Psychology, 97*(4), 673-686. doi:10.1037/0022-0663.97.4.673

Buckley, P., & Doyle, E. (2014). Gamification and student motivation. *Interactive Learning Environments*, 1-14. doi:10.1080/10494820.2014.964263

Bush, S. B., & Karp, K. S. (2013). Prerequisite algebra skills and associated misconceptions of middle grade students: A review. *The Journal of Mathematical Behavior, 32*(3), 613-632. doi:10.1016/j.jmathb.2013.07.002

Carpraro, M. M., & Joffrion, H. (2006). Algebraic equations: Can middle school students meaningfully translate from words to mathematical symbols? *Reading Psychology, 27*(2) 147-164. doi:10.1080/02702710600642467

Christianson, K., Mestre, J. P., & Luke, S. G. (2012). Practice makes (nearly) perfect: Solving “Students-and-Professor” -type algebra word problems. *Applied Cognitive Psychology, 26*, 810-822. doi:10.1002/acp.2863

Cohen, J. (Ed.). (1988). *Statistical power analysis for the behavioral science.* Hillsdale, NJ: Eribaum.

Domínguez, A., Saenz-de-Nacarrete, J., de-Marcos, L., Fernández-Sanz, L., Pagés, C., & Martínez-Herráiz, J.-J. (2013). Gamifying learning experiences: Practical implications and outcomes. *Computers & Education, 63*, 380-392. doi:10.1016/j.compedu.2012.12.020

Gadgil, S., Nokes, T. J., & Chi, M. T. H. (2012). Effectiveness of holistic mental model confrontation in driving conceptual change. *Learning and Instruction, 22*(1), 47-61. doi:10.1016/j.learninstruc.2011.06.002

Gentner, D., Loewenstein, J., & Thompson, L. (2003). Learning and transfer: A General role for analogical encoding. *Journal of Educational Psychology, 95*, 393-405. Retrieved from http://groups.psych.northwestern.edu/gentner/papers/GentnerLoewensteinThompson03.pdf

Guo, J. P., & Pang, M. F. (2011). Learning a mathematical concept from comparing examples: The Importance of variation and prior knowledge. *European Journal of Psychology of Education, 26*(4), 495-525. doi:10.1007/s10212-011-0060-y

Hanus, M. D., & Fox, J. (2015). Assessing the effects of gamification in the classroom: A Longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Computers & Education, 80*, 152-161. doi:10.1016/j.compedu.2014.08.019

Koster, R. (2004). *A Theory of fun for game design*. Farnham, UK: O’Reilly Media.

Landers, R. N. (2014). Developing a theory of gamified learning: Linking serious games and gamification of learning. *Simulation & Gaming, 45*(6), 752-768. doi:10.1177/1046878114563660

Lim, S. Y., & Chapman, E. (2013). Development of a short form of the attitude toward mathematics inventory. *Educational Studies in Mathematics, 82*(1), 145-164. doi:10.1007/s10649-012-9414-x

MacGregor, M., & Stacey, K. (1998). Cognitive models underlying algebraic and non-algebraic solutions to unequal partition problems. *Mathematics Education Research Journal, 10*(2), 46-60. doi:10.1007/BF03217342

Mason, L. (2004). Fostering understanding by structural alignment as a route to analogical learning. *Instructional Science, 32*(4), 293-318. doi:10.1023/B:TRUC.0000026512.88700.32

Mora, A., Riera, D., González, C., & Arnedo-Moreno, J. (2015). A Literature review of gamification design frameworks. In *Proceeding of the 7th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games).* doi:10.1109/VS-GAMES.2015.7295760

National Mathematics Advisory Panel. (2008). *Foundations for success: The Final report of the National Mathematics Advisory Panel.* Washington, DC: U.S. Department of Education. Retrieved from http://www.ed.gov/about/bdscomm/list/mathpanel/report/final-report.pdf

National Research Council. (2001). *Adding it up: Helping children learn mathematics*. Washington, DC: National Academy Press.

Ngu, B. H., & Yeung, A. S. (2012). Fostering analogical transfer: The Multiple components approach to algebra word problem solving in a chemistry context. *Contemporary Educational Psychology, 37*, 14-32. doi:10.1016/j.cedpsych.2011.09.001

Reed, S. K. (1987). A Structure-mapping model for word problems. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*(1), 124-139. doi:10.1037/0278-7393.13.1.124

Reed, S. K., Dempster, A., & Ettinger, M. (1985). Usefulness of analogous solutions for solving algebra word problems. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11*(1), 106-125. doi:10.1037/0278-7393.11.1.106

Richland, L. E., Holyoak, K. J., & Stigler, J. W. (2010). Analogy use in eighth mathematics classrooms. *Cognition and Instruction, 22*(1), 37-60. doi:10.1207/s1532690Xci2201_2

Richland, L. E., & McDonough, I. M. (2010). Learning by analogy: Discriminating between potential analogs. *Contemporary Educational Psychology, 35*(1), 28-43. doi:10.1016/j.cedpsych.2009.09.001

Rittle-Johnson, B., & Star, J. R. (2007). Does comparing solution methods facilitate conceptual and procedural knowledge? An experimental study on learning to solve equations. *Journal of Educational Psychology, 99*(3), 561-574.

Rittle-Johnson, B., & Star, J. R. (2009). Compared with what? The effects of different comparisons on conceptual knowledge and procedural flexibility for equation solving. *Journal of Educational Psychology, 101*(3), 529-544. doi:10.1037/a0014224

Rittle-Johnson, B., Star, J. R., & Durkin, K. (2012). Developing procedural flexibility: Are novices prepared to learn from comparing procedures? *British Journal of Educational Psychology, 82*(3), 436-455. doi:10.1111/j.2044-8279.2011.02037.x

Samuelsson, J., & Granstrom, K. (2007). Important prerequisite for students' mathematical achievement. *Journal of Theory and Practice in Education, 3*(2), 150-170.

Sidney, P. G., Hattikudur, S., & Alibali, M. W. (2015). How do contrasting cases and self-explanation promote learning? Evidence from fraction division. *Learning and Instruction, 40*, 29-38. doi:10.1016/j.learninstruc.2015.07.006

Silver, E. A., Ghousseini, H., Gosen, D., Charalambous, C., & Strawhun, B. (2005). Moving from rhetoric to praxis: Issues faced by teachers in having students consider multiple solutions for problems in the mathematics classroom. *Journal of Mathematical Behavior, 24*(3-4), 287-301. doi:10.1016/j.jmathb.2005.09.009

Star, J. R., Pollack, C., Durkin, K., Rittle-Johnson, B., Lynch, K., Newton, K., & Gogolen, C. (2015). Learning from comparison in algebra. *Contemporary Educational Psychology, 40*, 41-54. doi:10.1016/j.cedpsych.2014.05.005

Sun-Lin, H.-Z., & Chiou, G.-F. (2017). Effects of Comparison and Game-Challenge on Sixth Graders' Algebra Variable Learning Achievement, Learning Attitude, and Meta-Cognitive Awareness. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(6), 2627-2644. https://doi.org/10.12973/eurasia.2017.01244a

Sun-Lin, H.-Z., & Chiou, G.-F. (2017). Effects of Self-explanation and Game-reward on Sixth Graders' Algebra Variable Learning. *Educational Technology & Society, 20*(4), 126-137.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction, 12*(3), 185-233. doi:10.1207/s1532690xci1203_1

Sweller, J., Van Merrienboer, J. J. G., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296. doi:10.1023/A:1022193728205

Villagrá-Arnedo, C., Gallego-Durán, F. J., Molina-Carmona, R., & Llorens-Largo, F. (2016). PLMan: Towards a gamified learning system. In *Lecture Notes in Computer Science* (pp. 82-93). doi:10.1007/978-3-319-39483-1_8

Villagrasa, S., Fonseca, D., Redondo, E., & Duran, J. (2014). Teaching case of gamification and visual technologies for education. *Journal of Cases on Information Technology, 16*(4), 38-57. doi:10.4018/jcit.2014100104

Woodward, J., Beckmann, S., Driscoll, M., Franke, M., Herzig, P., Jitendra, A., Koedinger, K. R., & Ogbuehi, P. (2012). *Improving mathematical problem solving in grades 4 through 8: A practice guide (NCEE 2012-4055)*. Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education. Retrieved from https://ies.ed.gov/ncee/wwc/Docs/PracticeGuide/mps_pg_052212.pdf

Zan, R., Brown, L., Evans, J., & Hannula, M. S. (2006). Affect in mathematics education: An Introduction. *Educational Studies in Mathematics, 63*(2), 113-121. doi:10.1007/s10649-006-9028-2

Ziegler, E., & Stern, E. (2014). Delayed benefits of learning elementary algebraic transformations through contrasted comparisons. *Learning and Instruction, 33*, 131-146. doi:10.1016/j.learninstruc.2014.04.006

Ziegler, E., & Stern, E. (2016). Consistent advantages of contrasted comparisons: Algebra learning under direct instruction. *Learning and Instruction, 41*, 41-51. doi:10.1016/j.learninstruc.2015.09.006