



Effects of Comparison and Game-Challenge on Sixth Graders' Algebra Variable Learning Achievement, Learning Attitude, and Meta-Cognitive Awareness

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ABSTRACT

This study examined the effects of comparison and game-challenge strategies on sixth graders' learning achievement of algebra variable, learning attitude towards algebra variable learning, and meta-cognitive awareness of algebra variable learning. A 2×2 factorial design was used, and 86 students were invited to participate in the experimental instruction and assigned to four groups: comparison with game-challenge, comparison, game-challenge, and control. The results showed that (1) a significant interaction effect was found on students' learning achievement of algebra variable: the comparison with game-challenge group performed significantly better than the comparison group and the game-challenge group respectively; (2) a significant interaction effect was found on students' learning attitude towards algebra variable: the comparison with game-challenge group responded significantly more positively than the comparison group and the game-challenge group respectively; (3) a significant interaction effect was found on students' meta-cognitive awareness of algebra variable learning: the comparison with game-challenge group reported significantly higher scores than the comparison group and the game-challenge group respectively.

Keywords: comparison, game-challenge, algebra variable learning, learning attitude, meta-cognitive awareness

INTRODUCTION

Algebra variable learning

Many students experience difficulty mastering foundational algebraic concepts, one of which is variable concepts (Knuth, Alibali, McNeil, Weinberg, & Stephens, 2005; Philipp, 1992). In algebra learning, the ways in which primary-school students use variables play an important role in solving algebra problems and learning advanced mathematics (Brizuela, Blanton, Sawrey, Gardiner, & Newman-Owens, 2013; Küchemann, 1978, 1981). Küchemann, (1978,

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State of the literature

- Many students find it difficult to learn concepts of algebra variable; however, effective strategies that could improve learning achievement, learning attitude, meta-cognitive awareness are still only partially explored.
- Comparison is considered as an effective strategy in mathematics learning; however, the requirement of high cognitive effort may make learning tasks difficult for students to accomplish.
- Game-challenge could motivate students to learn; however, in many game-supported learning activities, the complex design of challenges may distract students from learning, and to date little research has been done on its educational applications.

Contribution of this paper to the literature

- A combination of comparison and game-challenge strategy is proposed to facilitate students' algebra variable learning. This proposed combined strategy could be applied to primary-school algebra teaching and learning in class.
- The design of mini learning system could effectively be used to enhance sixth graders' algebra variable learning achievement, learning attitude, and meta-cognitive awareness.
- Sub-tasks in comparison and simple/direct challenge settings could effectively motivate students keep meeting challenges and help them learn concepts of algebra variable, gain a sense of achievement, and develop their meta-cognition.

1981) noted that algebra variables could be used in various ways, and students' understanding of variables would affect their learning of algebra expressions and equations in following stages. Based on that, Philipp (1992) further stated that variables can take the following roles in algebra: labels, constants, unknowns, generalised numbers, varying quantities, parameters, and abstract symbols. NCTM (2011) also placed a priority on students' understanding of the multiple meanings of variables in algebra learning. However, national and international assessments have drawn attention to pervasive student difficulties in algebra variable learning. For example, National Center for Educational Statistics (2005) reported that only 59% of eighth graders were able to correctly understand the use of variables and find the relationship between variables while learning algebra variable concepts. To properly explore students' difficulty of learning concepts of algebra variable, Lucariello, Tine, and Ganley (2014) proposed three common problems that students may have: 1) a variable is ignored, 2) a variable is a label for an object, and 3) a variable is just a specific unknown value.

The first common problem, initially mentioned by Kuchemann (1978), was found in students' interpretations of variables. His study pointed out that some students consistently ignored variables. For example, in the question "Add 4 onto $n + 5$ ", about 68% of students were able to give the correct answer ($n + 9$), but at the same time, 20% of students answered incorrectly with answer 9. The second common problem has been found when students consider variables as labels for certain objects (McNeil et al., 2010). Stacey and Macgregor (1997) mentioned that when they asked middle graders the question "David is 10 cm taller than Con. Con is h cm tall. What can you write for David's height?", many students interpreted

the variable as a label associated with the name of an object (e.g. $C + 10 = D$). Stacey and Macgregor (1997) explained that the incorrect answer showed that students treated ' C ' as the meaning 'Con's height' and D as the meaning 'David's height'. The third common problem is that students are likely to treat a variable as a specific unknown value, not represent multiple ones (Lucariello, et al., 2014). For instance, students may assume x can only hold one value, as opposed to many values, and this difficulty would mislead their understanding of a variable's functions. To assist students in understanding concepts of algebra variable effectively, some researchers suggested specific instructional strategies, for example, increasing students' meta-cognition and creating cognitive conflict by providing students with correct/incorrect examples to compare, could be considered (Lucariello, 2009; Lucariello, et al., 2014). To date, while many studies have explored algebra learning such as expressions and equations (Bush & Karp, 2013), few studies have been specifically done on the issues of students' learning of algebra variable concepts.

Comparison

Comparing examples or solutions has been considered as an effective mathematics learning strategy (NCTM, 2000). Researchers stated that finding the similarities and differences between given examples would encourage students' reflection and deeper understanding of mathematics concepts (Sidney, Hattikudur, & Alibali, 2015; Silver, Ghouseini, Gosen, Charalambous, & Strawhun, 2005). Comparing, which requires students to differentiate correct/incorrect examples, can help students perform better in mathematics learning than just studying a single example or studying two examples separately. For example, in the study of Rittle-Johnson and Star (2007), seventh graders who compared two solutions to solve given equations gained significantly higher scores on mathematics tests than those who sequentially studied the two solutions. Schwartz, Chase, Oppezzo, and Chin (2011) pointed out that the process of comparison allows students to differentiate the features of correct and incorrect examples. This means that by comparing examples with contrasting answers and explanations, students would be able to correctly understand the concepts and further solve similar problems.

Although most previous studies focused on the use of correct examples, recent studies suggest that requiring students to compare correct examples with incorrect ones could help them understand concepts deeply, and the learning benefits of explaining differences could be twofold (Durkin & Rittle-Johnson, 2012; Siegler & Chen, 2008). First, making comparisons could help students realise the incorrect examples, by which they could reflect on the accurate concepts they learnt (Siegler & Chen, 2008). Second, making comparisons could attract students' attention to the specific characteristics in the examples that make the solutions and answers inaccurate (Booth, et al., 2013). Likewise, Sidney et al. (2015) stated that the comparison strategy basically involves noticing the similarities and differences between correct and incorrect examples, and it would also encourage students to reflect on the learnt concepts, that is, students' meta-cognitive abilities. However, the use of incorrect examples may not always effectively benefit students. For example, Große and Renkl (2007) found that

students might find it difficult to learn from incorrect examples when being required to identify the errors in the examples by themselves without clear and appropriate guidance, and they thus could not improve their learning achievement effectively. Therefore, to facilitate students' comparison, dividing an entire task into some sub-tasks, which may make it easier for students to accomplish, and offering appropriate step-by-step guidance could be more feasible and beneficial.

Game-Challenge

Challenging tasks have been found to boost positive learning attitude while enhancing students' academic performance (e.g. Fullagar, Knight, & Sovern, 2013; Hung, Sun, & Yu, 2015). Previous studies indicated that students would learn how to overcome the given challenges that typically start off easy-levels and then become more difficult when students' abilities improve (Hamari et al., 2016; McGonigal, 2011). Hwang, Wu, and Chen (2012) further stated that the game-challenge would not only be able to improve students' academic performance but help them gain a sense of achievement. This is because game-challenge could immediately represent students' learning progress and offer rewards for their participation and learning achievement while accomplishing tasks (da Rocha Seixas, Gomes, & de Melo Filho, 2016).

There are three important aspects of game-challenge that should be considered in terms of educational applications: goals, rewards, and levels. First, a clear goal directly indicates the required action or outcomes so that students know what to do in tasks. It makes the process of task accomplishment more effective, and when the progress to reach a goal is presented, the following rewards and levels are more efficient and meaningful to students (Hung et al., 2015). Second, a reward is to represent the progress of a task and be presented after a certain action (e.g. choose a correct answer) to encourage students to accomplish tasks. In game-supported learning activities, the main representation of reward is the points (Zichermann & Cunningham, 2011). Third, a level indicates that students accomplished goals/sub-goals: the higher the level is, the greater the status would be. Levels are usually defined as threshold points in which students would automatically level up based on their performance (da Rocha Seixas et al., 2016). Once students achieved the goal (or all the sub-goals) of a level, a higher-level challenge would be needed to hone their abilities. Students, therefore, could progress through increasingly difficult challenges at ever-higher levels (Hamari et al., 2016). In this kind of setting, students may find it easier to achieve sub-goals in tasks in terms of challenging activities such as comparing correct and incorrect examples to learn concepts of algebra variable.

Research purposes and questions

Although students usually struggle with algebra learning, few studies have been done on their learning performance of algebra variable. Comparison strategy has been often used to improve students' performance of algebra calculation; however, little empirical research

focuses on the design of guidance with incorrect examples. In addition, while game-challenge has been used in learning gamification, its possible educational applications are still partially explored. Therefore, this study aims to explore how comparison, game-challenge, and their interaction affect students' learning achievement of algebra variable, learning attitude towards algebra variable learning, and meta-cognitive awareness in algebra variable learning. For the purpose, the researchers designed a mini learning system combining comparison and game-challenge strategies to support students' algebra variable learning. In the system, four learning activities integrating game-challenge elements into comparison tasks were developed. To examine the learning effects, a 2×2 quasi-experiment was conducted in sixth-grade mathematics class by investigating the following research questions:

1. What are the effects of the comparison and the game-challenge, and the interaction between them, on sixth graders' learning achievement of algebra variable?
2. What are the effects of the comparison and the game-challenge, and the interaction between them, on sixth graders' learning attitude towards algebra variable?
3. What are the effects of the comparison and the game-challenge, and the interaction between them, on sixth graders' meta-cognitive awareness of algebra variable learning?

METHOD

This study adopted a quasi-experimental design with learning activities as the independent variable. According to the differences of learning activities, the students who received comparison tasks with game-challenge elements (as described in the section "The mini learning system") were considered as the comparison with game-challenge group (the C-G group), those who received comparison tasks without game-challenge elements were considered as the comparison group (the C-NG group), those who did not receive comparison tasks but were encouraged to accomplish all the tasks by game-challenge elements were considered as the game-challenge group (the NC-G group), and those who received neither comparison nor encouragement of game-challenge were considered as the control group (the NC-NG group).

The dependent variables were the students' learning achievement of algebra variable concepts, learning attitude, and meta-cognitive awareness in algebra variable learning. First, the learning achievement referred to the students' scores on the achievement tests. Second, the students' learning attitude referred to the students' responses to algebra variable learning on the learning attitude scale. Third, the meta-cognitive awareness of algebra variable learning referred to the students' responses on the meta-cognitive awareness scale.

Participants

A total of 86 students (35 females and 51 males), in an 11-13 age range ($M = 12.12$, $SD = .42$), were invited to participate in the instructional experiment. Of all participants, 20 were

Table 1. The treatments for the four groups in this instructional experiment

	Game-challenge (G)	Non-game-challenge (NG)
Comparison (C)	The C-G group: comparison with game-challenge	The C-NG group: comparison with non-game-challenge
Non-comparison (NC)	The NC-G group: non-comparison with game-challenge	The NC-NG group: non-comparison with non-game-challenge

assigned to the C-G group, 22 to the C-NG group, 21 to the NC-G group, and 23 to the NC-NG group. The treatments of groups in this instructional experiment are shown in **Table 1**.

All the participants of this study 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 mini learning system

A mini learning system which combined comparison and game-challenge strategies to support students' algebra variable learning was developed via software Construct 2. The learning system provides students with nine learning tasks, and each task comprised (1) a reading page that introduced a concept of algebra variable, (2) a sample question and the solution that demonstrated the application of the algebra variable concept, and (3) a practice question, which comprised two examples (one was correct and the other could be correct or incorrect), helped students reflect on what they learnt.

In the task, the comparison groups were required to compare two examples, in which one example presented a correct answer to a question and an explanation of the answer, but the other answer to the other question could be correct or not. To know the correctness, the students were required to compare these two examples, then explained their own judgements (see **Figure 1**). On the other hand, the non-comparison groups were just required to answer the questions by choosing given options directly and explain their choices without any comparison (see **Figure 2**).

The game-challenge strategy used in this study was to provide students with learning tasks with game-challenge elements, including goals (to inform student about the task requirement, e.g. "Goal: Gain 10 points for level-up"), points (to represent the progress in single unit task, e.g. "Point: 6"), and levels (to represent the entire learning progress, e.g. "Current level: 5"). The game-challenge groups were informed about the different challenge levels and received above-mentioned components (see **Figure 3**); the non-game-challenge groups did not receive any information regarding gamified tasks and encouragement by game elements, and directly entered the reading pages.

To engage students in these tasks with game-challenges without distracting them from learning, all game-challenge elements were kept simple and direct rather than complex and too visual-oriented such as special effects or animations. As to non-game-challenge groups,



Figure 1. A screenshot of a comparison task



Figure 2. A screenshot of a non-comparison task



Figure 3. A screenshot of a note page that informed students about the challenges of tasks

they were required to finish general practices in which they did not receive any encouragement by above-mentioned game-challenge elements and did not progress through increasingly difficult challenges at higher levels. The learning activities that students experienced in the four groups are described and shown in **Table 2**.

Instruments

In this study, the algebra achievement tests (pre-test and post-test) and the algebra learning attitude scale (pre-survey and post-survey), and the algebra meta-cognitive

Table 2. The learning activities of the four groups

Group	Description	Example	Comparison	Challenge
C-G	Students read the descriptions of algebra variable concepts	Students read the question examples of algebra variable concepts	Students were required to compare two examples (one is correct and the other could be correct or incorrect) and explain their answers	Students were informed about the game goals, points, and levels. They accomplished the tasks one by one and were encouraged by these game-challenge elements during the process of task accomplishment
C-NG	Students read the descriptions of algebra variable concepts	Students read the question examples of algebra variable concepts	Students were required to compare two examples (one is correct and the other could be correct or incorrect) and explain their answers	Students accomplished the tasks one by one and did not receive any encouragement of game-challenge elements during the process of task accomplishment
NC-G	Students read the descriptions of algebra variable concepts	Students read the question examples of algebra variable concepts	Students were required to direct answer the practice question and explain their answers. In this case, students did not receive the juxtaposed two examples	Students were informed about the game goals, points, and levels. They accomplished the tasks one by one and were encouraged by these game-challenge elements during the process of task accomplishment
NC-NG	Students read the descriptions of algebra variable concepts	Students read the question examples of algebra variable concepts	Students were required to direct answer the practice question and explain their answers. In this case, students did not receive the juxtaposed two examples	Students accomplished the tasks one by one and did not receive any encouragement of game-challenge elements during the process of task accomplishment

awareness scale (pre-survey and post-survey) were used. The objective of the pre-test was to understand whether the four groups of students had an equivalent prior knowledge of algebra variables and the pre-surveys were utilised to understand students' prior learning attitude and meta-cognitive awareness before attending the learning activities. If the results of pre-test or pre-surveys were unequal among groups, such data of pre-test or pre-surveys would be used as the covariate to conduct statistics analyses.

Achievement test

An existing algebraic variable assessment, created by Lucariallo, Tine, and Ganley (2014), was modified and used as it covered the three important concepts proposed by previous studies and targeted by this study. The original test was translated into Mandarin because all the participants were native Mandarin speakers. Each test (pre-test and the post-

test) comprises nine multiple-choice items concerning three algebra variable concepts (three items for each concept): (1) a variable represents an unknown quantity, (2) a symbol represents a varying quantity, and (3) systematic relationships between symbols. Some examples are presented below.

Example 1: n is a whole number greater than 0 and less than 5. How many values of $3n$ can there be?

- A. 0
- B. 3
- C. 4 (correct)
- D. 5

Example 2: At a university, there are six times as many students as professors. This fact is represented by the equation $S = 6P$. In this equation, what does the letter S stand for?

- A. number of students (correct)
- B. professors
- C. students
- D. none of the above

Example 3: Rita put some hummingbird feeders in her backyard. The table shows the number of hummingbirds that Rita saw compared to the number of feeders. Which equation best describes the relationship between h , the number of hummingbirds, and f , the number of feeders?

Number of Feeders (f)	Number of Hummingbirds (h)
1	3
2	5

- A. $h = 11f$
- B. $h = 2f + 1$ (correct)
- C. $h = f + 2$
- D. $h = f + 6$

To ensure the quality of the measurement, 133 sixth graders who did not participate in the instructional experiment were invited to answer the items of the achievement test. Cronbach's α measure was used to compute the reliability of the tests: for the pre-test $\alpha = .855$ and for post-test $\alpha = .939$; there was a strong positive correlation between pre-test and the post-test ($r = .397, p = .000$). As to the content validity, three primary-school mathematics teachers with over five years of teaching experience were invited to review the tests. The tests also showed significant correlations with the regular school mathematics examination, which covered concepts of algebra variable. The significant positive correlations (between the pre-test and the examination, $r = .543, p = .000$; between the post-test and the examination, $r = .734, p = .010$) indicated good criterion-related validity.

Learning attitude scale

The scale, which was from the instrument developed by Lim and Chapman (2013), was modified by translation for effective student responses. The attitude scale consisted of 19 items with four-point Likert scale. Examples of the items: "I enjoy learning algebra concepts", "I am willing to learn more algebra concepts", and "I am confident that I could learn algebra well". To ensure the appropriateness to measure students' learning attitude towards algebra variable, the invited primary-school mathematics teachers reviewed all the items. The 133 sixth graders were also invited to respond each item of the scale to examine the reliability, and the Cronbach's α value for the entire scale was .927, showing good reliability in internal consistency.

Meta-cognitive awareness scale

The meta-cognitive awareness scale, based on the instrument created by Panaoura, Philipou, and Christou (2003), was modified by translation. It comprised 27 questions that were developed based with four-point Likert scale. Here are some examples of question items: "I know how well I understand the algebra concepts that I have learnt", "I know what makes it difficult for me to solve algebra problems", and "I would like to know whether I learnt the new concept after the learning activity". After the three invited teachers reviewed all the questions, and the 133 students were also invited to answer the questionnaire. The Cronbach's α value for entire questionnaire was .959, showing good reliability in internal consistency.

Procedure

The experimental instruction took around 285 minutes in four weeks. First, the researchers explained the purpose of the instruction (5 minutes), and the students were required to answer the pre-test of algebra variable concepts (20 minutes), respond the pre-survey of learning attitude scale (10 minutes), and finish the pre-survey of meta-cognitive awareness (10 minutes).

During the learning activity, the four groups learnt concepts of algebra variable with different learning strategies and accomplished all the tasks in 200 minutes. The differences among groups were the tasks consisted of comparison (or non-comparison) requirement with game-challenge (or non-game-challenge) elements. The descriptions of learning activities are presented in [Table 2](#).

After the learning activity, all the participants were required to answer the post-test of algebra variable concepts and to respond the post-surveys of learning attitude scale and meta-cognitive awareness (took 20, 10, and 10 minutes respectively).

Table 3. The two-way ANOVA results of students' learning achievement

Source	SS	df	MS	F	η^2
Comparison	4.354	1	4.354	1.059	.013
Game-challenge	1.133	1	1.133	.275	.003
Comparison*game-challenge	19.618	1	19.618	4.770*	.055
Error	337.221	87	4.112		

* $p < .05$

Table 4. The descriptive data of students' learning achievement

Comparison	Game-challenge	Post-test		n
		M	SE	
Comparison	Game-challenge (C-G)	6.550	.453	20
	Non-game-challenge (C-NG)	5.364	.432	22
Non-comparison	Game-challenge (NC-G)	5.143	.443	21
	Non-game-challenge (NG-NG)	5.870	.423	23

Table 5. The simple main effect analysis results of students' learning achievement

Pair	SS	df	MS	F	η^2
C-G versus C-NG	14.725	1	14.725	4.913*	.109
NC-G versus NC-NG	5.797	1	5.797	1.121	.026
C-G versus NC-G	20.283	1	20.283	4.898*	.112
C-NG versus NC-NG	2.878	1	2.878	.704	.016

* $p < .05$

RESULTS

Learning achievement

Levene's test was used to examine the assumption of homogeneity, and the result showed that the population variances are equal ($F = 1.517, p = .216$). The results of two-way ANOVA (see **Table 3**) indicated that a significant interaction effect was found between comparison and game-challenge ($F = 4.770, p = .032, \eta^2 = .055$) on students' learning achievement of algebra variable, thus a simple main effect analysis was employed. The descriptive data of the students' test scores are presented in **Table 4**.

As shown in **Table 5**, a significant difference ($F = 4.913, p = .032$) was found between the C-G group and the C-NG group while the results were grouped by the comparison/non-comparison strategy. The test score of the C-G group ($M = 6.550, SE = .453$) was significant better than that of the C-NG group ($M = 5.364, SE = .432$), as presented in **Table 4**. According to the definition of effect size proposed by Cohen (1988), the partial Eta-squared (η^2) of the results of the simple main effect analysis represented a medium effect size ($\eta^2 = .109 > .059$).

As the results were grouped by the game-challenge/non-game-challenge, a significant difference ($F = 4.898, p = .033$) was also found between the C-G group and the NC-G group. To be specific, as shown in **Table 4**, the learning achievement of the C-G group ($M = 6.550, SE = .453$) was significant higher than that of the NC-G group ($M = 5.143, SE = .443$). The partial

Table 6. The two-way ANOVA results of students' learning attitude

Source	SS	df	MS	F	η^2
Comparison	300.250	1	300.250	1.694	.020
Game-challenge	556.108	1	556.108	3.138	.037
Comparison*game-challenge	1353.008	1	1353.008	7.635*	.085
Error	14531.829	1	177.217		

* $p < .05$

Table 7. The descriptive data of students' learning attitude

Comparison	Game-challenge	Post-test		n
		M	SE	
Comparison	Game-challenge (C-G)	60.400	2.977	20
	Non-game-challenge (C-NG)	47.364	2.838	22
Non-comparison	Game-challenge (NC-G)	48.714	2.905	21
	Non-game-challenge (NG-NG)	51.565	2.776	23

Table 8. The simple main effect analysis results of students' learning attitude

Pair	SS	df	MS	F	η^2
C-G versus C-NG	1780.395	1	1780.395	13.570*	.253
NC-G versus NC-NG	89.221	1	89.221	.404	.010
C-G versus NC-G	1398.866	1	1398.866	9.640*	.198
C-NG versus NC-NG	198.501	1	198.501	.962	.022

* $p < .05$

Eta-squared (η^2) of the simple main effect analysis results indicated a medium effect size ($\eta^2 = .112 > .059$).

Learning attitude

To assess the assumption of homogeneity, Levene's test was employed, and the result showed that the population variances are equal ($F = 1.164, p = .329$). As shown in **Table 6**, the results of two-way ANOVA indicated that a significant interaction effect was found between comparison and game-challenge ($F = 7.635, p = .007, \eta^2 = .085$) on students' learning attitude, so a simple main effect analysis was conducted. The descriptive data of the students' learning attitude are presented in **Table 7**.

As shown in **Table 8**, as the results were grouped by the comparison/non-comparison strategy, a significant difference ($F = 4.913, p = .032$) was found between the C-G group and the C-NG group. The C-G group ($M = 60.400, SE = 2.977$) responded significantly more positive results than the C-NG group ($M = 47.364, SE = 2.838$), as shown in **Table 7**. The partial Eta-squared of the results of the simple main effect analysis ($\eta^2 = .253 > .139$) represented a large effect size.

A significant difference ($F = 9.640, p = .004$) was also found between the C-G group and the NC-G group in terms of learning attitude when the results were grouped by the game-challenge. To be specific, as shown in **Table 7**, the C-G group ($M = 60.400, SE = 2.977$)

Table 9. The two-way ANOVA results of students' algebra meta-cognitive awareness

Source	SS	df	MS	F	η^2
Comparison	66.309	1	66.309	.316	.004
Game-challenge	155.573	1	155.793	.742	.009
Comparison*game-challenge	1922.923	1	1922.923	9.177*	.101
Error	17182.651	82	209.545		

* $p < .05$

Table 10. The descriptive data of students' algebra meta-cognitive awareness

Comparison	Game-challenge	Post-test		n
		M	SE	
Comparison	Game-challenge (C-G)	90.800	3.237	20
	Non-game-challenge (C-NG)	78.636	3.086	22
Non-comparison	Game-challenge (NC-G)	79.571	3.159	21
	Non-game-challenge (NG-NG)	86.348	3.018	23

Table 11. The simple main effect analysis results of students' algebra meta-cognitive awareness

Pair	SS	df	MS	F	η^2
C-G versus C-NG	1549.995	1	1549.995	11.506*	.223
NC-G versus NC-NG	504.072	1	504.072	1.795	.041
C-G versus NC-G	1291.560	1	1291.560	5.832*	.130
C-NG versus NC-NG	668.669	1	668.669	3.364	.073

* $p < .05$

responded significantly more positively than the NC-G group ($M = 48.714$, $SE = 2.905$), and the simple main effect analysis results indicated a large effect size ($\eta^2 = .198 > .139$).

Meta-cognitive awareness

Levene's test was used to assess the assumption of homogeneity, and the result shows that the population variances are equal ($F = 1.912$, $p = .134$). As shown in **Table 9**, the results of two-way ANOVA showed that a significant interaction effect was found between comparison and game-challenge ($F = 9.177$, $p = .003$, $\eta^2 = .101$) on students' meta-cognitive awareness, a simple main effect analysis thus was conducted. The descriptive data of the students' meta-cognitive awareness are presented in **Table 10**.

As shown in **Table 11**, when the results were grouped by the comparison/non-comparison strategy, there was a significant difference of meta-cognitive awareness ($F = 11.506$, $p = .002$, $\eta^2 = .223$) between the C-G group and the C-NG group. The C-G group ($M = 90.800$, $SE = 3.237$) reported significantly more positive results than the C-NG group ($M = 78.636$, $SE = 3.086$), as shown in **Table 10**. The partial Eta-squared of the results of the simple main effect analysis ($\eta^2 = .223 > .139$) represented a strong level of effect size.

Additionally, a significant difference ($F = 5.832$, $p = .021$) was also found between the C-G group and the NC-G group in terms of learning attitude when the results were grouped by the game-challenge. To be specific, as shown in **Table 10**, the C-G group ($M = 90.800$, $SE =$

3.237) responded significantly better meta-cognitive awareness than the NC-G group ($M = 79.571$, $SE = 3.159$), and the simple main effect analysis results indicated a middle effect size ($\eta^2 = .130 > .059$).

DISCUSSION AND CONCLUSIONS

This study integrated game-challenge elements into comparison activities and examined their interaction effects on sixth graders' learning of algebra variable. The results showed that the combination of the two strategies significantly enhanced students' learning achievement, learning attitude, and meta-cognitive awareness.

Significant interaction effects on learning achievement of algebra variable

The results of two-way ANOVA indicated that a significant interaction effect of the two strategies was found on students' learning achievement. First, the C-G group performed better than the C-NG group. This result showed that when students were required to compare correct and incorrect examples, the game-challenge could encourage them to accomplish the tasks and enhance their learning performance. One possible explanation is that the game-challenge effectively motivated students to accomplish each sub-goal in comparison tasks by offering direct and immediate feedback such as points and levels that showed their learning progress. The students might find it interesting because the goals were clear and easy to understand, the points could immediately represent their current performance, and the process of level-up could inform them about the current progress. Such design not only motivated students but helped them gain a sense of achievement. The result supports findings of da Rocha Seixas, et al. (2016) and Hung et al. (2015). Additionally, this study further explores the potential of simple challenge design in which the sub-goals, the rewards, and levels are simple and direct rather than complex or too visual-oriented feedback. According to the result, simplification might be a feasible approach in terms of designing game-challenge tasks for students' algebra variable learning.

Second, a significant difference was also found between the C-G group and the NC-G group. The possible reason lies in that the comparison provided the students with opportunities to reflect on what they have learnt and apply learnt concepts in practice, i.e. distinguishing correct and incorrect examples. After the step-by-step comparison tasks, the students were more likely to be able to realise how to answer correctly when they were solving similar problems than those did not have such activities. Such practice was likely to help them gain a sense of achievement, and they thus could be willing to make an effort to face next challenge and accomplish the task. The result is in line with previous findings (e.g. Rittle-Johnson & Star, 2007; Schwartz, et al., 2011). The comparison process in each task encourages students to differentiate the features of correct and incorrect examples, thereby deepening their understanding of algebra variable concepts.

Significant interaction effects on learning attitude towards algebra variable

The results of the instructional experiment showed that a significant interaction effect of the two strategies was found on students' learning attitude. Firstly, the C-G group reported significantly higher scores than the C-NG group. This result demonstrated that when students were required to compare correct and incorrect examples, the game-challenge could effectively encourage them to accomplish the tasks. The game-challenge used in the learning tasks could increase the students' interest, give them direct feedback, and inform them about their progress, thereby boosting the students' confidence and immersing them in accomplishing sub-tasks. Similar to the findings of Hwang et al. (2012), the game-challenge would not only improve students' academic performance but help them gain a sense of achievement. Such feelings would have a positive effect on their learning attitude. As Hamari et al., (2016) stated: when students go through increasingly difficult challenges and are aware of their own progress, they would keep moving forward with their positive learning attitude.

A significant difference was also found between the C-G group and the NC-G group in terms of the learning attitude. The possible explanation lies in the process of comparison which provided the students with more opportunities to accomplish the tasks. Apart from game-supported learning strategy, the learning system was designed and developed based on the meta-cognition strategy: comparison, which required the students to compare examples in this study. The students might find the process slightly challenging, but they could easily get a sense of achievement during the learning activity because each task comprised simpler and easy-to-accomplish sub-tasks. This result resolves the issues that Große and Renkl (2007) mentioned: novice learners usually find it challenging to learn from incorrect examples while being required to identify the errors themselves. With the design of simple and direct challenge, sub-tasks could make it less difficult for students to compare examples and learn from the process. They might, at the same time, enhance the learning attitude because students would be able to successfully segue into the next level by effectively achieving sub-goals and gaining rewards.

Significant interaction effects on meta-cognitive awareness of algebra variable learning

The results indicated that there were interaction effects on students' meta-cognitive awareness. Firstly, the C-G group responded significantly higher scores than the C-NG group; secondly, the C-G group reported significantly higher score than the NC-G group. According to these results, the comparison strategy played an important role in students' development of meta-cognitive awareness, and at the same time, the game-challenge might potentiate the effects. The comparison activity required students to find the similarities and differences between examples, such process encouraged them to reflect on what they understood indeed and what they were still confused about. During the comparison activity, the design of game-challenge might not directly affect students' meta-cognitive awareness, but it made the process more interesting and feasible in students' learning of algebra variable. For example, this study

divided a comparison tasks into several sub-tasks in which students received direct feedback such as points and levels that encouraged them to keep moving forward. These results support previous studies' findings (Sidney et al., 2015; Siegler & Chen, 2008) that the comparison facilitates students' meta-cognitive ability, and they also contribute a feasible idea that integrating game-challenge elements into the comparison process to promote the learning effects.

Implications for future research and practice

Overall, according to the results of this study, the combination of comparison and game-challenge elements could be feasible to facilitate sixth graders' learning of algebra variable. With the computer-based mini learning system, students would be able to receive appropriate tasks and to be encouraged to accomplish them through game-challenge design.

On the one hand, as to the tasks combining comparison and game-challenge strategies, in the mini learning system used in this study, the simple and direct design of game-challenge seemed to lead to positive results that students were effectively motivated to keep accomplishing learning tasks, and their learning performance, learning attitude, and meta-cognitive awareness were better than those who did not receive any encouragement of game-challenge design. The students could be more confident to challenge the next task by being informed about their current achievement and the next given goal. Each message and feedback in game-challenge that students received could not only help to present their learning progress but show what and where they might not well understand yet when they cannot successfully achieve the goals. The system used in this study is an example to show that the combined applications could be implemented to facilitate sixth graders' learning of algebra variable in a computer-supported learning context.

On the other hand, while the group received comparison with game-challenge tasks performed or responded better than the comparison group and the game-challenge group in terms of the three learning outcomes, there was no significant differences between the control group and other groups. Although the four groups were learning in the same computer settings (i.e. every student accomplished learning tasks by using their own computers with same specifications), some issues of technology use and learning gamification might be worth considering for future design of instructional materials. First, students may be used to take some notes or draw several diagrams to help them make comparisons. Although it could be quite challenging to meet every student's needs, the function support from digital or computer-based systems may affect students' performance and experience in meta-cognitive learning activities that usually require more cognitive effort. Second, there could be a variety of ways to gamify learning, each game element, such as game-reward and game-rule, may have different learning effects that can be properly designed in various ways. For example, the applications of game-reward or game-challenge could be used to encourage students to do certain actions, but in helping to gain the experience of learning/gaming process, the design of game-rule is more likely to play an important role. To better the quality of the learning

system design and enhance students' learning outcomes more effectively, these issues may need further exploration.

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