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A Pilot study to assess the impacts of game-based construction learning, using scratch, on students' multi-step equation-solving performance

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ABSTRACT

This study examined the effects of students' construction of computer-based educational games, using Scratch, on their mathematical equation-solving performance and their attitudes towards learning mathematics with the assistance of technology. A one-group, pretest-posttest quasi-experimental study design, was adopted. A total of 89 seventh grade students from three classes at a public school in Beijing, China, offering 9 years of compulsory education, participated in Scratch-based mathematical game-making activities. Data were collected via an equations-solving test, surveys, interviews and member checking, and pairwise t-tests were performed for data analysis. The results indicated significant improvements in students' equation-solving performance and in their attitudes towards learning mathematics with the assistance of technology.

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Scratch; mathematic games; equation-solving; learning attitudes

Introduction

In the twenty-first century, the integration of information and communications technology into educational curricula has emerged as a major trend. Previous studies have shown that computer-based activities have positive effects on students' learning attitudes and performance in the field of mathematics (Kenneth, 1996). Moreover, technology can be used as a tool for supporting deeper cognition which is required for meaningful learning (Jonassen & Carr, 2000). Acknowledging the potential impact of technology on education, in September 2015, China's Ministry of Education issued guidelines (a consultation draft) on accomplishing the informatization of education during the 13th Five-year Plan. This document referred to the incorporation of elements of information technology into teaching and the promotion of changes in teaching content and patterns based on the use of this technology.

The theory of constructivism views learning as a process whereby learners proactively interact with their environment to construct their own knowledge. It posits that children should be encouraged to develop knowledge through game making. Game-based construction learning (GBCL) is defined as "an innovative learning approach that uses appropriate tools in order to allow games to be constructed to support learning and teaching" (Wilson, Hainey, & Connolly, 2013, p. 588). It, therefore, meets the requirements of "learning by doing". Robertson and Howells (2008) have suggested that the construction of games entails setting important learning goals whereby students can develop and exercise a wide range of skills. Vos, van der Meijden, and Denessen (2011) have

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observed that it is necessary for learners to understand the point of knowledge and apply this knowledge executing the game designing task. In their study titled "Effects of constructing versus playing an educational game on student motivation and deep learning strategy use", 235 students, distributed across four primary schools in Holland, were divided into two groups. While the experimental group constructed a "drag and drop" game, the control group played with the pre-constructed game. The study found that the process of constructing games could improve students' motivation to learn and promote their deep learning better than playing pre-constructed games. Peppler and Kafai (2007) have reported on the benefits for learners of game making related to learning software design and other academic content. Among these benefits were learning how to programme, collaborate with others and become a member of an affinity group.

An extensive literature has explored the relationship between computer games and the learning of mathematics. Earlier studies demonstrated that students who played pre-constructed educational computer games evidenced improved attitudes and abilities related to learning mathematics (e.g. Kebritchi, Hirumi, & Bai, 2010; Shin, Sutherland, Norris, & Soloway, 2012). Ke (2014) has explored the impacts of educational computer games created by students themselves on their mathematical learning in cases where the participants were free to choose mathematical knowledge that was not specific to a particular mathematical problem in designing games.

Some researches in recent years have suggested that students' learning environment should be designed and organized with consideration of the mathematics in Scratch programming activities (Grover, Pea, & Cooper, 2015; Han, Bae, & Park, 2016), including procedural programming language with solving math problems, like Scratch and programming games to improve students learning motivation (Mladenovic, Krpan, & Mladenovic, 2016). Lee and Park (2015) implemented the Scratch game programme to minimize the learning deficit of underachievers in third grade of elementary school. Their study found that students' competence of arithmetic operation was enhanced and their level of interest about learning increased.

Equation solving is one of the key learning areas within mathematics that students find difficult to grasp. Linear equation solving is regarded as a basic mathematical skill that has been recommended as a core component of the curriculum for seventh grade students by the organization "National Council of Teachers of Mathematics" (Rittle-Johnson & Star, 2007, p. 562). The objective of teaching equations to seventh graders is to enable them understand the application of mathematical symbols in algebra (Zhang, 2011).

Based on feedback obtained from teachers and students who were interviewed for this study, equation solving evidently constitutes one of mathematical difficulties for Chinese seventh grade students for the following reasons. First, it is difficult for students to make the transition from arithmetical thinking to algebraic thinking. Second, it is not easy for beginners to shift from the use of everyday to symbolic language (Zhang, 2011).

Before the experiment, an interview was held between the teachers and the students. According to teachers, students usually made procedural errors such as removing brackets, moving the expression or using the laws of operation when attempting to solve an equation. Most students claimed that it was difficult for them to remain attentive when the class was boring or the topic was difficult. Nearly all of the low-level students who ranked in the last 25% and some medium-level students who ranked in the middle 50% claimed that they lacked the confidence to do well in mathematics and had no interest in learning this subject. Some of the feedback obtained from students was as follows:

> Solving equations is difficult for me. I got a poor score in the test, and my parents sent me to a cram school, but it's boring to learn the knowledge again and do a lot of exercises.

> I don't think I can learn mathematics well, because it's difficult and I'm not smart enough.

> Most of the time, I can concentrate on the class, but when the topic is difficult or boring I get distracted.

> I like mathematics and I want to learn it well, but my math performance is poor, so I have no confidence in mathematics.

Researchers have explored ways of enabling students to more easily learn how to solve equations. Rojano and Martínez (2009) applied a virtual version of a balance model for teaching secondary students how to solve linear equations. Hewitt (2012) adopted Grid Algebra, a computer software programme, to teach three lessons on linear equation solving to students aged 9–10 years old. The software continually interpreted the formal notation of equations and provided the students with feedback so that they could educate themselves. Consequently, the students were found to be remarkable confident when working with complicated linear algebraic expressions. Rittle-Johnson and Star (2007) conducted a study in which they divided 70 seventh grade students into two groups and taught them algebraic equation solving. The method they applied was to compare different solutions, and reflect on each solution, one at a time. The study found that students who compared and contrasted alternative solutions made greater gains in learning how to solve equations.

Scratch is a free graphical programming tool developed by MIT Media Lab. The tool targets children over 8 years old, and is used to create animations, stories, simulations and games. It can help students to express themselves and develop learning skills, creative thinking and the ability to cooperate. Scratch is easy to learn and can offer "opportunities to create increasingly complex projects over time" (Su, Huang, Yang, Ding, & Hsieh, 2015, p. 332). Mengxian (2010) conducted a study comparing Scratch with other tools, namely, Logo, Stagecast Creator, Game Maker, Alice 3-D and RPG. The level of difficulty of Scratch, which used bricks instead of complex commands and did not entail a steep learning curve, was assessed to be moderate. Several recent studies on computer-supported learning in mathematics have also used Scratch. Jianzhi (2011) analysed the impacts of Scratch on primary students' learning and motivation relating to Cartesian Coordinates. The researcher divided 68 fifth grade students into two groups: an experimental group and a control group. The two groups respectively underwent teaching with Scratch and traditional teaching. The study's findings suggested that the learning motivation and achievement of elementary students could be improved by using Scratch. Taylor, Harlow, and Forret (2010) found that Scratch could encourage students to study cooperatively and to use problem-solving processes such as goal setting and generating and testing of ideas when learning mathematics. Calder (2010) has demonstrated the application of mathematical concepts in areas such as geometry and measurement among students exposed to Scratch programming.

Thus, it is important to examine how GBCL impacts on students' learning how to solve equations. For this study, Scratch was chosen as the students' game-making tool.

With the development of educational informatization and game-based learning, the impact of information technology and digital games on students' learning has become a hot research at home and abroad, compared with the previous research. This study not only focuses on students' game making, more important is the combination of mathematics and difficult mathematics knowledge. The main features of this research are as follows:

(1) Students make games by themselves. This study allows students to do their own game in order to study how making game can influence difficulties learning to help make up for the lack of research on applying game-based learning to mathematics difficulties.
(2) Aiming at the mathematics difficult knowledge. This research aims at the mathematical difficult knowledge. It has certain reference significance to the teaching of difficult knowledge and students' Autonomous learning.

Method

This study had two aims: (1) to design and develop a curriculum for making equation-solving games using the Scratch software; and (2) to examine the impacts of the curriculum on seventh-grade students' attitudes towards learning mathematics with the assistance of technology and their equation-solving performance. To gather relevant information, a one-group, pretest-posttest quasi-experimental study design was adopted. The main problem addressed by this study was whether

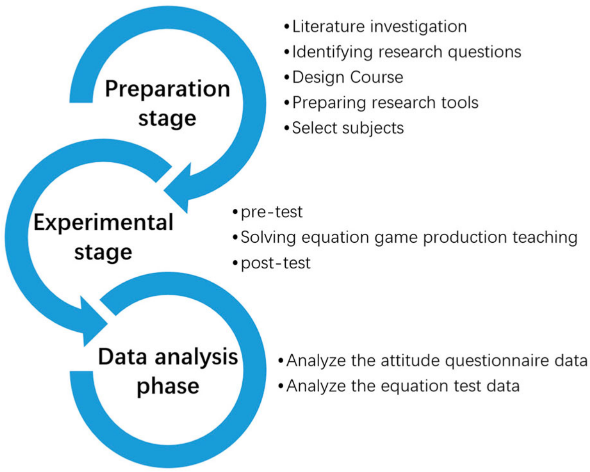

Figure 1. Research process of the pilot study.

games made by students themselves influenced their attitudes towards learning mathematics with the assistance of technology and their equation-solving performance. Figure 1 shows the research process of the pilot study.

The study also addressed the following sub-questions:

(1) Was there any significant improvement in the students' attitudes towards learning mathematics with the assistance of technology after they had made equation-solving games with Scratch?
(2) Was there any significant improvement in the students' equation-solving performance after they had made equation-solving games with Scratch?

Setting

The study site was a public school in the eastern section of Beijing, offering 9 years of compulsory education. The school had almost 130 teaching staff and more than 1,400 enrolled students distributed across 48 classes. The curriculum, which centred on making games to solve equations, was taught over a ten-week period during a weekly 45-minute session. Lessons were incorporated into participants' school-based courses and were held every Friday afternoon at the school's computer labs in which each student was assigned a computer with preinstalled Scratch software.

Participants

The participants in the study comprised 89 seventh grade students from three classes, one expert, one graduate student and one mathematics teacher. The sex composition of the student sample was 47 boys and 42 girls. None of the students had previously been exposed to Scratch-based games. The students in each class were randomly divided into groups of four or five individuals, with each group comprising both boys and girls. One student from each team was subsequently selected by his or her peers to be the group leader. The frequency distribution of the students is shown in Table 1.

The expert was an associate professor in the field of Chinese educational technology whose research focused on STEM (Science, Technology, Engineering, Mathematics) education, learning science and integration of information technology into educational curricula. The expert provided guidance and advice on the curriculum design and the formulation of the equation-solving test. In addition, the mathematics teacher assisted substantively in the test composition and provided inputs on the form of the

Table 1. Division of students according to class and sex.

Classes	Male		Female		Total	
	f	%	*f*	%	*f*	%
Class 1	14	15.7	9	10.1	23	25.8
Class 2	19	21.3	13	14.6	32	36.0
Class 3	14	15.7	20	22.5	34	38.2

f: number of students.

game. This individual taught mathematics to seventh grade students and had significant experience in teaching mathematics at the level of junior high school. The teacher's suggestion that students should be able to practice each step of the equation-solving procedure through the game design was adopted. The graduate student had majored in educational technology and had worked for 4 years as an elementary school mathematics teacher prior to becoming a graduate student. Her role was to design the curriculum, conduct the lessons and collect and analyse data.

The curriculum

The ten-class curriculum for making equation-solving games comprised three modules (see Table 2). The contents of each module are described below.

- Module 1: Basics of Scratch (four sessions). The objective of this module was to help students to acquire basic knowledge of Scratch, including mastering its core operations, learning how to programme with Scratch and using the Scratch board. At the end of the module, the students produced a Scratch game.
- Module 2: Design and implementation of mathematical operation games (two sessions). The objective of this module was to enable students to experience the form of a Scratch-based mathematical game by combining operational knowledge with the game developed during Module 1. This module's outcome was a Scratch-based game for conducting mathematical operations.
- Module 3: Design and implementation of equation-solving games (four sessions). The objective of this module was for students to design and implement equation-solving games themselves to practice solving equations. For this module, students produced equation-solving games. Instruction provided for Module 3 followed five steps: demonstration, imitation, design, implementation and display of their work.

At the outset, the teacher presented an example of an equation-solving game to the students. Consequently, students learnt the core code, using Scratch, for equation-solving games. They subsequently imitated the example to produce a game, thereby mastering the core code. Having

Table 2. The course outline.

Module	Lessons	Teaching content	Teaching objectives
Basics of Scratch	Lesson 1	Enter the Scratch world	To master the basic operations of the Scratch
	Lesson 2	A fun example featuring Michael Jackson	To gain familiarity with Scratch programming through a dancing animation
	Lesson 3	Big fish eat small fish	To acquire greater mastery of Scratch programming through a game
	Lesson 4	Pinball game	To learn how to use the Scratch board
Design and implementation of games for conducting mathematical operations	Lesson 5	A small fish that can calculate	To combine games and mathematical knowledge: operations
	Lesson 6	Plants versus Zombies	To combine games and mathematical knowledge: operations
Design and implementation of equation-solving games	Lesson 7	A paper-based design	To design games with pen and paper
	Lesson 8	Programming the game (1)	To use Scratch for programming the game
	Lesson 9	Programming the game (2)	To use Scratch for programming the game
	Lesson10	Presentation and sharing	To share works produced with classmates

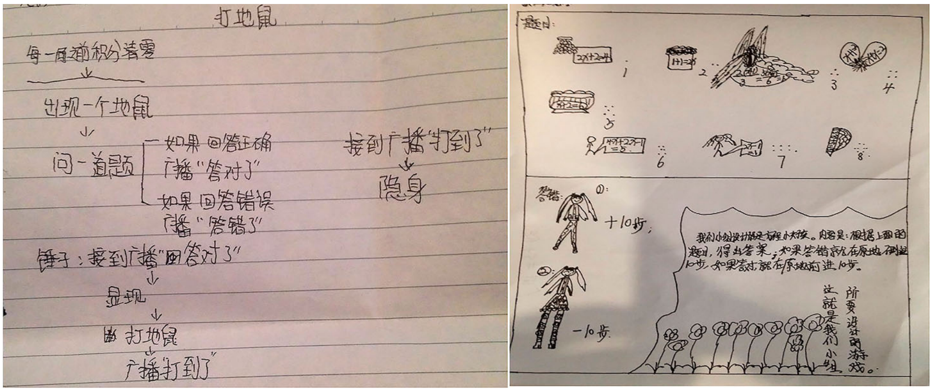

Figure 2. Paper prototypes of games created by students.

completed these first two steps, they entered the design phase. During this phase, students within each group brainstormed, negotiated and presented their game design ideas via drawings and design notes made with pens and paper. Each group completed a paper-based prototype of their game (see Figure 2).

Students within a group then worked together, using Scratch to programme their game design. Figure 3 illustrates a student's work as an example of how this was done. Following the initiation of the game, the first step asked for the solution to the equation. Providing that the answer was correct, the rocket would ascend a little higher and the next question would then be asked. Otherwise, the rocket would remain in the same position, and the first step would be repeated. The process would continue to be repeated until the problem was successfully solved, at which point the rocket would rise and connect with the apple. The game would then proceed to the next level. As the final step, students would submit their work to the teacher, and would present their products to their peers, playing each other's games and exchanging comments and critiques. Students would thus have an opportunity to practice solving equations during the last two steps.

Data collection and analysis

Data were collected through pre- and post-curriculum attitudinal surveys on technology-facilitated mathematical game creation, through a pre- and post-game-making test to assess equation solving, and through interviews conducted with individual students. Member checking was also

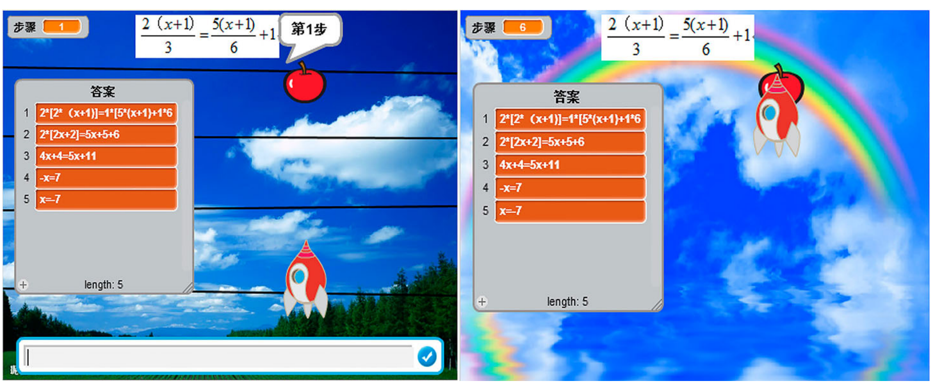

Figure 3. An example of a student's work.

Table 3. The questionnaire items modified in MTAS.

MTAS	Adapted MTAS
6. I am good at using things like VCRs, DVDs, MP3s and mobile phones.	6. I am good at using devices like MP3s, smart phones and tablets.
17. I like using graphics calculators for mathematics.	17. I like using computers for mathematics.
18. Using graphics calculators in mathematics is worth the extra effort.	18. Using computers when doing mathematics is worth the extra effort.
19. Mathematics is more interesting when using graphics calculators.	19. Learning mathematics is enjoyable.
20. Graphics calculators help me learn mathematics better.	20. Computers help me to learn mathematics better.

included in the data collection. The surveys entailed completion of a questionnaire, modified from the Mathematics and Technology Attitudes Scale (MTAS, Pierce, Stacey, & Barkatsas, 2007) (see Table 3) by all of the students before and after completing the 10-week curriculum. The MTAS is a 20-item scale used to monitor the attitudes of middle secondary school students' attitudes towards learning mathematics with the assistance of technology. It includes five subscales that measure the levels of students' mathematics confidence (MC), technology confidence (TC), attitude to learning mathematics with the assistance of technology (MT), affective engagement (AE) and behavioural engagement (BE) in learning mathematics. The scale's reliability was tested using the Cronbach Alpha coefficient, the value of which was calculated as 0.924. Based on this value, the scale appeared to be reasonably reliable. The equation-solving test was administered to all of the students before and after completing the four sessions of game creation for equation solving. The tests were jointly compiled by the researcher, the seventh-grade mathematics teacher and the expert. Alignment of the tests with the mathematics standards for seventh grade students was confirmed. The questions in the posttest and pretest evaluations differed, but were similar regarding the difficulty level. Four multi-step equations were included in each test (see Table 4). The maximum test score was 10 points, and the students were asked to complete the test within 10 min.

For the interview component, eight students in total were randomly selected and interviewed at the end of the course. The interviews focused on participants' perceptions about learning with Scratch as well as learning mathematics though game creation. The interviews included the following four main questions: (1) Do you think making a game can help you to improve your performance in mathematics/equation solving? Why or why not? (2) Do you think players who use your game can learn how to solve equations? Why or why not? (3) Do you feel a sense of accomplishment after successfully creating a mathematical game? (4) Would you like to use the game-making method to learn mathematics?

As part of the member checking process, after producing their own games, students randomly evaluated the games produced by their classmates and answered the following questions (1). Did you find any problems in the game you were evaluating? (2) What can you learn from the game? (3) Do you have any suggestions or ideas regarding the game?

Results

Attitudes towards technology-assisted learning of mathematics

A pairwise t-test was conducted based on an adapted MTAS at the beginning and end of curriculum implementation to compare the attitudes of participating students towards learning mathematics

Table 4. Sample test items.

$\frac{2(x+1)}{3} = \frac{5(x+1)}{6} + 1$	$3(1-2x) = 6 - 2(x+2)$

Table 5 . Pairwise *t*-test results for students' attitudes towards learning mathematics.

	M	SD	*t*	Sig. (2-tailed)
Pretest-posttest	−5.101	18.903	−2.546	.013

Subscales	Items	*M*	SD	*t*	Sig. (2-tailed)
BE pretest-posttest	I concentrate hard in mathematics. I try to answer the questions asked by the teacher. If I make mistakes, I keep working on them until I can correct them. If I can't solve a problem, I keep trying different solutions.	−.607	4.207	−1.361	.177
TC pretest-posttest	I am good at using computers. I am good at using devices like MP3s, smart phones and tablets. I can fix a lot of computer problems. I can master any computer programme at school.	−1.022	4.034	−2.391	.019
MC pretest-posttest	I have a mathematical mind. I can get good results in mathematics. I know I can handle difficulties in mathematics. I am confident in mathematics.	−1.393	5.682	−2.313	.023
AE pretest-posttest	I am interested in learning new things in mathematics. In mathematics, your efforts are rewarded. Learning mathematics is enjoyable. I get a sense of satisfaction when I solve mathematical problems.	−.798	4.498	−1.673	.098
MT pretest-posttest	I like using computers for mathematics. Using computers when doing mathematics is worth the extra effort. Mathematics is more interesting when computers are used. Computers help me to learn mathematics better.	−1.281	4.673	−2.586	.011

BE: behavioural engagement; TC: technology confidence; MC: mathematics confidence; AE: affective engagement; MT: attitude to learning mathematics with the assistance of technology.

with the assistance of technology (see Table 5). The *t*-test indicated a significant result, namely, t (89) = −2.546, $p < .05$. Participants reported significantly more positive than negative attitudes relating to technology confidence, mathematics confidence and the use of technology in learning mathematics. However, the differences between pretest and posttest results for these two aspects of engagement when learning mathematics were insignificant.

Mathematical equation-solving performance

A pairwise *t*-test was performed to assess the effects of game making on students' equation-solving accomplishment before and after their participation in game-making activities (see Table 6). The total valid sample comprised 77 students after excluding those who were absent during either the pretest or the posttest. The result, t (77) = −3.199, $p < .05$, showed a notable difference in the students' accomplishments, indicating that their scores were significantly higher after completing the curricular activities over a period of 4 weeks.

Interviewing

An analysis of the interviews revealed that most students agreed that making games with Scratch was positively associated with their attitudes to learning mathematics and could improve their

Table 6. Pairwise *t*-test result for students' equation-solving performance.

	M	SD	*t*	Sig. (2-tailed)
Pretest-posttest	−.714	1.959	−3.199	.002

equation-solving performance. The following quotes from interviews illustrate their perceptions of the relationship between making games with Scratch and learning mathematics.

> Making games can improve my equation learning, because I am clearer about each step for solving equations through the programming. (S4, 20151224)

> I'm not sure whether making games can help [one] to learn mathematics, but it should be able to increase interest in learning mathematics. (S6, 20151224)

> Scratch can help me to learn mathematics, because I have to use mathematical knowledge to make a mathematical game. (S7, 20151224)

> I feel more confident about mathematics after making a game, because I think if I can make a game, I can also learn mathematics well. (S8, 20151224)

> Scratch is interesting. When I encounter a problem, I like to ask my classmates for help, or discuss it with them to improve my performance in mathematics. (S10, 20151224)

Member checking

At the end of the course, students were asked to choose a game to evaluate. Their evaluations showed that they were able to practice solving equations by playing the games made by their peers. When asked the question "Did you find any problems in the game you were evaluating?" the students carefully checked the game and provided their comments on the game's design and equation-solving method (see Figure 4). The students were able to practice and improve their equation-solving abilities by correcting their peers' mistakes and learning from better solution methods.

General discussion and conclusion

The purpose of this study was to examine the impacts of Scratch-based games made by seventh grade students to solve equations, on their equation-solving performance and attitudes towards learning mathematics with the assistance of technology. Pairwise *t*-tests were conducted for data analysis. In addition, interviews and member checking were conducted to cross-validate the quantitative results.

The findings of the study indicated that computer-based educational game making, using Scratch, had a significant positive effect on the equation-solving performance of seventh grade students, and on their attitudes towards learning mathematics with the assistance of technology.

Findings from students' interviews and member checking supported the quantitative results. The students' perceptions were that game making could positively influence their equation-solving performance and attitudes towards learning mathematics with the assistance of technology for the

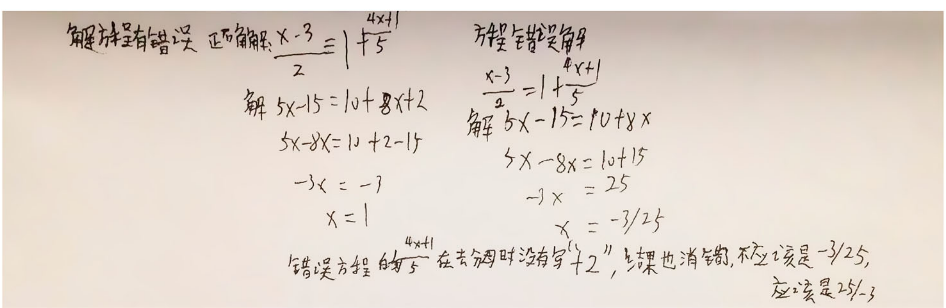

Figure 4. Examples of students' comments on the equation-solving methods of other students' games.

following reasons. First, they could learn mathematics through playing. Most students felt pressurized and bored during mathematics classes. However, learning through game creation promoted feelings of relaxation and curiosity. Second, they felt more self-confident after they had made a game. Making a game is not an easy accomplishment for students. Consequently, they felt proud and confident when they succeeded in making a complicated game and then shared it with their classmates. Third, they were very willing to share their games with classmates. By sharing their work, students could discover their own mistakes and learn effective or better solution methods from others. Fourth, to complete a game, students had to correctly solve the equations. They would only have their own completed work when they were able to correctly solve the equations. This prompted them to learn equations well.

The positive findings of this study support those of previous studies on the effects of mathematical games. For example, Ke (2014) has suggested that designing games can improve students' mathematical learning attitudes, while Kebritchi et al. (2010) have indicated that computer games can significantly influence students' achievements in mathematics. The students' interviews, conducted for this study, also demonstrated that students were more willing to ask for help from teachers and classmates, or to discuss problems with them. This suggests that students may cooperate better when programming games. This finding is consistent with that of Taylor et al. (2010).

The study indicated that students would be more willing to engage in learning when this involved designing games. Thus, teachers could attempt to incorporate game making into lessons when teaching difficult topics, especially during review classes. However, two important questions that they should consider are how to combine the objective of knowledge with game programming and how to balance the time spent by students with the gains they obtained.

Further research is needed to confirm and validate the results of the study. To further explore the effect of designing games on students' performances and motivation in mathematics, the following issues should be considered. First, it is important for similar studies to ensure that sufficient time is allocated for the game-design module. In this pilot study, some students failed to complete the design of a game because there were only four sessions assigned for that activity. Thus, students should have sufficient time for designing games because this would lead to more convincing findings when examining the results. Second, there is need to examine the impacts of game designing on the attitudes of high-level, medium-level and low-level students who ranked in the first 25%, middle 50% and last 25% respectively towards learning mathematics with the assistance of technology and equations performance, respectively. Third, the learning progress of low-level students should be observed and recorded to inform classroom practices. A study that addresses the question of how low-level students can benefit from the course would be worth conducting, and its findings would be valuable in enabling teachers to find ways to improve the students' performances. Fourth, it is preferable to form groups with specific tasks assigned to each student. In this pilot study, groups consisting of four students resulted in an uneven division of labour. For instance, one or two students within certain groups did most of the work, while the others had nothing to do. This would result in difficulties when attributing learning outcomes to individual effort. Fifth, in addition to basic multi-step equations, one or two more advanced questions can be included in the test to further assess the students' equation-solving performance. Follow-up studies can perform a comparative analysis of the test results based on the investigation of the basic and advanced test sections.

There were some limitations in the study. First, a retrospective analysis was not conducted, and conducting such a study would provide a holistic view on data interpretation. Retrospective analysis to compare pre-test and post-test data should be done to get a thorough understanding of the changes in students' learning attitudes and equation-solving abilities. Second, pragmatic concerns about subject bias should be handled carefully and avoided. In this study, since the instructor also was the researcher, it was inevitable that the shared roles might lead to subjective bias. For instance, when interviewing the students, the instructor could unconsciously guide students to have positive attitudes. To avoid biasing the interviewees, it is recommended that a research assistant who is not involved in the teaching activities be hired to interview the students.

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The researcher did not ask for the children's names and any reference to them. The authors can state explicitly that there was no conflict of interest in the work reported here. I would like to declare on behalf of my co-authors that the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part.

Disclosure statement

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