Embedding game-based problem-solving phase into problem-posing system for mathematics learning

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**Article info**

Article history:
Received 20 January 2011
Received in revised form 4 October 2011
Accepted 6 October 2011

Keywords:
Interactive learning environments
Elementary education
Teaching/learning strategies
Applications in subject areas

**Abstract**

A problem-posing system is developed with four phases including posing problem, planning, solving problem, and looking back, in which the “solving problem” phase is implemented by game-scenarios. The system supports elementary students in the process of problem-posing, allowing them to fully engage in mathematical activities. In total, 92 fifth graders from four different classes were recruited. The experimental group used the problem-posing system, whereas the control group followed the traditional paper-based approach. The study investigates the effects of the problem-posing system on students’ problem-posing ability, problem-solving ability, and flow experiences. The results revealed more flow experiences, and higher problem-solving and problem-posing abilities in the experimental group.

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1. Introduction

To help students actively engage in mathematical learning, numerous researchers have proposed incorporating problem-posing as a supplement to instructional activities. It has been found that problem-posing activities can enhance students’ thinking and create more learning opportunities for students at different levels (Baxter, 2005; Silver & Cai, 2005; Whitin, 2004). Tsubota (1987) noted that students who usually appear inactive in classes become surprisingly active during problem-posing activities and adopt a positive attitude toward the curriculum. The students also cross into other subject fields when generating problems. Tsubota believed that problem-posing is a cognitive and metacognitive strategy. Students required to focus on important concepts in the learning materials in the process of problem-posing improves their comprehension of the materials and allows them to monitor their understanding.

Numerous researchers have attempted to understand the relationship between problem-posing and problem-solving (Crespo, 2003; English, 1998; Kar, Özdemir, Ipek, & Albayrak, 2010; Keil, 1965; Leung & Silver, 1997; Nicolaou & Philippou, 2004; Silver & Cai, 1996). Keil (1965) delivered a problem-posing instruction to approximately 800 sixth graders. He found that for mathematical problem-solving ability, those in the experimental group, who generated problems on their own and then solved them, performed better than those in the control group, who only solved problems from the textbook. Silver and Cai (1996) investigated the relationship between problem-posing and problem-solving in a group of 509 middle school students. Problem-posing ability (scored according to the complexity of steps required to solve the problem) was compared to the students’ performances on solving eight open-ended questions. They found a highly positive correlation between problem-posing and problem-solving abilities. English (1997a, 1997b) also found a close relationship between the two abilities. This suggests that the inspiration for problem-posing could come from the process of problem-solving. Problem-posing not only trains students to identify the key elements in a question, but also enhances their problem-solving ability. Nicolaou and Philippou (2004) investigated the relationship between problem-posing and mathematical achievement, and found a strong correlation between the ability in problem-posing and general mathematical performance. Additionally, it was found that efficacy beliefs in problem-posing could predict mathematical achievement fairly well. Kar et al. (2010) also found a significant relationship between the problem-posing and problem-solving skills of prospective elementary mathematics teachers. Prospective teachers who posed two or more problems have higher levels of problem-solving than the prospective teachers who posed less than two problems. A parallel was established between the number

Leung (1993) adapted the four phases of problem-solving, introduced by Polya (1945), to the four phases of problem-posing: problem-posing, planning, problem-solving, and looking back. She found that the problem-posing activities helped students solve problems that they generated by themselves. When solving their own posed problems, they performed calculations and looked back at the process. They then revised their posed problems and generated new ones. Through the process of problem-posing, students could clarify and enhance their understanding of the concepts of the subject matter.

With the rapid advancements in information technology and the discovery of the boosting effect of problem-posing on problem-solving abilities and motivation in mathematical learning, researchers have attempted to develop web-based problem-posing systems by applying information technology (Barak & Raeli, 2004; Denny, Hamer, Luxton-Reilly, & Purchase, 2008; Fellenz, 2004; Hirai & Hazeyama, 2007; Wilson, 2004; Yu, 2011; Yu & Liu, 2009; Yu, Liu, & Chan, 2005). Most of them focused on problem-posing by using different media formats, and some included a peer-assessment function during students’ problem-posing activities (Yu, 2011; Yu & Liu, 2009; Yu et al., 2005). However, the same difficulties that are encountered in traditional problem-posing activities also occur in web-based problem-posing activities. Yu et al. (2005) investigated four web-based learning activities (problem-posing, peer-assessing, item-viewing, and drill-and-practice) in mathematics, natural science, and social science. They found that most students (69%) felt that problem-posing was the most difficult task of the four, especially in mathematics. Observations made during the study showed that lower-achieving students had an especially difficult time generating questions. The students begin to tire as the number of problem-posing exercises increased, which adversely affected the learning outcomes. Furthermore, because the students usually only solve questions posed by themselves, there is a lack of variation in problem types. As a result, students are not motivated to perform the activity, which makes it difficult to promote problem-posing during the instruction (English, 1998; Mestre, 2002). Because of the drawbacks of problem-posing, most researchers believe that problem-posing should be integrated with other activities to sustain students’ intrinsic motivation. For example, games could be added to the original problem-posing activities (Umetsu, Hirashima, & Takeuchi, 2002; Yu et al., 2005).

Computer games as educational tools have been suggested as an intrinsic motivational factor that encourages curiosity and allows learners to be in control of their own learning (Dickey, 2007; Huizenga, Admiraal, Akkerman, & ten Dam, 2009; Kumar, 2000; Papastergiou, 2009). Recent studies have shown that a game-based learning environment can facilitate cognitive performance such as geometric thinking (Chang, Sung, & Lin, 2007), multiplication (Chang, Sung, Chen, & Huang, 2008), and taxonomic concept development (Sung, Chang, & Lee, 2008). Several studies on computer gaming have examined learning engagement (Barah, Sadler, Heiselt, Hickey, & Zuiker, 2007; Gee, 2003, 2005; Huizenga et al., 2006; Ketelhut & Schiffer, 2011; Sanchez & Olivares, 2011; Squire, 2003; Squire & Jan, 2007; Squire & Jenkins, 2004), and numerous researchers have investigated whether game-based learning increases learning motivation (Burguillo, 2010; Charsky & Ressler, 2011; Huang, Huang, & Tschopp, 2010; Liu and Chu, 2010). Some researchers found game-based learning can bring a flow learning experience (Admiraal, Huizenga, & Akkerman, 2011; Liu, Cheng, & Huang, 2011). Several researchers also suggest that being in a state of flow could augment students’ motivation and learning process (Chen, Wigand, & Nilan, 1999; Keller, 2009).

Flow occurs when people fully engage in a task with personal satisfaction (Csikszentmihalyi & Csikszentmihalyi, 1988). Game users will immerse in a flow experience during game play because motivation and flow experience are positively related. If the game can produce flow, it enhances their motivation to play the game. Several studies have investigated what sort of design features would enhance learning engagement and motivation by measuring students’ flow experiences in a game-based learning context (Inal & Cagiltay, 2007; Kiili, 2005; Lim, Nonis, & Hedberg, 2006).

This study proposed a system with four problem-posing phases: posing problem, planning, solving problem, and looking back, in which the “solving problem” phase is implemented by game-scenarios to support students in the process of problem-posing, allowing them to fully engage in the problem-posing activities. The study also investigated the effect of the problem-posing system on students’ problem-posing ability, problem-solving ability, and flow experience by examining the processes of problem-posing system.

2. Problem-posing activities and system design

2.1. Problem-posing activities

The design of problem-posing activities in the study is based on the following two models: (1) that proposed by Polya (1945), which entails four phases of problem-solving (understand → plan → carry out → look back), and (2) the four phases of problem-posing that Leung (1993), adapted from Polya’s work (pose problems → plan → carry out → look back).

The problem-solving model of Polya shows that, when solving problems posed by others, the problem solver should understand the content of the problem before planning the solution. Four phases are implemented as a top-down process. However, if the problem solver is also the problem poser, he or she can immediately plan the solution and execute it (Leung, 1993). Finally, when looking back at the solving process, the student might be prompted to create new problems. Once again, this induces the cycle of the four phases of problem-posing: problem-posing, planning, carrying out, and looking back. Therefore, the phases of problem-posing and problem-solving are connected to form a continuous cycle (Leung, 1993), through which problem posers are able to reflect on whether the posed problems are appropriate. Since students either pose problems or solve those generated by others, they have to identify key points in the question, determine the solution, solve it, and reflect upon it. After sufficient practice, students will acquire the skills needed to solve similar problems, consequently increasing the processing speed in problem-solving. The procedures of problem-posing and problem-solving are closely tied to each other and foster students’ synthesis and induction abilities (Dillon, 1982).

2.2. System design

We implemented the system and developed its procedure based on Leung’s problem-posing model (1993), adapted from Polya. It has four steps: posing problem, planning, solving problem, and looking back (see Table 1).
Instructions are provided at each interface to help students understand the process of problem-posing. When they log into the system and enter the interface of the problem-posing activity, they encounter four further phases.

1. **Posing problems.** Students are asked to pose problems in a given range and type them into the system. They type in the content of their problems and the correct answers (see Fig. 1).

2. **Planning.** After students send out the posed problems, they proceed to the interface in which the posed problems are verified. All the posed problems are listed, and students can refine them as they wish. By clicking on the trial button, students can try out the questions they have created in the game-based setting. They obtain feedback from their teacher and judge whether the solution is reasonable. They can use the refine button to refine their posed problems (see Fig. 2).

3. **Solving problem.** In this phase, students solve the posed problems in the game-based setting. The posed problems and their detailed response options are shown on the left of the interface. The game field is displayed on the right of the interface, with response options embedded into it. The system contains six interactive games: Coby the Cat, Millionaire, Star Wars, Rescuing the Mice, Uncle Tu Climbing the Coconut Palm, and Racers.

For example, “Millionaire” (see Fig. 3) is a game with lifelines (contestants can obtain help in three ways if they need to) such as elimination, call in, call out. Based on Prensky’s elements of educational game design, the six games have three elements which include continuous game scenario, immediate feedback, and reward characteristics (Prensky, 2000) to pull students into a state of flow. Students try to win the game, and at the same time they revisit and review the learning material (Lepper, Iyenger, & Corpus, 2005). Then, students activate their prior knowledge and transfer knowledge from other venues (Oblinger, 2004). The game-scenarios in the “solving problem” step were designed for helping students achieve the state of flow, so we can thus investigate students’ flow experiences during game play.

### Table 1
Procedure of problem-posing.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Four phases of problem-solving according to Polya (1945)</th>
<th>Four phases of problem-posing adapted by Leung (1993) from Polya’s model</th>
<th>Procedure of the proposed problem-posing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Understand Plan</td>
<td>Pose problems Plan</td>
<td>Self-posed problems</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>1. Attempt to solve self-posed problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Obtain feedback from the teacher</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Judge whether the solution is reasonable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Refine problems</td>
</tr>
<tr>
<td>3</td>
<td>Carry out</td>
<td>Carry out</td>
<td>Solve posed problems in the game-based setting</td>
</tr>
<tr>
<td>4</td>
<td>Look back</td>
<td>Look back</td>
<td>1. More feedback from the teacher</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Get new ideas and be prompted to create new problems</td>
</tr>
</tbody>
</table>

Fig. 1. The first phase of problem-posing: posing problems.
4. **Looking back.** After students complete the phase of solving problem, they are taken to the feedback interface, which provides immediate information about their performance, such as the time spent, the number of correct answers, and the scores on the phase of solving problem. After the entire phase of solving problem is completed, students get feedback from their teacher. Finally, students return to the phase of posing problem and start generating a new problem.

3. **Method**

The purpose of the study is to understand the effect of the system on the problem-posing and problem-solving abilities and flow experiences of elementary students. The topic used for research was the addition and subtraction of fractions with different denominators, presented in the form of word problems. We designed the study to detect changes in the four dimensions of problem-posing (that is, accuracy, flexibility, elaboration, and originality), problem-solving (that is, equation-listing and calculation), and flow experiences between before and after treatments.

3.1. **Participants**

The study process involved four fifth grade classes from an elementary school in Taipei, with 92 participants consisting of 48 males and 44 females with an average age of 11 years old. The students were assigned to groups according to their classes. The two experimental classes used the problem-posing system while the two control classes took the traditional paper-based approach to the problem-posing.
activity. The experimental and control groups contained 45 and 47 students, respectively. Both the experimental and the control groups had the same teacher for the experiment.

3.2. Experimental design

For this research we implemented a quasi-experimental design. The independent variable was the group treatment (that is, the problem-posing system vs. the traditional paper-based instruction), and the dependent variables were the posttest scores for the four dimensions of problem-posing and on overall problem-solving ability. The experiment was conducted once a week for two weeks, with the activity divided into two sessions of 80 min. Before the experiment, both groups took the pretests for the problem-posing and problem-solving tests. Then, the experimental classes were given an additional 40 min to try out the system on their own. Next, as shown in Fig. 4, the experimental classes posed problems using the system for 20 min, and verified these self-posed problems for another 20 min. Students got feedback from their teacher and were given 10 min to refine their self-posed problems. They were then asked to put their revised posed problems into the system again. In the following 20 min, students were asked to solve posed problem in the game-based setting. Finally, students obtained feedback from the teacher and were given new ideas to create new problems for 10 min. The control classes were involved in the same problem-posing activity by using the traditional paper-based method as shown in Fig. 4. Students in control group first carried out the paper-based problem-posing activity for 20 min. Then, they were asked to verify their self-posed problems for 20 min and revise the questions for another 10 min. For the next 20 min they solved the posed problems using paper and pencil. Finally, they received feedback from the teacher, and over the next 10 min generated new questions. The Flow Experience Scale was given to both groups at the end of the experiment. After the two-week experiment was finished, each participant was given the posttest of problem-posing and problem-solving.

3.3. Instruments

The problem-posing system was implemented on a tablet PC, which allowed users to use handwriting input in the classroom.

3.3.1. Pre- and posttests for problem-posing

The study developed pre- and posttests for problem-posing to examine the changes in students’ problem-posing ability after the experiment. In the pre- and posttests, participants were asked to pose five free questions and five semi-structured questions (with given stem) for the addition and subtraction of fractions with different denominators. The posed problems were scored for accuracy, flexibility,
elaboration, and originality (Torrance, 1966). For each problem, the scores from all the dimensions were summed up to form the score for the overall problem-posing.

(1) Accuracy: If a problem was posed accurately and independently from any help, one point would be awarded. Yet, it would be considered as 0.

(2) Flexibility: It refers to the number of correctly posed problem types. For problem-posing, although the amount of posed problems matters, the variety of problem types is also encouraged since it is an important indication of creativity showing participants are not constrained in a certain model. For problem-posing, high flexibility refers to the ability of applying a variety of models. For example, problem A states, “Mike has two apples, and Helen has three apples. How many apples do they have in total?” Problem B states, “Mike has two apples, and Helen has three more apples than Mike. How many apples do they have in total?” Problem B contains two problem types, comparison and addition, while problem A only consists of addition. Hence, problem B is regarded to be more flexible.

(3) Elaboration: It denotes the solving steps of the posed problem. Problems which require one translation (i.e., representation), comparison or operation, would be given a point. Problems not awarded for accuracy would not be awarded for elaboration either. In the past, problem-posing was assessed according to the complexity of posed problems and required solving steps (Getzels & Jackson, 1962). The schema concept from cognitive psychology can be applied here for evaluating elaboration of posed problems—how many mathematical schemas are incorporated into a problem? For example, problem A states, “Mike has two apples, and Helen has three apples. How many apples do they have in total?” Problem B states, “Mike has two apples, and Helen has three more apples than Mike. How many apples do they have in total?” In the case of problem B, two problem types, comparison and addition, are incorporated, which two steps of calculation are needed. In contrast, problem A only involves addition requiring only one-step operation. Therefore, problem B can be deemed more elaborate.

(4) Originality: Another important characteristic of creativity is originality meaning that the posed problem types are different from others (Mayer, 1982). The scoring for originality was determined by the occurring percentage of problem types found in the pilot. If the occurring percentage of the posed problem type was in the range of 5% and above, one point would be given. For the ones in the range of 2–4.99%, and 2% and below, 2 and 3 points were awarded respectively. Problems not awarded for accuracy would not be awarded for originality either.

The initial draft of the test was reviewed by experts in mathematics education and four experienced elementary school teachers of grade five and six mathematics. The revised draft of the test was later pilot tested on 70 participants from an elementary school in Taipei. From these, 10 participants were randomly selected to analyze their problem-posing performance according to the four dimensions (accuracy, flexibility, elaboration, and originality). The scoring for problem-posing ability was performed by one of the researchers and an experienced elementary school teacher. The correlation coefficients were .69 for accuracy, .782 for flexibility, .782 for elaboration, and .835 for originality. There was thus a fair reliability in tests for problem-posing ability.

3.3.3. The Flow Experience Scale

In this study, the Flow Experience Scale was adapted from Hoffman and Novak method (2009). The scale was divided into three sections. The first section handled participants’ experiences of the problem-posing activity and computer usage. The second section assessed dimensions of the flow state and participants’ perceptions of the problem-posing activity, which included three factors: antecedents of flow, structural properties of flow, and the experience of flow. The third section handled the flow experience in the problem-posing activity.

Prior to the actual assessment, participants were required to read three descriptions of a flow experience. Then, the scale posed three questions about the flow experience during the problem-posing activity. These questions were: Did you experience the aforementioned description of a flow experience? What is the frequency of experiencing a flow? Did you feel that you were in a flow during the problem-posing activity?

The scale ranged from 1 to 5, where 1 represents strongly disagree and 5 represents strongly agree. Unanswered items were considered as missing data. The adapted scale of the flow experience was piloted with 198 sixth graders, with the obtained reliability coefficient of .791 indicating a moderate internal consistency.

4. Results

4.1. Analysis of problem-solving scores

Table 2 presents the mean and SD values of the pre- and posttests. One-way ANCOVA was used to examine the posttest scores when excluding the effect of the pretest (that is, covariance). Prior to the one-way ANCOVA, the test of homogeneity of within-class regression was conducted for overall problem-solving, equation-listing, and calculation scores, for which the F values were 10.04 (p = .002 < .05), 9.88 (p = .002 < .05), and 5.88 (p = .02 < .05), respectively. These significant differences indicated that the two within-class regression slopes were nonparallel and that the presumption of homogeneity of the within-class regression coefficient was not valid. Therefore, ANCOVA could not be used to analyze the differences in the scores of the posttest. Instead, the Johnson–Neyman method was implemented to examine the interaction effect of the instruction methods.
Figs. 5–7 show the regression intersection point and significant difference point for the posttest scores in overall problem-solving, equation-listing and calculation as derived by the Johnson–Neyman method and the regression lines of the two groups.

Examination of the interactions revealed that the posttest scores (maximum score = 24) for overall problem-solving did not differ between the two groups for pretest scores between 19.39 and 22.27. However, for pretest scores lower than 19.39, the posttest performance of the experimental group was better than that of the control group, indicating that students with pretest scores lower than 19.39 were more likely to improve in overall problem-solving after using the system.

The posttest scores for tests of equation-listing (maximum score = 12) did not significantly differ between the groups with pretest scores between 8.72 and 10.94, whereas the posttest performance of the experimental group was better than that of control group students with pretest scores lower than 8.72. This indicates that students with pretest scores lower than 8.72 were more likely to exhibit improved equation-listing after using the system.

The overall posttest score (maximum score = 12) revealed that when total pretest scores are lower than 10.56, the posttest performance of the experimental group was better than that of the control group. There was no difference between the two groups when pretest scores were between 10.56 and 11.87, indicating that students with pretest scores lower than 10.56 were more responsive to the experimental group.

For the scores of overall problem-solving, equation-listing and calculation from the posttest, the interaction and the points of significant differences of the within-class regression slopes situated on a 24-point, 12-point, and 12-point scale (with 24, 12,12 as the full mark) were examined using the Johnson–Neyman method. The two groups showed insignificant differences in their pretest scores (between 19.39 and 24, 10.56 and 12, 8.72 and 12). Therefore, neither the experimental group nor the control group appeared to be more effective in promoting overall problem-solving, equation-listing, and calculation. However, when the pretest score was lower than 19.39 (overall problem-solving score, see Fig. 5), 10.56 (equation-listing score, see Fig. 6), or 8.72 (calculation score, see Fig. 7) the experimental group was found to be more effective than the control group. In other words, students with lower pretest scores benefited more from the problem-posing system.

![Fig. 5](image_url) Regression lines of the experimental and control groups on the test scores for overall problem-solving.

<table>
<thead>
<tr>
<th>Test score groups</th>
<th>Equation-listing</th>
<th>Calculation</th>
<th>Overall problem-solving</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td><strong>Experimental group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest (n = 45)</td>
<td>10.16 (1.86)</td>
<td>8.11 (2.69)</td>
<td>18.27 (4.39)</td>
</tr>
<tr>
<td>Posttest (n = 45)</td>
<td>10.71 (1.63)</td>
<td>9.24 (2.35)</td>
<td>19.95 (3.70)</td>
</tr>
<tr>
<td><strong>Control group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest (n = 47)</td>
<td>9.97 (2.32)</td>
<td>7.83 (2.43)</td>
<td>17.77 (4.48)</td>
</tr>
<tr>
<td>Posttest (n = 47)</td>
<td>9.68 (2.42)</td>
<td>7.87 (2.89)</td>
<td>17.55 (5.11)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest (n = 92)</td>
<td>10.04 (2.10)</td>
<td>7.97 (2.55)</td>
<td>18.01 (4.42)</td>
</tr>
<tr>
<td>Posttest (n = 92)</td>
<td>10.18 (2.13)</td>
<td>8.54 (2.71)</td>
<td>18.73 (4.61)</td>
</tr>
</tbody>
</table>
4.2. Analysis of problem-posing scores

Table 3 presents the results of the pre- and posttests, including the sample size, the mean, and SD values of the scores in the control and experimental groups. One-way ANCOVA was used to examine the posttest scores when excluding the effect of the pretest (that is, covariance). First, the homogeneity of the regression coefficient of the posttest scores were conducted for the overall problem-posing.
The statistical results demonstrated that the outcomes of the aforementioned tests match the basic hypothesis of the homogeneity of the regression coefficient. ANCOVA was used to examine these data (see Table 4). The overall scores of problem-posing, accuracy, flexibility, elaboration, and originality were significantly higher in the experimental group than in the control group ($F = 17.69$ and $p < .01$ for the overall scores of problem-posing, $F = 24.49$ and $p < .01$ for accuracy, $F = 22.36$ and $p < .01$ for flexibility, $F = 10.42$ and $p < .01$ for elaboration, and $F = 11.39$ and $p < .01$ for originality).

4.3. Analysis of the Flow Experience Scale

Table 5 shows the results of the Flow Experience Scale, including the sample size, the mean, and SD values in the control and experimental groups. Independent $t$-tests indicated that the flow experience score was significantly higher in the experimental group than in the control group ($t = 5.39$, $df = 78$, $p = .00 < .001$).

5. Discussion and conclusions

This study involved the development and implementation of a problem-posing system and explored the effectiveness of the system on the development of problem-posing, problem-solving, and flow experience. Three conclusions were reached. Firstly, the overall scores of problem-posing, accuracy, flexibility, elaboration, and originality were significantly higher in the experimental group than in the control group. Secondly, the results of the Flow Experience Scale indicates that the score of flow experience was significantly higher in the experimental group than in the control groups. Finally, the problem-posing system was effective at promoting students with lower problem-solving scores.
For the four dimensions of the problem-posing ability and their scores in total, the study found that the experimental group performed significantly better than the control group. It can be inferred that compared with the traditional problem-posing activities, the scenarios in the system might provide students with more opportunities to reflect on their problem-posing techniques by examining posed problems. The features of the system allowed students to improve their problem-posing skills. Students in the experimental group repeatedly returned to the interface of solving problem to improve their scores. Once they did so, they had more opportunity to view more posed problems and solve them. Through system function, comments and feedback given by the teacher, the student can refine his or her problem-posing skill. Thus, students in experimental group performed better in the problem-posing posttest.

For example, a student from the experimental group posed the following problem in the pretest: “John has 2/3 of a pack of cookies. After giving his classmate 1/6 of the pack of cookies, how much is left for John?” For the posttest, the same student posed the following question: “Jenny has 1/4 of a box of chocolates, which is less than Mark who has 3/8 of the box. How much of a box of chocolates do they have altogether?” The examples show that the student progressed in terms of flexibility, from using one problem type to integrating two problem types. The elaboration dimension evolved from one-step to two steps, and the student also employed the keywords “less” and “altogether” to evoke problem-solving. The elaboration dimension evolved from one-step to two steps, and the student also employed the keywords “less” and “altogether” to evoke problem-solving. A problem solved by the student was: “Peter ate 4/9 of a cake. Leo had 2/5 more than Peter. How much of the cake did they have altogether?” From this question, it is evident that the students reflected on and adjusted problem-posing skills during the process of game-based problem-solving, and that these behaviors in turn influenced their problem-posing performance. This result is compatible with the study by Kamberman and Dori (2009), which found that stimulating students to pose problems enables them to be aware of their own cognitive processes and to self-regulate themselves with respect to the learning task.

The problem-posing activities played an important role in students’ understanding of mathematics concepts. To succeed in problem-posing activities, students must integrate their own experience and knowledge. When their knowledge was inadequate to accomplish the activity, they had to revisit the materials to add to information temporarily stored in their memories. In other words, the system encouraged students to focus again on materials they had already encountered, and apply strategies such as review, elaboration, organization, planning, and adjustment to further process information and make more connections with the mathematical concepts.

The results of the Flow Experience Scale indicate that the experimental group was in the higher state of flow than the control group. This result is in agreement with Barak and Rafaeli’s (2004) contention that the scores of the students in their final examination were higher in those who were highly motivated to engage in on-line problem-posing activities. Thus, during the state of flow, they would spend more time participating in the activities to accomplish a satisfying learning outcome (Ellington, Adinall, & Percival, 1982). In contrast with the experimental group, the traditional problem-posing instruction in the control group was constrained by the classroom environment. Participants became tired of the task as they continued to pose or solve more problems, which adversely affected their learning outcomes (Yu et al., 2005). Conversely, the experimental group was infused with challenges, which aroused and sustained students’ interest in the problem-posing activities. The result is consistent with the contention that computer games can induce a higher interest level in students, which in turn enables them to experience a higher level of flow (Inal & Cagiltay, 2007; Raybourn & Bos, 2005).

Finally, we found that the system was effective at promoting students with lower problem-solving scores (see Figs. 5–7). This is inconsistent with several results suggesting that problem-posing instruction can enhance the problem-solving ability (English, 1997a, 1997b; Skinner, 1991; Tsubota, 1987). This discrepancy might be caused by the ceiling effect for high performers in both groups (Berger, 1992). Therefore, despite the use of the system in both groups, the posttest scores of high performers from both groups were already close to the full mark, which resulted in insignificant differences in the posttest.

Conversely, there is a significant difference in the problem-solving posttest scores for the low performers from both groups. The motivation of the experimental group might be enhanced by the system so as to improve their problem-solving ability. Immediate feedback and reward characteristics from games (for example, the game scores and rankings) will encourage students to complete the problem-solving tasks. This is consistent with previous research pointing out that game-based activities could induce and sustain motivation in and reward characteristics from games (for example, the game scores and rankings) will encourage students to complete the problem-solving tasks. Through game-based activities, students must integrate their own experience and knowledge. When their knowledge was inadequate to accomplish the process of game-based problem-solving, and that these behaviors in turn influenced their problem-posing performance. This result is compatible with the study by Kamberman and Dori (2009), which found that stimulating students to pose problems enables them to be aware of their own cognitive processes and to self-regulate themselves with respect to the learning task.

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Being capable of correctly posing mathematical problems is important to the understanding of mathematical concepts. Enhancing learning engagement by organizing thoughts and posing new problems has positive effects on learners. The experimental results indicate that the system can improve the learning engagement (that is, flow experiences) of the fifth graders and their problem-posing ability in word problems dealing with the addition and subtraction of fractions with different denominators. The study has shown that problem-posing activities enhanced by technological tools can be beneficial to the learning process. This is consistent with Freitas and Jameson’s contention (2006) that technology can contribute to increase meaningful learning experiences and result in successful learning outcomes.

We propose several issues for future studies. First, scaffolding could have been beneficial to help students with lower prior knowledge to improve their problem-posing performance. Therefore, further research may design scaffolding for problem-posing processes and examine their effectiveness. Second, more game mechanisms to assist problem-posing could be included such as brain-storming, mind tools, and sentence puzzles. Finally, because gender difference was also an important factor in the prediction of performance on problem-posing and problem-solving, future research might investigate the influence of the implementation of the problem-posing system on gender differences.

Acknowledgements

This research project was supported by grants from the National Science Council, Taiwan, Republic of China (Contract No. NSC99-2511-S-003-026-MY3, NSC99-2631-S-003-001, NSC99-2631-S-003-003, NSC100-2631-S-003-007).

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