Exploring Learners' Problem-Solving Behaviors in an Educational Game for Computer Assembly Instruction: A Preliminary Study

Ming-Chaun LI[a*], Huei-Tse HOU[a], Yi-Syuan Wu[a], Hao CHEN[a] & Yi-Shiuan CHOU[b]
[a]*Graduate Institute of Applied Science and Technology, National Taiwan University of Science and Technology, Taiwan*
[b]*Graduate Institute of Digital Learning and Education, National Taiwan University of Science and Technology, Taiwan*
*mli1tw@gmail.com

Abstract: This is a pilot study aimed to explore students' problem-solving behaviors in a room escape adventure game for computer assembly instruction. The participants were 18 night school students at a university in Taiwan. Students' game playing actions were screen recorded, classified into different problem-solving codes, and descriptive analysis, difference analysis, and correlation analysis were then conducted. The results of this preliminary analysis showed that students performed more than half of their actions in exploring the game context. Male students were seemed to apply more trail-and-error behaviors than female students. Students who successfully achieved the game goal demonstrated more active behavior engagement than those who failed to complete the goal. It is suggested to conduct a future study to collect a larger sample and analyze students' behaviors using different method.

Keywords: Game-based learning, problem-solving behavior, adventure game, simulation game, computer assembly

1. Introduction

Problem-solving is one of the important 21st century skills. It has being emphasized by a lot of researchers and educators in their studies and curriculums. With the advancement of game technologies, digital games have been used to construct situated problem-solving environments and facilitate learning by many researchers [1-3, 5, 9, 11, 12]. Students were required to solve the game problems either individually or collaboratively. Some studies adopted multi-player virtual environment to provide a problem-based context that asked students to explore the virtual world and propose solutions or suggestions for the stated problem [2, 5]. Some studies utilized game technologies to provide a context where students were asked to achieve assigned game goals. Students could learn knowledge or concepts from the process of game playing [1, 3]. Games were also used as a place where students could learn by applying their knowledge to construct rail systems or future cities [11, 12]. These games were shown to promote students' knowledge learning, learning engagement, intrinsic motivation, and flow experience. However, although the games were designed to provide problem-solving experience for students, the analysis of this experience or process was only found in few studies. The studies that analyzed students' actual behaviors of problem-solving activities were even scarcer. In a study conducted by Liu, Cheng, and Huang [11], students who experienced different degrees of flow experience were found to perform different patterns of problem-solving strategies. More research will be needed to investigate students' problem-solving behaviors and explore their relationships with other gaming or learning outcomes.

In this study, a problem-solving-based adventure game was implemented to instruct computer assembling knowledge. With the prevalence of personal computers and the availability of various choices of computer hardware, it is beneficial if one can acquire basic knowledge of computer hardware and learn how to assemble a personal computer. People can assemble a computer according to their needs or replace a broken computer component when necessary. To be able to make good use of these knowledge and skills, one must spend sufficient time to review and practice them repeatedly. However, the opportunities of hands-on exercises provided in school are usually constrained by limited time and equipments. With little research focused on the development and implementation of technology tools to support the instruction of computer assembly, a problem-solving game was developed to assist the learning of this knowledge [8]. The implementation results of this game were analyzed and reported in this study.

As found in the literature, there is a lack of studies that explored students' behaviors in game playing. To better understand how students learn from solving the game problem, the purpose of this study was to conduct a preliminary analysis of students' problem-solving behaviors performed in the computer assembly game.

2. Methodology

Participants

Eighteen night school students at a private university in Taiwan participated in this study. The participants included 6 male and 12 female students aged from 19 to 36 (M = 23.33, SD = 3.82).

2.1 Game Description

A room escape adventure game, *Boom Room©*, was utilized in this study to investigate students' in-game problem-solving behaviors. This game was designed and developed by Hou and Chou [8] to promote students' knowledge of personal computer assembly. In this game, a situated problem-solving context was provided in combine with simulation manipulation and instant feedback guidance. Students could use different strategies to solve the problem that they encountered in the game and reflect on their actions based on the game feedback they received, as suggested by Kiili [9]. To win the game, students must collect computer components and assemble a desktop computer to disable a bomb and escape the room within 10 minutes. A preliminary evaluation of the game showed that it was well accepted to be useful for learning and was agreed to comprise expected game elements [8]. A screenshot of the game is shown in Figure 1.

2.2 Research Design and Procedure

A pilot case study was conducted to explore students' problem-solving behaviors during game playing. Each student was assigned to an account and corresponding password for logging into the game. Each account could only be used once. Before the students began to play *Boom Room©*, the researchers gave them a brief instruction of game operation. After the instruction, these students were asked to log into the game, fill out background information, and start the game. They would have to complete the game task (i.e., disable the bomb) within 10 minutes, otherwise they would fail. The game playing process of each student was recorded using screen recording software.

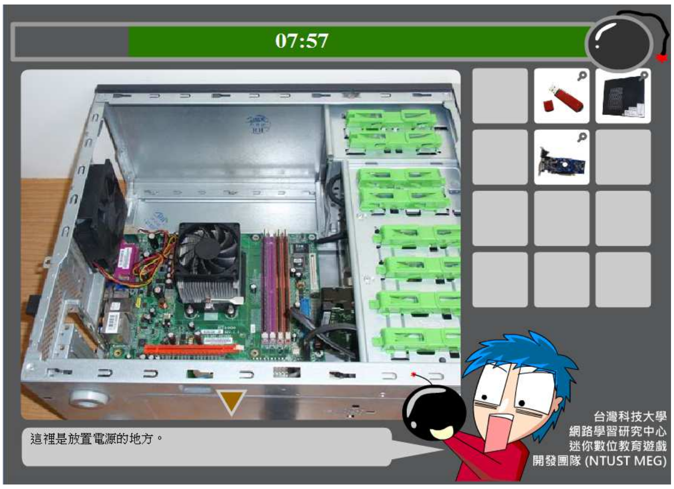

Figure 1. Screenshot of *Boom Room*© Manipulation of computer assembly simulation

2.3 Coding Scheme and Data Analysis

To investigate students' problem-solving behaviors, a coding scheme was developed. Based on a summary of problem-solving models integrated by Deek, Turoff, and McHugh [4] and the design of *Boom Room*©, three categories of problem-solving behaviors were identified including exploration, analysis, and implementation. Specific problem-solving operations under each category were defined and assigned with codes. The coding scheme is shown in Table 1 including the description and example behavior of each code.

The recorded students' game playing behaviors were coded using the above-mentioned coding scheme. Two researchers of this study performed the coding process. To ensure inter-rater reliability, one of the students' recorded data was randomly selected and coded as a pilot analysis. In the pilot analysis, these two researchers coded the student's gameplay actions once every 5 seconds. A total of 110 valid actions were coded. The Kappa reliability was 0.84, indicating almost perfect agreement [10]. Eighteen students' screen recording video files were then randomly assigned to these two researchers and coded separately. In this formal coding process, all actions were coded. Each action performed by a student was classified into a code according to the code descriptions. The results of the game playing (i.e., success or failed) were also included in the data. The coded data were further analyzed to illustrate the students' problem-solving behaviors in the game. The descriptive analysis, difference analysis, and correlation analysis were conducted respectively.

Table 1. Coding scheme of problem-solving behaviors in *Boom Room*©

Category	Code	Description	Example Behavior
Exploration	E1	Pick up target objects	• Click "display card" so that it is collected and shown in the items bar.
	E2	Click the scenes to observe game context	• Click closet, drawers, door, or bedside lamp etc. to explore the room.
	E3	Switch between scenes	• Click right or left arrows to switch to a different scene of the room.
Analysis	A1	Analyze objects using magnifier	• Click the magnifier tool of the "display card" item box to read larger image and detailed item information.

	A2	Browse collected objects by clicking objects in the items bar	• Click the "display card" in the items bar.
Implementation	I1	Assemble object correctly	• Click (choose) "display card" in the items bar and put it to the correct section in the computer case with correct assembling sequence.
	I2	Assemble object incorrectly	• Click (choose) "display card" in the items bar and put it to the wrong section in the computer case or in wrong assembling sequence.
	I3	Valid problem-solving actions other than computer assembling	• Click the power button to turn on the computer.

3. Results and Discussion

3.1 Descriptive Analysis

The frequency and the percentage of each problem-solving behavior are presented in Table 2. The percentages of the behaviors in regarding to exploration, analysis, and implementation were 64.91%, 13.22%, and 21.87%, successively. This indicates the design of the game could indeed promote students' exploration behaviors by engaging them in a problem-solving game context.

Table 2. Frequency and percentage of problem-solving behaviors (n = 18)

	Exploration			Analysis		Implementation			Total
	E1	E2	E3	A1	A2	I1	I2	I3	
Frequency	140	778	913	76	297	73	515	29	2821
Percentage	4.96	27.58	32.36	2.69	10.53	2.59	18.26	1.03	100

To achieve the game goal successfully, students would have to complete three sub-tasks in sequence. First, they need to find all computer components. Second, they have to complete the computer assembling task. Finally, they must figure out how to use the computer to disable the bomb. The data showed that only 5 (27.8%) of the 18 students successfully stopped the bomb before the time was running out. Among those students who failed to accomplish the final task, two of them finished the computer assembling but were unable to disable the bomb and the rest of them (n = 11) could not even completed the first sub-task. A further analysis showed that the majority of the students (n = 9) failed the computer assembling task because they could not find the last computer component (i.e., the power). Since the power is hidden in a corner that required more exploration of the scenes, it seems that this design might cause some problems that would impede students' problem-solving process. Due to the limited sample size in this pilot study, a larger sample will be needed in a future study to investigate this design issue.

3.2 Difference Analysis

Due to small sample size, nonparametric statistical analysis was carried out to compare students' problem-solving behaviors between male and female students and between students who succeeded and failed the game task.

3.2.1. Gender Differences

In this pilot study, the success rates were 50 % (3 out of 6) for the male students and 16.7% (2 out of 12) for the female students that implies a gender difference in playing the game. However, the results of Mann-Whitney test showed no significantly gender differences across all problem-solving behaviors. This finding suggests that the design of the game could promote problem-solving behavior of both genders.

To investigate possible gender differences in problem-solving behaviors, the effect size was calculated for each behavior to show the degree of substantive differences existed between male and female students. Because the sample size was small and unequal between genders, Hedge's $\hat{g}$ method that took the sample size into considerations was chosen to compute the effect size in this study [6]. The effect size of gender differences in each problem-solving behavior is reported in Table 3. The results indicate that male students practically performed more actions to observe the game context (E2), assemble object incorrectly (I2), and carry out valid problem solving steps (I3) than female students did. A relative large effect size found in I2 implies that the male students might be more likely than female students to adopt trail-and-error strategy to solve the problem. Although male students seemed to prefer to use trial-and-error strategy, this strategy did not effectively help them to perform more correct assembling behaviors (I1) than female students. This finding suggests that in addition to trial-and-error strategy, some other strategies might also be needed to accomplish the computer assembling task. Future analysis of a larger sample using additional analysis techniques (e.g., sequential analysis) will be helpful to illustrate the strategies used by male and female students.

3.2.2. Task Result Differences

Mann-Whitney test was adopted to compare the differences of problem-solving behaviors between task-success and task-failed students. The results showed that task-success students performed significantly more actions on picking up target objects (E1) ($U = 5.00$, $z = -3.00$, $p = .002$), correctly assembling the computer (I1) ($U = 5.00$, $z = -2.84$, $p = .004$), and processing valid problem-solving steps (I3) ($U = 0.00$, $z = -3.70$, $p = .000$) than task-failed students. However, the frequencies of these behaviors (E1, I1, and I3) were equal to the number of the objects picked up or the steps completed in the previously stated sub-tasks. Only when a student collected all objects (E1 = 9), completed computer assembling process (I1 = 7), and finished bomb disable process (I3 = 5), he or she could accomplish the game. Therefore, the significant differences found in these three behaviors were within expectations that needed no further discussion.

To further explore whether there were substantive differences existed in behaviors other than E1, I1, and I3, the effect size using Hedge's $\hat{g}$ method was also calculated. The results are presented in Table 4. A medium to large effect size found in E2 and I2 suggests that task-success students showed more active behavioral engagement than task-failed students because they clicked more to observe the game context and tried more errors when assembled the computer. This finding implies that active engagement might be a key factor for students to solve the game problem successfully. Further investigations are needed to better understand how different degrees or patterns of behavioral engagement might affect the outcomes of game play.

Table 3. Gender comparisons of problem-solving (PS) behaviors

PS Behavior	Gender	n	M	SD	Mean Diff.	Effect Size [a]
E1	Male	6	8.17	1.33	0.58	0.53
	Female	12	7.58	0.90		
E2	Male	6	50.33	19.52	10.67	0.80
	Female	12	39.67	7.88		
E3	Male	6	57.00	22.49	9.42	0.41

	Female	12	47.58	21.61		
A1	Male	6	3.33	3.27	-1.33	0.23
	Female	12	4.67	6.39		
A2	Male	6	22.17	15.20	8.50	0.48
	Female	12	13.67	17.68		
I1	Male	6	4.67	3.61	0.92	0.28
	Female	12	3.75	2.80		
I2	Male	6	70.00	84.08	62.08	1.20
	Female	12	7.92	18.40		
I3	Male	6	2.83	2.48	1.83	0.82
	Female	12	1.00	1.95		

[a] Absolute value of effect size ĝ

Table 4. Task result comparisons of problem-solving (PS) behaviors

PS Behavior	Students	n	M	SD	Mean Diff.	Effect Size [a]
E1	Success	5	9.00	0.00	1.69	2.18
	Failed	13	7.31	0.85		
E2	Success	5	50.40	8.85	9.94	0.73
	Failed	13	40.46	14.06		
E3	Success	5	51.20	5.45	0.66	0.03
	Failed	13	50.54	25.66		
A1	Success	5	2.60	3.29	-2.25	0.39
	Failed	13	4.85	6.11		
A2	Success	5	18.20	12.03	2.35	0.13
	Failed	13	15.85	18.89		
I1	Success	5	7.00	0.00	4.08	1.59
	Failed	13	2.92	2.81		
I2	Success	5	54.60	80.39	35.98	0.61
	Failed	13	18.62	44.69		
I3	Success	5	5.00	0.00	4.69	6.87
	Failed	13	0.31	0.75		

[a] Absolute value of effect size ĝ

3.3 Correlation Analysis

The Pearson correlation analysis was conducted to explore the relationships of these coded problem-solving behaviors. The results show that the number of target objects obtained (E1) was correlated with the number of clicking actions performed to observe the context (E2) ($r = .53$, $p < .05$) but not with the frequency of scenes switching (E3) ($r = .11$, $p > .05$). In addition, the more the students carried out the clicking actions (E2), the more behaviors they would perform on correct assembling (I1) ($r = .54$, $p < .05$), incorrect assembling (I2) ($r = .75$, $p < .001$), and valid bomb disabling (I3) ($r = .47$, $p < .05$). Again, no statistical significance was found between the relationships of scenes switching frequency (E3) and all three categories of the implementation behaviors (I1, I2, and I3). These findings suggest that when students actively explored the learning context (E2), they could perform better on their game tasks than when they barely browsed the scenes (E3). This implies that various game playing actions might lead to different degrees of behavioral engagement and therefore affect the process or results of game-based learning.

4. Conclusion

In this preliminary investigation, the problem-solving behaviors of the students were classified and analyzed. The results of the analysis not only provide important reference for the game evaluation, but also provide valuable insights for future studies on game-based learning. Educational games are usually evaluated using self-reported surveys or interviews. In this study, the game was examined based the actual behaviors acted by the students. the analysis results of the students' game playing behaviors were viewed as supporting evidence to demonstrate the affordance of *Boom Room©* to provide an effective problem-based gaming context for learning as suggested by Kiili [9]. The findings indicate that the design of the game would attract students to actively explore the problem and encourage them to solve it using different strategies other than just adopt trial-and-error method. On the other hand, the results of behavioral analysis could also help to identify some important design problems. For example, most of the students showed great difficulties in finding the last computer component. In addition, among three categories of problem-solving behaviors, the analysis was the least performed behavior and had no significant relationships with other behavior categories. These problems will have to be confirmed by collecting behavioral data from more students in future studies.

The comparisons of problem-solving behaviors between different genders and between two groups of students who got different task results showed no statistically significant differences. However, the effect size results suggested that some substantive differences did exist in specific problem-solving behaviors. It seems that male students performed more trial-and-error actions than female students. Moreover, the students who successfully accomplished the game task showed more active engagement behaviors than those who failed the tasks. To learn more about these differences and understand the effect of them on game playing, further analysis of the behaviors will be needed. As suggested by Hou [7], two behavioral analysis methods could be adopted: lag sequential analysis and cluster analysis. The former is used to explore the sequences of students' problem-solving behavior and the latter is use to identify and investigate the potential gamer groups. Moreover, as founded by Liu, Cheng, and Huang [11], students' problem solving patterns were associated with their flow experience. Therefore, it is also suggested to investigate the relationships between behavioral patterns and other factors such as students' gaming experience (e.g., flow) and learning outcomes to extend our knowledge of game-based learning.

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