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Embedding Collaboration into a Game with a Self-explanation Design for Science Learning

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Abstract: The purpose of this study was to examine the impacts of embedding collaboration into a game with a self-explanation design on supporting the acquisition of light and shadow concepts. The participants were 184 fourth graders who were randomly assigned to three conditions: a solitary mode of the game with self-explanation, a collaborative mode with self-explanation, or the control condition of a single-user game without integrated self-explanation. Students' conceptual understanding was measured through an immediate posttest and a retention test with a three-week delay. The findings showed that having students collaboratively or solitarily play science-based games embedded with a self-explanation design is not sufficient to help them learn science concepts. Rather, it was the level of engagement in responding to the self-explanation prompts that mattered.

Keywords: Game-based learning, self-explanation, science learning, multiplayer game

1. Introduction

The call to embed instructional principles into digital games (hereafter named games) for science learning has been receiving growing attention in recent years. If designed well, games can successfully help learners articulate and relate their understandings to more explicit structures (Clark & Martines-Garza, 2012). Researchers (Hsu, Tsai, & Liang, 2011) have suggested that pedagogy plays an essential role in determining the success of game-based learning. Among the pool of pedagogy, self-explanation is one of the effective approaches to stimulating the development of deeper understanding. Roy and Chi (2005) indicated that learning is enhanced when learners are engaged in or are prompted to generate explanations to themselves during an activity. Through the process of self-explaining, a linkage is built up between the newly learned materials and prior knowledge (Chi, De Leeuw, Chiu, & LaVancher, 1994). The results of previous studies have identified that integration of the self-explanation principle into a game environment can facilitate students' construction of science concepts. In Johnson and Mayer's (2010) study, they found that students who played a Circuit Game with self-explanation prompts outperformed than those who played the game without any prompts. In addition to self-explanation, collaboration in game play is also an ideal approach to not only allow students to help one another and assume responsibility for their success or failure (Zea, Sánchez, Gutiérrez, Cabrera, & Paderewski, 2009), but also to promote students' learning attitude and motivation (Sung & Huang, 2013), as well as engaging players in active participation. Meanwhile, Nelson (2007) pointed out that a collaborative game context enables players to form an understanding in partnership with peers, which can enhance their individual comprehension through guidance from the group.

An engaged player enthusiastically keeps playing and focuses on the game tasks over time, which is an essential part of the learning progress. The previous research (Hsu, Tsai, & Wang, 2012) has suggested that the level of engagement plays an essential role in the effectiveness of a game embedded with a self-explanation design. That is, while responding to the prompts, the players who showed high engagement outperformed those who had low engagement and those who were in control groups. Based on the findings, this study intended to integrate the collaboration approach into the self-explanation game design for enhancing the players' engagement and learning outcomes. An experiment has been conducted to evaluate the effectiveness of the proposed approach via investigating the following research questions:

1. What were the impacts of embedding collaboration into a game with a self-explanation design on supporting the acquisition of light and shadow concepts?
2. Did the participants' engagement in answering the self-explanation prompts influence their learning outcomes?

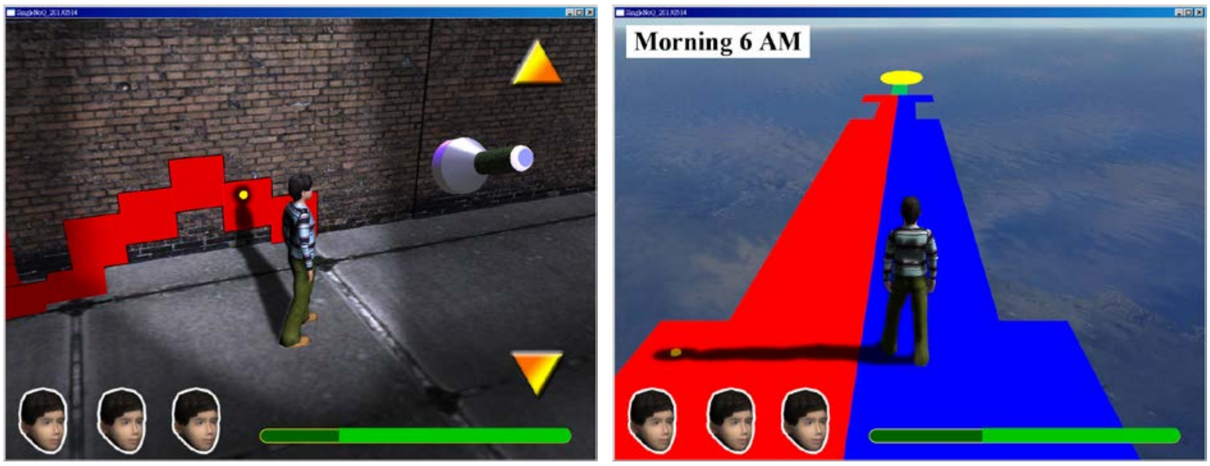
2. Methodology

Participants

The participants were 184 fourth graders (77 females and 107 males) recruited from an elementary school in southern Taiwan. They were randomly assigned into three groups: experimental group 1 (playing a single-user game embedded with self-explanation, hereafter named experimental 1), experimental group 2 (playing a multi-user game embedded with self-explanation, hereafter named experimental 2), and the control group (playing a single-user game without integrated self-explanation). There were 44, 96, and 44 participants in these groups, respectively.

Materials

Participants played "*Saving the Princess*," a game developed in this study to facilitate the fourth graders' acquisition of light and shadow concepts. The subject content was drawn from their textbooks and adhered to the national curriculum standards for science in Taiwan (Ministry of Education, 2008). The game consists of three stages, each of which delivers a core concept, for instance, the relationship between the height of a light source and the length of the shadow produced, shadow changes in a day, and shadow intensity. In the first stage, the game rules required that the player constantly adjust the height of a flashlight so as to control the length of the avatar's shadow within the restricted area (see Picture A in Figure 1). The game rules of the second stage need the player to either move around or pause in order to keep the avatar's shadow within the floor during the changing time (see Picture B in Figure 1). The last stage is similar to the second one, except for a more complex floor and adding changing weather. A time limitation of four and a half minutes was imposed on each of the three stages of the game. Every player has to pass through the three stages within 35 minutes. If they fail, they are directed to the posttest.



A. Screenshot of stage 1 B. Screenshot of stage 2

Figure 1. Screenshots of the game, *Saving the Princess*.

The game has three versions, a basic version for the control group, a self-explanation version for experimental 1, and a self-explanation with collaboration version for experimental 2. These versions share the same features, except that the self-explanation version of the game offers a multiple-choice question as a self-explanation prompt and the collaboration version allows two players to co-play in the game context. A self-explanation prompt appears whenever a mistake is made during game playing. The prompt includes three options, one of which accurately explains the cause of the failure. Take Stage 1 for example; the options are: 1) I adjusted the position of the flashlight too high; 2) I adjusted the position of the flashlight too low; and 3) I have no idea. The game does not continue until one of these options is selected. Students in a collaborative mode played the game with a peer. Neither of them knew who their partner was or where she or he was situated. When either one of the players made a mistake while playing, they both had to stop playing and respond to the prompt (see Figure 2). If one failed the prompt, his or her partner's screen would show the occurrence of the failure and required him or her to choose an option as a suggestion within one minute. Finally, the player who made a mistake would receive a suggestion from the partner.

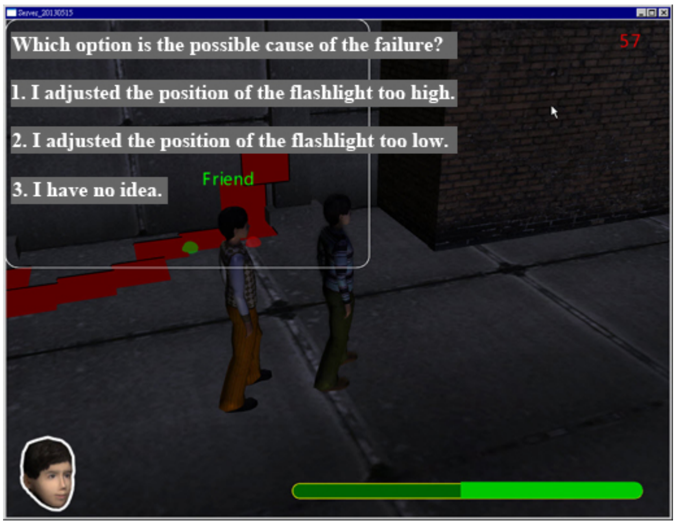


Figure 2. Screenshot of collaboratively responding to the prompt.

Measurement

The participants' learning outcomes were measured by a posttest and a retention test. The former was administered right after the treatment, while the latter was administered three weeks later. Both tests shared the same 10 multiple-choice questions that merely varied in the order of displaying the questions and options. The sample items include: "How does the shadow length change when the light keeps moving upward?" and "How does the shadow intensity change when fog appears?" Each question item of each test was counted as one point so that the maximum score was ten points.

Procedure and data analysis

Before the start of the game, the participants received a random assignment of three conditions (experimental 1, experimental 2, and control). The researchers helped those in experimental 2 build up an online connection with their partners, but they did not know who their partners were. Next, all the students received a brief introduction of the study and played *Saving the Princess*. During the game playing, they were told to remain silent and raise a hand if they had any questions. A posttest was given when the players had either completed the three stages of the game or after the required time of 35 minutes. No time limitation was imposed on taking the posttest or the retention test.

The participants selected for analysis were those who had played Stage 3 of the game during the treatment, which ensures that every player had experienced the core concepts the game was designed to instruct. Among a total of 184 students, 153 (61 females and 92 males) were chosen, of whom 40, 42, and 71 respectively were in experimental 1, experimental 2, and the control group. To examine the impacts of integrating self-explanation into a multi-user game on supporting the acquisition of light and shadow concepts, an analysis of variance (ANOVA) was used to compare the group differences in the posttest and retention tests. To examine whether the participants' engagement in answering the self-explanation prompts influenced their learning outcomes, an analysis of variance was used to compare the group differences in the posttest and retention test. The players' engagement was categorized into high and low. The high engagement group represents those whose correct responses are greater than the sum of their incorrect and unknown responses, whereas the low engagement group refers to those whose correct responses are fewer than their incorrect responses together with their unknown responses. That is, if one responded to 10 prompts with 3 correct, 5 incorrect, and 2 unknown responses, then that player would be classified into the low engagement group.

3. Results

Does the multi-user game embedded self-explanation affect learning outcomes?

The participants' scores of the posttest and 3-week retention test are displayed in Table 1. As shown, except for five students who failed to take the retention test, a total of 153 students who at least entered the third stage of the game were analyzed. The ANOVA results identified a statistically significant difference in the posttest scores ($F = 3.44$, $p < 0.05$). The post hoc test (Fisher's least significant difference, LSD) suggests that while playing the game embedded with the self-explanation design, the participants who played the single-player mode, rather than the collaborative mode, outperformed those of experimental 2 and the control group. However, after a delay of three weeks, no statistically significant difference was found by an ANOVA test. This finding implies that no difference in learning outcomes was identified when the students played the game with or without self-explanation as well as with or without peers.

Table 1: Comparisons of the posttest and retention scores within groups.

Test	Group	N	Mean	SD	F	Post hoc tests
Posttest	(1) Experimental 1 (Single)	42	7.95	1.75	3.44*	(1) > (2); (1) > (3)
	(2) Experimental 2 (Collaborative)	71	6.99	2.07		
	(3) Control	40	7.05	2.08		
Retention	(1) Experimental 1 (Single)	42	7.38	2.10	0.17	
	(2) Experimental 2 (Collaborative)	71	7.28	2.15		
	(3) Control	40	7.13	1.65		

Did the participants' engagement in answering the self-explanation prompts influence their learning outcomes?

As described in the data analysis section, each student's engagement in the experimental groups was categorized into either a high or low engagement group according to their responses to the prompts. A total of five groups were displayed, which are experimental 1 (high), experimental 1 (low), experimental 2 (high), experimental 2 (low), and the control group. Table 2 displays the results of ANOVAs with post hoc comparisons of students' posttest and retention test scores among these groups. As shown, a statistically significant difference was identified in the posttest ($F = 2.49$, $p < 0.05$). The post hoc comparisons indicate that students in the experimental 1 (high) group performed better than those in the experimental 2 (low) and control groups. That is, while playing the game embedded with self-explanation prompts, individual players who concentrated on answering the prompts tended to perform better on the immediate test than those who carelessly played with a peer or who were in the control group.

Furthermore, a statistically significant difference was found in the retention test ($F = 4.33$, $p < 0.01$). As shown in Table 2, both the experimental 1 (high) and experimental 2 (high) groups outperformed the experimental 1 (low), experimental 2 (low), and control groups. This finding reveals that those who engaged in answering the prompts as well as those who engaged in answering the prompts and helping their peers with the prompts were inclined to have better performance than those who did not or who were in the control group. Of particular note is the fact that when it comes to integrating collaboration into a game with a self-explanation design, the effectiveness may not become significant until after a period of time (e.g., a three-week delay in the present study).

Table 2: Comparisons of the posttest and retention scores within groups of different levels of engagement.

	Posttest			Retention test		
	N	Mean	SD	N	Mean	SD
(1) Experimental 1 (High)	16	8.50	1.10	16	8.38	1.46
(2) Experimental 1 (Low)	26	7.62	2.00	26	6.77	2.22
(3) Experimental 2 (High)	28	7.29	2.31	28	8.18	1.74
(4) Experimental 2 (Low)	43	6.79	1.90	43	6.70	2.21
(5) Control	40	7.05	2.08	40	7.13	1.65
F	2.49*			4.33**		
Post hoc	(1) > (4)*; (1) > (5)**			(1) > (2)*; (1) > (4)*; (1) > (5)**; (3) > (2)*; (3) > (4)**; (3) > (5)**		

4. Discussion

Researchers of game-based learning (Sung & Hwang, 2013; Shih, et al., 2010) have identified the positive impacts of playing games collaboratively on promoting the acquisition of science concepts. Thus, to enhance students' engagement in a game with a self-explanation design, this research attempted to seek the solution of collaboration and investigated its effects. The results revealed that while playing a game embedded with self-explanation, those in the collaborative mode did not outperform those who played in single-player mode (with or without self-explanation embedded). That is, adding collaboration into an educational game with self-explanation design does not necessarily result in better learning gains. This finding is resonant with van der Meij, Albers, and Leemkuil's research (2011) which suggested that collaboration in a strategy game, allowing students to practice the law of supply and demand by manipulating variables such as recruiting and stock, may not positively influence the students' learning outcomes. Similarly, researchers (Meluso, Zheng, Spires, & Lester, 2012) have also found no difference in learning performance between the collaborative and single player conditions on playing a game for science learning.

However, in this study we have found that the absence of an effect of collaboration could be attributed to a lack of engagement while answering the self-explanation prompts. After including this influential factor in the analysis, we found that the impacts of collaboration on the students' learning output became significant. That is, those who engaged themselves in answering the prompts as well as in helping their peers with the prompts tended to outperform those who were disengaged or who were in the control condition. Similarly, for those who played a solitary mode of the game with self-explanation, the highly-engaged performed better than the low-engaged and those in the control group. These findings suggest that having students collaboratively or solitarily play science-based games embedded with a self-explanation design is not sufficient to help them learn science concepts. The effects became significant and were retained longer only when the players were engaged in answering the prompts. In sum, the integration of self-explanation and collaboration strategies into game play can potentially support students' construction of science concepts. Future studies should pay more attention to promoting players' engagement in the self-explanation mechanics.

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