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Investigating 3rd Graders' Behavioral Patterns of Playing an Educational Game for Learning Light and Shadow

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Abstract: The purpose of this study was to investigate the students' game-playing behaviors and learning outcomes in terms of their different levels of prior knowledge. Based on the measurement of a pretest, 22 out of 44 third-graders were divided into high and low prior knowledge groups. They all played a game integrating the design of a self-explanation prompt. The log data of the game were analyzed by sequential analysis to visualize the game-playing patterns. The students' conceptual understanding was evaluated through a pretest and a posttest that occurred right after the treatment. The results indicate that although the design of the self-explanation prompts could engage the players in reflection on the causes of their failure during game-playing, it still had some limitations when it came to improving the students' learning outcomes. Possible suggestions are proposed for future studies.

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

1. Introduction

The traditional learning context has been criticized for not engaging students in learning activities. Many educational practitioners and researchers may consider game-based learning as a way to remedy this motivational problem and to further promote students' knowledge building [1] [2]. According to Prensky and Thiagarajan [3], games can provide a number of merits such as giving the players enjoyment, providing motivation and opportunities for doing, engaging the students' emotions, and promoting learning. However, games are not a panacea for all learning problems [4]. Some researchers indicated that reflection on the outcomes plays an important role in a player's game-playing. Without it, players may tend to simply try out certain actions until their outcomes improve (e.g., scores), which does not foster higher order thinking. Thus, to develop more effective educational games, it is necessary to integrate instructional strategies into game design, and self-explanation principles are one of them. Self-explanation is an instructional method in which learners are prompted to explain to themselves orally, in writing, or by a multiple choice question. The prior research [5] has indicated that the self-explaining process has a positive impact on learning and is a constructive process supporting the linkage between the newly learned materials and prior knowledge. In addition, many researchers [6] have pointed out that the prior knowledge the students bring to the class is a major factor enabling meaningful learning. Nonetheless, how the students' prior knowledge (PK) guides their playing of an educational game is rarely investigated. Thus, this study, implementing a game to facilitate third graders' acquisition of light and shadow concepts, intended to answer the following questions:

1. What was the role played by the students' different levels of prior knowledge in their game-playing behaviors?
2. What learning outcomes did students with different levels of prior knowledge have after playing the game?

2. Methodology

2.1 Participants

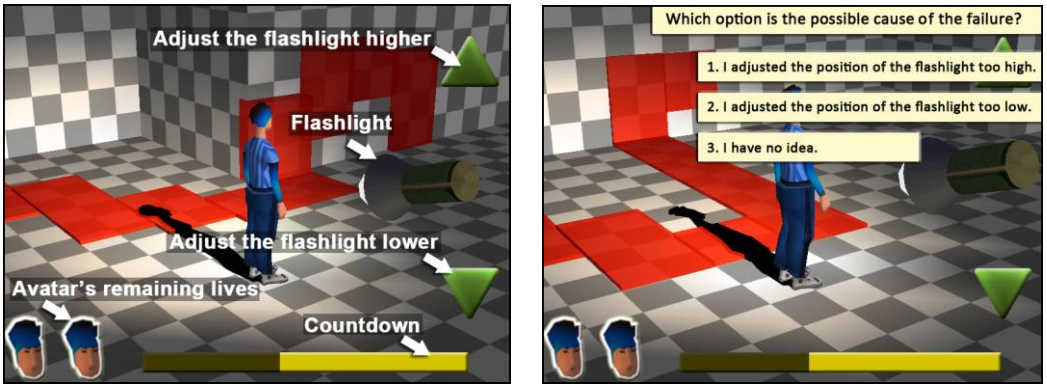
This study recruited 44 third graders from two elementary schools in northern Taiwan. The students whose pretest scores (described later) were within the top or bottom 25 percent were selected as the participants, totaling 22 students in all. Those with pretest scores within the top 25 percent were categorized into the high PK group (4 females and 7 males), while those with pretest scores within the bottom 25 percent were classified into the low PK group (5 females and 6 males).

2.2 Instrument

The instructional objective of the game implemented in this study was to help the participants learn the relationship between the height of a light source and the length of the shadow produced. The content was determined by individually interviewing 14 students out of the target population. The results showed that most of them seemed to have alternative conceptions of this concept. For example, they thought the higher a light source, the longer the shadow of a lighted object. The goal of the game requires the player to control the avatar toward a destination while adjusting the height of the flashlight to keep the shadow of the avatar's head within the red path (see Figure 1). As illustrated in the game interface of Figure 1, the player should click the arrow buttons so as to change the height of the flashlight. When failing to maintain the avatar's head shadow within the red path, the avatar's shadow would be sucked up and the game would produce a scream as a negative sign. Meanwhile, a self-explanation prompt appears to help the player reflect on the possible cause of the failure. As displayed in the Screenshot of the self-explanation prompt in Figure 1, the player needs to select one of three possible options, namely: 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. No feedback was given to inform the player whether their selection was right or wrong. Each player has three opportunities and can replay the game until he/she runs out of chances. Any button clicked and any option selected is recorded in the log file together with the time information.

2.3 Procedure

The experiment began with a brief introduction of the aims of the study delivered by one of the researchers. Each student individually used a computer in a computer class. Before playing the game, the students were required to take a pretest consisting of five multiple choice questions to probe their prior knowledge. Since the game-playing instructions had been embedded in the game, they were told to remain silent during the game playing and to raise their hands if they had any questions. After completing the game, each player took the



The game interface Screenshot of self-explanation prompt

Figure 1. Screenshots of the game context

posttest that shared the same test items with the pretest, except for a change in the question and option orders. No time limitation was imposed on playing the game or taking the tests. On average, each player took around 7 minutes to complete the game. All the user information (e.g. buttons clicked, time spent, and test responses) was recorded in a log for later analysis.

2.4 Data analysis

The participants' log data were analyzed through sequential analysis (Bakeman & Gottman, 1986) to visualize their game-playing process. To do so, the researchers first categorized the participants' game-playing behaviors and then developed a coding scheme in terms of these behaviors. In this study, the coding scheme consists of seven behaviors, as described in Table 1. According to the scheme, each player's log record was coded in chronological order. For instance, the sequence of I->SI->C represents that a player makes a wrong adjustment and then fails to offer an accurate response to the self-explanation prompt. After replaying the game, the player correctly adjusts the height of the flashlight. In sum, there are 22 sets of data and 2,245 nodes in total. The computation of adjusted residuals (z-scores) was conducted to identify sequences with statistically significant difference.

Table 1. A coding scheme of game-playing behaviors

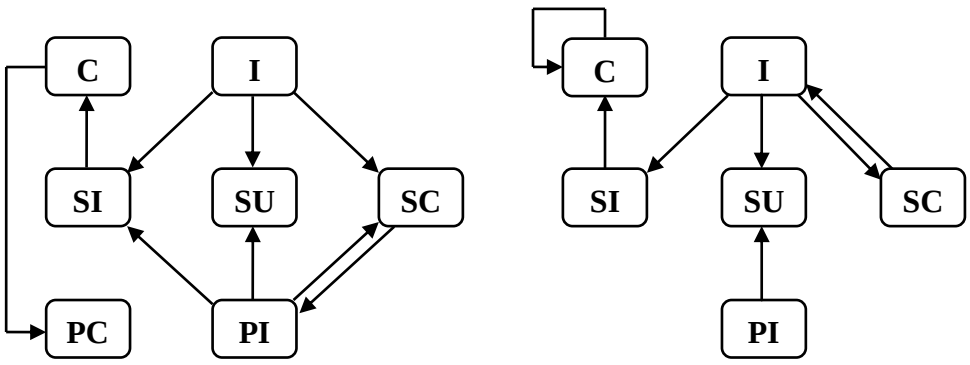
Code	Behaviors	Description
C	Make a correct adjustment.	A player adjusts the flashlight and maintains the avatar's head shadow within the red path.
I	Make an incorrect adjustment.	A player adjusts the flashlight and fails to maintain the avatar's head shadow within the red path.
PC	Pause and make a correct adjustment.	After pausing for more than three seconds, a player adjusts the flashlight and maintains the avatar's head shadow within the red path.
PI	Pause and make an incorrect adjustment.	After pausing for more than three seconds, a player adjusts the flashlight and fails to maintain the avatar's head shadow within the red path.
SC	Make a correct response to a self-explanation prompt.	A player accurately replies to a self-explanation prompt.
SI	Make an incorrect response to a self-explanation prompt.	A player inaccurately replies to a self-explanation prompt.
SU	Select the option, "I do not know", to a self-explanation prompt.	A player selects the option, "I do not know", to a self-explanation prompt.

3. Results

3.1 Investigating the game-playing behaviors in terms of different levels of prior knowledge

The results from the sequential analysis show that nine and seven sequences, respectively for the high and low PK groups, reached statistically significant difference ($p < 0.05$). To visualize the game-playing behaviors, these sequences are illustrated in Figure 2. As shown, students with high prior knowledge would pause to think a few seconds before manipulating the flashlight (C->PC). Their responses to the self-explanation prompt were inconsistent (i.e., I ->SI, I ->SU, and I ->SC; PI->SI, PI->SU, and PI->SC), which implies that responding to a self-explanation prompt is not simple. That is, the process requires a player to pay a certain degree of attention to reflecting on the causes of the failure. In addition, the sequence SI->C means that even though the students with high PK failed the self-explanation prompt, they could still adjust the flashlight accurately after replaying the game. The students might either learn from the trial-and-error process or pay less attention to the prompt so as to randomly select an option instead. Finally, the sequence SC->PI indicates that when correctly replying to the prompt, the students with high PK could fail to maintain the avatar's shadow within the red path, which means that they might encounter misconceptions of the targeted concepts.

The students with low PK tended not to pause to think while manipulating the flashlight (i.e., C->C). Like the students in the high PK group, their responses to the self-explanation prompt were also inconsistent (i.e., I->SI, I->SU, and I->SC). This finding means that they were inclined to engage in reflecting on the causes of the failure during the game playing. Furthermore, the sequence PI->SU indicates that when pausing a while and still making an incorrect adjustment, they tended to be aware of their misunderstanding and selected the option, "I do not know" in response to the prompt. Similarly, the low PK students might encounter misconceptions (i.e., SC->I) during the game playing.



High prior knowledge group Low prior knowledge group

Figure 2. Sequential patterns of high and low prior knowledge groups.

3.2 Investigating the learning outcomes in terms of different levels of prior knowledge

An independent t-test was conducted to examine whether there was any statistically significant difference in the posttest scores between the high and low PK groups. The results show that no statistically significant difference was identified ($t= 0.42$, $p>0.05$). Students with high PK did not outperform those with low PK. When looking further into the pretest and posttest scores, Table 2 reveals the results of paired t-tests regarding the high and low PK groups. As shown, a statistically significant difference was only found in the low PK group. This means that the posttest scores of the low PK group were higher than their pretest

scores, whereas the high PK group's scores did not show improvement. Further, the pretest scores of the high PK group were higher than their posttest scores, which may imply that the high PK students did not learn from playing the game.

Table 2: Paired t-tests for the scores of high and low prior knowledge groups

	Group	Mean difference	SD	*t*-value
Pretest – Posttest	High PK	0.73	1.62	1.49
	Low PK	-2.64	1.69	-5.18***

***$p < 0.001$.

4. Discussion

The primary intention of this paper was to utilize the sequential analysis method to explore how the behavioral patterns of the students with different levels of prior knowledge may differ while playing an educational game. The findings indicate that, first of all, during the game playing, the students with high PK tended to pause a while before adjusting the flashlight (i.e., C->PC), whereas those with low PK rarely did (i.e., C<->C). Since this study investigated the player's pauses during the game-playing, future studies should utilize qualitative approaches (e.g., thinking aloud) to examine what the players were thinking while pausing for more than three seconds. For instance, it might take more than five seconds for the players to really engage in thinking, rather than only three seconds. Second, the players' inconsistent responses to the prompts imply that the self-explanation prompt worked well in terms of engaging the players in reflection on the cause of their failure (i.e., I->SI, I->SU, and I->SC for both groups). It is likely that the students' engagement might influence their game-playing. Or, since the game did not offer any feedback when the players failed to select the accurate option for the prompt, it is also possible that the students from both groups needed to have several trials until they got it right. In addition, not offering any feedback to the prompt could be the reason why the High PK students' posttest scores were lower than their pretest scores. This can be seen in the sequence (i.e., SC->I, SC->PI) appearing in both groups, showing that the players still failed to maintain the avatar's shadow within the red path, even though they accurately answered the prompt. According to Kulhavy and Wager [7], feedback can be viewed as (1) a motivator or incentive for increasing the rate or accuracy of performance; (2) a satisfying state of affairs; or (3) information which learners could use to validate or change a previous response. It is therefore suggested that future researchers and designers should consider adding feedback (e.g. offer feedback when an incorrect option to a self-explanation prompt is selected) into the design of the game, as well as investigating the players' engagement.

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