Chang, M. et al. (Eds.) (2019). Proceedings of the 27th International Conference on Computers in Education. Taiwan: Asia-Pacific Society for Computers in Education

Probing Digital Game-Based Science Learning Experience through Eye-Tracking

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Abstract: This study aimed to investigate the role the students' prior knowledge in their visual attention and behavioral patterns while playing a digital game. The participants were 39 fourth graders from an elementary school in the southern part of Taiwan. The Tobii 4C Eye Tracker (with a sampling rate of 90Hz) was utilized to track the students' visual attention while they were playing the game. In addition, the lag sequential analyses were conducted to examine the visual transitional patterns of the participants with different levels of prior knowledge. The results of this study showed that students with the lower level of prior knowledge tended to put more mental effort on the trivial information of the game. In contrast, the participants with the higher level of prior knowledge were more likely to employ more effective gameplaying strategies (e.g., evaluation).

Keywords: Science learning, game-based learning, eye-tracking, prior knowledge

1. Introduction

Game-based science learning has been receiving a growing attention since the last decade. Many researchers suggested that learning science by playing digital games might not only effectively promote students' knowledge acquisition (Papastergiou, 2009), but also enhance their problem-solving skills. Particularly, although many scientific concepts are abstract, invisible, and difficult to grasp, they can be easily illustrated in the virtual world of the digital games (Cheng, She, & Annetta, 2015). In addition, previous studies indicated that students' prior knowledge played an essential role in playing games and could be used to predict their gameplaying performance (Lee & Chen, 2009). Although a large amount of studies have been conducted to examine the effectiveness of game-based learning, little has been known about how players process visual information and make decision while playing games. Therefore, this study aimed to explore whether students with different levels of prior knowledge have different patterns of visual attention while playing a digital game.

2. Methodology

2.1 Participants

The participants were 39 fourth graders (18 girls and 21 boys) in this study. They were categorized into two groups based on their pretest scores. The participants whose scores were on the top 40% were assigned into the high prior knowledge group (H-PK), whereas those whose scores were on the bottom 40% were assigned into the low prior knowledge group (L-PK). As a result, there were 18 participants in the H-PK (5 girls and 13 boys) and 15 participants in the L-PK (10 girls and 5 boys).

2.2 Materials and Apparatus

A game, "Saving the princess", was used in the present study. The learning objective of the game was to understand the relationship between the height of a light source and the length of a shadow produced by the light source. In this game, players should control the location of the shadow of the avatar's head to keep it within a zigzag path by changing the height of the light source. If players failed to maintain the avatar's shadow within the zigzag path, the game would stop immediately. In addition, if the players failed three times, the game would be over. Moreover, a self-explanation prompt would appear each time the player failed. The prompt was designed to help players reflect on the cause of their failure.
The Tobii 4C Eye Tracker (with a sampling rate of 90Hz) was utilized to track the students' visual attention while they were playing the game. In addition, we developed a fixation identification program (Hsu, Tsai, & Chiou, 2016) for identifying fixations and calculating a series of eye-movement indices.

In addition, we developed a pre-test and a post-test to assess the participants' understanding of basic optics. Both tests included 10 multiple-choice questions and were carefully examined and validated by two science educators.

2.3 Procedure

Before playing the game, each participant took the pretest and then went through an eye-tracking calibration. Afterward, each participant started to play the game, and the Tobii 4C was used to record her/his eye movements throughout the gameplaying. The participants were requested to use a chin holder during the gameplaying to ensure the stability of the eye movement data. When the participant passed the game or had played the game for 10 minutes, the game would be automatically terminated and the Tobii 4C would stop recoding. After the gameplaying, the participants took the posttest.

2.4 Data analysis

To analyze the eye-tracking data, we defined a total of 15 areas of interest (AOIs) as shown in Figure 1 and 2. The detailed description of each AOI was shown in Table 1. For each AOI, a set of eye-movement indices were computed to determine each participant's visual attention distribution, including Total time spent in zone, Total fixation duration in zone, Total fixation count in zone, Percentage of time spent in zone, Percentage of Fixation Duration in Zone, and Percentage of Fixation Count in Zone. Moreover, we conducted a series of independent *t* tests to examine the difference between the H-PK and L-PK groups in previous eye-movement indices. In addition, the lag sequential analyses (LSA, Bakeman & Gottman, 1997; Tsai et al., 2016) were conducted to establish the visual transitional patterns of the two groups.

Table 1
Description of the AOIs.

AOI	Description
Up_Arrow	Representing the control button whose function was to lift up the flashlight
Down_Arrow	Representing the control button whose function was to lower down the flashlight
Light	Representing the flashlight in the game
Shadow	Representing the region of the avatar's shadow
Path_shadow	Representing the region of the avatar's current head shadow
Path_passed	Representing the region where the avatar's head shadow had passed
Path_next	Representing the region ahead of the avatar's head shadow
Live	Representing the remaining lives of the avatar
Countdown	Representing the remaining time of the game
Avatar	Representing the avatar that the player manipulated in the game environment
Red_point	Representing the region that the avatar's head shadow transcended the red path
Question	Representing the region of the self-explain prompt
Answer	Representing the region of the participants' responses to the self-explain prompt
Out	Representing the area outside of the previous 13 AOIs

Figure 1. The AOIs in the game

3. Results

3.1 The differences in the eye-movement indices between the two groups

Table 1 shows the results of independent t tests that were conducted to examine the differences in the eye-movement indices between the H-PK and the L-PK groups. As shown in Table 1, some significant differences could be identified in the Light AOI, including the *Total time spent in zone* ($t = 2.78$, $p < .05$), *Total fixation duration in zone* ($t = 2.47$, $p < .05$), and *Total fixation count in zone* ($t = 2.30$, $p < .05$). In other words, in the Light AOI, the L-PK group tended to have higher TTS ($M = .46$, $SD = .52$), TFD ($M = .34$, $SD = .44$), and TFC ($M = .87$, $SD = 1.13$). In addition, some significant differences were found in the Path_shadow AOI, including the *Percentage of time spent in zone* ($t = 2.66$, $p < .05$), *Percentage of fixation duration in zone* ($t = 2.88$, $p < .01$), and *Percentage of fixation count in zone* ($t = 3.19$, $p < .01$). In the Path_shadow AOI, the L-PKgroup were more likely to have higher PTS ($M = 35.25$, $SD = 10.55$), PFD ($M = 49.16$, $SD = 11.26$), and PFC ($M = 43.87$, $SD = 9.36$).

Table 1

Results of the t-tests that examined the differences in the eye-movements between the two groups

AOI	Indices	H-PK	L-PK	*t*
		Mean(*SD*)	*Mean*(*SD*)	
Light	Total time spent in zone (TTS)	.08(.16)	.46(.52)	2.78*
	Total fixation duration in zone (TFD)	.05(.12)	.34(.44)	2.47*
	Total fixation count in zone (TFC)	.17(.38)	.87(1.13)	2.30*
Path_shadow	Percentage of time spent in zone (PTS)	25.52(10.40)	35.25(10.55)	2.66*
	Percentage of fixation duration in zone (PFD)	37.50(11.81)	49.16(11.26)	2.88**
	Percentage of fixation count in zone (PFC)	33.03(10.00)	43.87(9.36)	3.19**

Note: * $p < .05$; ** $p < .01$

3.2 Patterns of the visual transitions of the two groups

We conducted lag sequential analyses to examine the significant visual transitions among the AOIs of the H-PK and L-PK groups. The significant visual transitions were illustrated in Figure 2. Both groups would look up the red point when they failed to keep the avatar's head shadow within the path (Red point→Answer). However, the major differences were, first, the L-PK group were likely to focus on the trivial information (Light →Avatar, Avatar→Light). Second, instead of focusing on the path the avatar's head shadow located, the H-PK group would further evaluate the path in the front (See Path_shadow→ Path_shadow, Path_next→Path_shadow in Figure 2).

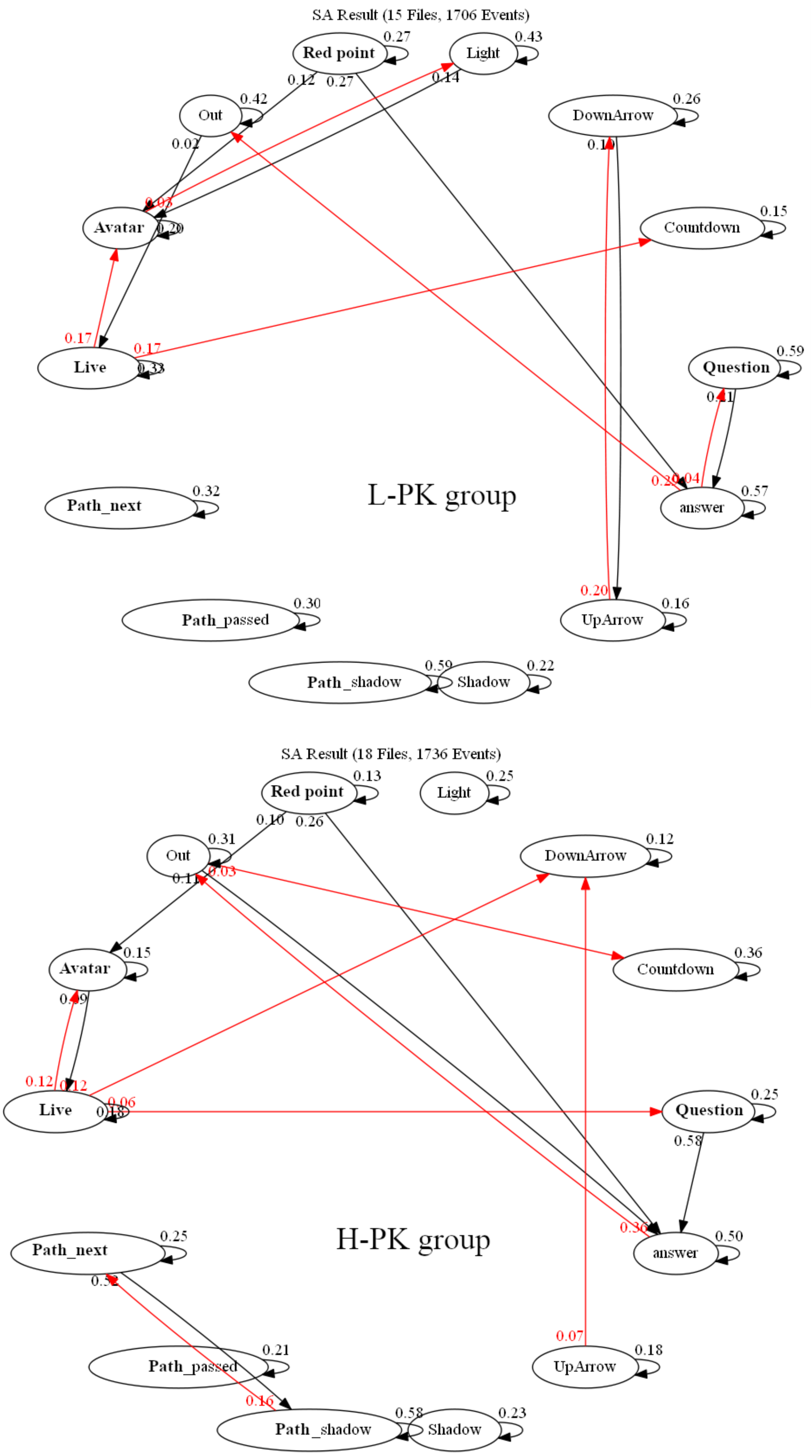

Figure 2. Significant visual transitions of the H-PK group and the L-PK group

4. Discussion

This study aimed to investigate the role the students' prior knowledge in the distributions of their visual attention and visual patterns while playing a digital game. The findings showed that the L-PK group tended to put more mental effort on the Light AOI than the H-PK group. This difference in visual attention might be explained by the difference in the levels of prior knowledge of the two groups. In other words, without insufficient prior knowledge, the L-PK group might need to look at the position of the flashlight to learn the relationship between the height of a flashlight and the length of the shadow. In addition, given that paying attention to the Path_shadow AOI was the most essential key to succeed in the game, the H-PK group could not only appropriately allocate their visual attention to this AOI, but also move from the Path_shadow to the Path_next AOI. The visual transition from the Path_shadow to the Paht_next AOI might denote an effective strategy to pass the game. That is, the players needed to check back and for the current and the future locations of the avatar's head shadow in order to immediately adjust the height of the flashlight for successfully passing the game. In sum, the results of this study agree with previous findings that students' levels of prior knowledge played an essential role in game-based learning. Moreover, through eye-movement analyses, we provide fresh evidence to account for how prior knowledge affected gameplaying behaviors in terms of visual attention and visual transitions.

Acknowledgements

This work was supported by the Ministry of Science and Technology, Taiwan, under grant contract numbers 105-2628-S-003 -004 -MY3, 106-2628-S-020 -001-MY3 and 106-2511-S-003-064 -MY3.

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