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Patterns of Simulation-based Physics Learning: An eye-movement Analysis

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Abstract: The purpose of this study was to investigate the scan patterns of simulation-based physics learning performed by learners' with different knowledge backgrounds. The eye-tracking technique was used to record ten graduate students' visual attention while learning with two physics simulations, and sequential analyses were conducted to construct their scan patterns. The participants were divided into either the better or the less prior knowledge group according to their pretest scores. The results showed that, the participants with better prior knowledge tended to make more visual transitions between texts and graphics, to explore more connections among the resulting images and other graphics, and to take more advantage of the interactivity of the simulations.

Keywords: Computer simulations, Eye-tracking, Physics learning

1. Introduction

Although computer simulations are claimed to offer enormous potential for overcoming the difficulties in learning abstract physics concepts and theories, how they can be used to support physics learning remains a contentious issue. Researchers have proposed many factors that may influence the effectiveness of physics simulations (e.g., Chang, Chen, Lin & Sung, 2012; de Jone & van Jooligen, 1998), and one key factor can be concluded as the differences in learners' knowledge and experience of physics learning. According to constructivism (von Glasersfeld, 1989), learners with different prior experience and knowledge have different starting points for learning physics, and may prefer different approaches to learning physics and conducting physics inquiry. We therefore argue that, students with different knowledge backgrounds may utilize different strategies for simulation-based physics learning, and it is more informative to investigate how students learn with physics simulations than to merely evaluate their learning outcomes.

Accordingly, this study aimed to explore the patterns of simulation-based physics learning between learners with different knowledge backgrounds. Owing to the development of eye-tracking technologies and statistical techniques in sequential analysis, it is now promising to study learners' scan patterns of simulation-based learning. One the one hand, an eye-tracking machine can simultaneously trace and recode the fixations and sequences of learners' visual attention while conducting physics simulations, and the obtained information can be used to infer the corresponding cognitive processes (please refer to Just & Carpenter (1980) for the *eye-mind assumption*). On the other hand, the technique in sequential analysis (Bakeman & Gottman, 1997; Tsai, et al., 2012) offers a method for constructing patterns of individuals' scan paths while learning with simulations.

2. Methodology

2.1 Participants

The participants in this study were ten graduate students recruited from a graduate-level course in research method. They were assumed to have different experience of learning physics because of their educational backgrounds; while four of them had a bachelor's degree in science, the other six had a bachelor's degree in art and social science.

2.2 Materials and measurement

Two computer simulations of pinhole physics were used as the learning materials in this study. The main difference between these two simulations lay in the level of interactivity. One of them was a non-interactive simulation that used shooting lines to represent light rays (starting from an object, through a pinhole, and then forming an image on a screen) for demonstrating how a pinhole camera works. In contrast, the other was an interactive simulation containing a movable cardboard with a pinhole that the participants could draw back and forth to change the sizes of the resulting pinhole images. Both simulations were accompanied by text that described the characteristics of pinhole images and explained how the resulting images were formed. However, it is worth noting that the two simulations were not presented in a fixed sequence. The participants could start with either simulation and then freely switch between them by clicking an icon within the simulation program.

In addition, this study used a paper-and-pencil test to measure the participants' understanding of pinhole physics. The test contained one problem that provided an object and a pinhole camera, and asked the participants to draw its resulting pinhole image. The test score was graded based on the correctness of the shape, size and orientation of the resulting images that the participants drew.

2.3 Apparatus

This study used FaceLAB 4.5 (with a sampling rate of 60 Hz) as the eye-tracking system to track the participants' visual attention while conducting the simulations. Also, GazeTracker 8.0, MATLab programming and SPSS 22.0 software were utilized to store or analyze the eye movement data.

2.4 Data collection and analysis

Each participant underwent a two-stage procedure for data collection in this study. First, each participant took the pretest individually by drawing their construed pinhole images of the given question. Then, after an eye-tracking calibration, each participant started to play the simulations individually with a ten-minute limitation. The participants' eye movements were tracked and recorded by the FaceLAB 4.5 and GaceTracker 8 throughout the learning process.

Based on the relevance to the understanding of pinhole physics, ten areas of interest (AOI) were designated within the two simulations for eye-movement analyses. For each AOI, we calculated the total reading time, total fixation duration and the total regression number (please refer to Lai, et al. (2013) for the definitions of these eye-tracking indicators). In addition, the sequence of each participant's visual attention transitions between any two AOIs was also coded for conducting further sequential analysis (Bakeman & Gottman, 1997) to find out the scan patterns.

Moreover, this study used the following procedure to examine whether the participants' prior knowledge correlated with their scan patterns. First, the participants were divided into two groups according to their pretest scores. Four participants who obtained the full score were assigned to the better prior knowledge (BPK) group, while the other six who scored zero were assigned to the less prior knowledge (LPK) group. Then, for each AOI, a series of Mann–Whitney U tests were conducted to examine the differences between the BPK and LPK groups in terms of the three eye-movement indicators mentioned above. In addition, both groups' scan patterns of simulation-based physics learning were constructed and compared according to the results of sequential analyses.

3. Results

For each AOI, the eye-tracking measures were calculated in terms of the total reading time, the total fixation duration, and the total regression number. The results of a series of Mann–Whitney U tests reveal no significant difference between the BPK and the LPK groups in any of the eye-tracking measure for each AOI.

The technique of sequential analysis (Bakeman & Gottman, 1997) was utilized to find out both the BPK and LPK groups' scan patterns of simulation-based learning. The LPK and the BPK groups' scan patterns can be visualized as Figure 1 and 2. The squares in the figures represent all AOIs (the meaning of each AOI was listed below the figures), and the arrows represent either a significant transition between any two AOIs or a significant repletion within the same AOI (each arrowhead points to the direction of transition). For example, regarding the AOI '1D' in Figure 1, the LPK participants tended to repeatedly read the ‘1D’ (1D→1D, $p < .05$) or shifted their attention from ‘1D’ to ‘1Im’ (1D→1Im, $p < .05$).

Some differences between the LPK and the BPK groups’ scan patterns can be identified by comparing Figure 1 and 2. For example, the BPK participants made more transitions between textual and graphical AOIs in the first simulation. More specifically, after attending on the graphical AOI (such as ‘1Im’ and ‘1P’), the BPK participants might turn into the textual description ‘1D’ (1Im→1D, $p < .05$; 1P→1D, $p < .05$). In addition, the BPK participants were more likely to switch their attention between graphical AOIs, such as from ‘1Im’ to ‘1P’ (1Im→1P, $p < .05$) and bi-directionally between ‘1O’ and ‘1P’ (1O→1P, $p < .05$; 1P→1O, $p < .05$). In contrast, the LPK group made less transition both between textual and graphical AOIs and between any two graphical AOIs. Moreover, the BPK participants tended not to repeatedly focus on the resulting pinhole images in both simulations (1Im and 2Im), but to immediately switch their attention from the image to the pinhole (1Im→1P, $p < .05$), or from the image to the text description (1Im→1D, $p < .05$). In contrast, the LPK participants were more likely to repeatedly study the resulting images in both simulations (1Im→1Im, $p < .05$; 2Im→2Im, $p < .05$), but less likely to switch from the images to other textual or graphical AOIs (except that of 2Im→2P, $p < .05$). Furthermore, the BPK participants paid more attention on ‘2In’ (2In→2In, $p < .05$) and made more transitions from ‘2O’ to ‘2In’ (2O→2In, $p < .05$).

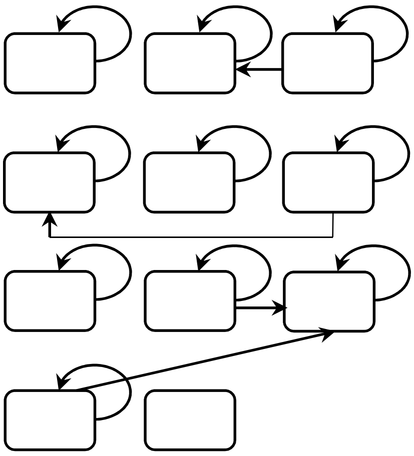

Fig 1. LPK group’s scan patterns

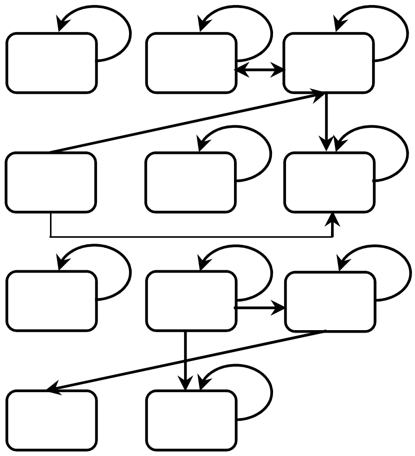

Fig 2. BPK group’s scan patterns

Note: **1C**: the text that gives an overall instruction to pinhole physics in the 1st simulation; **1O**: the object that “emits” light in the 1st simulation; **1P**: the cardboard with a pinhole in the 1st simulation; **1Im**: the resulting pinhole image in the 1st simulation; **1D**: the text that describes the features of the resulting pinhole image in the 1st simulation; **2C**: the text that describes the features of the resulting pinhole image in the 2nd simulation; **2O**: the object that “emits” light in the 2nd simulation; **2P**: the cardboard with a pinhole in the 1st simulation; **2Im**: the resulting pinhole image in the 2nd simulation; **2In**: the instruction for manipulating the pinhole in the 2nd simulation.

4. Conclusion

According to the results of sequential analyses, the BPK and the LPK participants had different scan patterns of simulation-based physics learning in the following three aspects. First, the BPK participants made more transitions both between textual and graphical AOIs and between any two graphical AOIs than the LPK participants. Second, while the LPK participants tended to focus repeatedly on the resulting pinhole images in both simulations, the BPK participants were more likely to connect the images with other textual or graphical AOIs in the simulations. Last, the BPK participants took more advantages of the interactivity of the second simulation by actively manipulating the distance between the pinhole and the object than the LPK participants. These findings may provide profound implications for improving simulation-based physics learning, particularly for learners with different knowledge backgrounds.

4. **References** (All references will be provided in the conference.)