

Eye tracker gaze analysis of learners watching the writing process

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Abstract: We used an eye tracker to record and analyze the gaze of learners watching text and drawings being written, as in the case of a teacher writing on a blackboard. Many teachers and learners understand the benefit of using blackboards, but there remains insufficient scientific evaluation of their use. Course content presentation that includes in-process writing of text is highly characterized by the sequential presentation of the writing processes. We believe that this presents a visualization of the thought process, and is thus far richer in educational information than simple presentation of completed forms. We focus on gaze during the presentation of graphs and equations as fundamental research to elucidate the benefit of presenting the writing process.

Keywords: gaze, eye tracker, writing process, blackboard, slide

1. Introduction

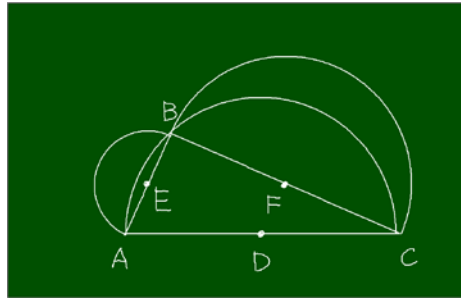
Advances and diffusion of information and communications technology have made more common the replacement of traditional blackboards with slide-based presentation tools. When presentations are slide-based, the illustrations and animations to be shown to learners can be prepared beforehand, and design functions can be used to easily create slides with high visual appeal. Slides are also beneficial in that they can be reused in future presentations. Although slides have many benefits, numerous problems with the use of presentation software have been indicated, such as the amount of information that is delivered and the monotony of such presentations (Reynolds, 2007; Tufte, 2003).

Though perhaps now in the minority, many teachers and learners prefer classes that use blackboards in preference to presentation software (Yanagisawa & Fukuda, 2008), and many teachers use their experience, knowledge, and teaching skill to determine how a variety of information should be presented to learners.

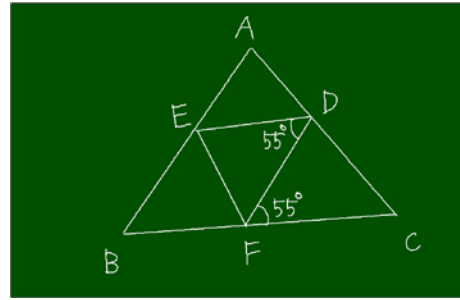
One of the predominant features of the traditional methods of presenting information on a blackboard is that learners watch information presentation as it is being written (Brown, 2012). Research is currently being performed that focuses on such features to examine the benefits of presentations that incorporate representations of the writing process (Bando et al., 2002; Kurihara, 2006).

We believe that this represents a visualization of the thought process, and thus is far richer in educational information than simple presentation of results. Presentation software has advanced features such as animations, but these features are simply methods for drawing attention or mechanically creating sequential divisions, and do not reflect the structure or thought process behind the object being displayed. Showing this process has meaning with regard to understanding, and is different from presentation of completed forms or mechanical step-by-step presentations.

We focused on learners' gaze as fundamental data for elucidating the benefits of presenting the writing process. There has been much progress in technologies related to detecting with high precision where a person is looking, and there has been cognitive research using gaze detection equipment for, for example, relating comprehension of a text passage based on gaze.



(a) Plane figure 1



(b) Plane figure2

$$1 + \frac{1}{2 + \frac{4}{1 + \frac{3}{5}}}$$

(c) Equation1

$$3^4 + \frac{1}{2^3} - \frac{9^{2+3}}{5}$$

(d) Equation2

Figure 1. Presentation stimuli

For presentation materials, we selected plane diagrams and equations containing exponents and fractions on the assumption that these items will allow for a hierarchical understanding of structures. We used an eye tracker (a system for following the path of a person's gaze) (Duchowski, 2007) to determine exactly what learners were looking at as information was written on a blackboard, and we investigated differences between this case and one where learners were simply presented with the final form of information.

2. Experimental methodology

We used the following method to measure participants' gaze. Tobii T60 Eye Tracker was used to track gaze (Tobii Technology, 2013a). Participants were 6 men and 3 women who were students in their early 20s. Experiments were performed on October 10, 17, and 31 in 2012.

Presentation stimuli were the 2 plane figures and 2 equations shown in Figure 1. Two presentation patterns were used: presentation of the stimuli that included writing the displayed object, and presentation of the final result only. These figures and equations are represented by structurally linked objects, and have hierarchical structures. We therefore believe that presentation that includes writing of the stimuli includes a demonstration of the thought process by which such objects can be understood.

We created the presented stimuli using the HPT (Handwriting Presentation Tool), which we are developing in our laboratory. This tool allows presentation of information being written as if on a blackboard (Hosoki et al., 2011).

We instructed the 9 participants to memorize the information being shown, and presented the 4 stimuli on a screen in sequence. When the presentation of a screen completed, participants took a reproduction test, and moved to the next presentation. Each participant was shown 2 plane figures and 2 equations. In either case stimuli 1 and 2 were presented, but in consideration of possible order effects, the stimuli that presented the writing process and the order in which stimuli were presented varied among participants.

Stimuli were presented for the amount of time required to write the content plus 5 s. When only final results were presented, participants saw the image for the same amount of time as those viewing the writing process. After all 4 stimuli were presented, participants responded to a questionnaire.

3. Experimental results

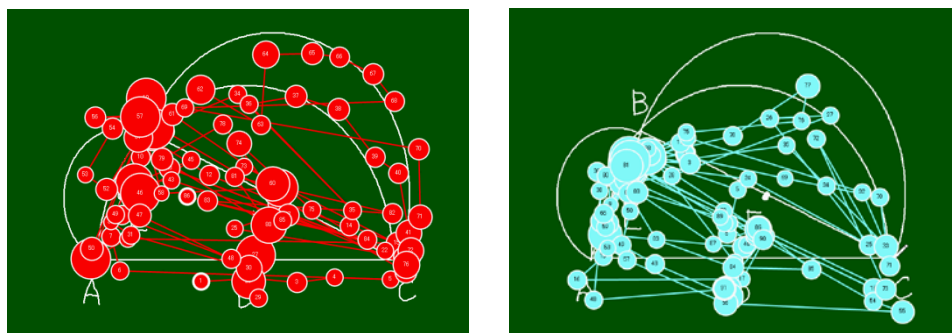
We used Tobii Studio for analysis of the gaze data (Tobii Technology, 2013b). We used gaze plots and bee swarm diagrams for dynamic analysis of the gaze data, and heat maps and clusters for analysis of static images. Data other than gaze analysis included tests of reproducing the presented stimuli and questionnaire results.

3.1 Gaze plots

Gaze plots are superimposed over the figure or equation presented as visual stimulus and a track of the participant's gaze is reproduced as an animation showing the flow and time spent looking at the stimulus, creating a visual representation of what parts of the stimulus the participant viewed and in what order.

As example gaze plots, Figure 2(a) shows the case where the visual stimulus was the writing process of plane figure 1, and Figure 2(b) shows the case where the visual stimulus was the completed diagram only. The plots show the order that the participant looked at areas, and the size of the circles (stopping points) indicate the length of time the participant paused there. The graphs enabled confirmation that when the writing process was presented to a participant, the participant's gaze followed the writing, and that there was a tendency to focus on characters used to label vertices and intersections. We also found that gaze sometimes, though rarely, strayed from the presented object.

In contrast, when only the completed diagram was presented in the absence of the writing process, gaze transition and stopping points varied widely among participants; gaze traveled to a variety of places and returned, showing no consistency.



(a) Plane figure1 with writing process (b) Plane figure1 with the static image only

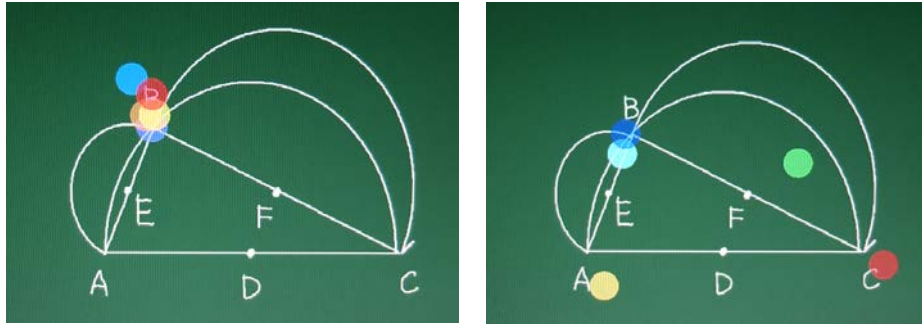
Figure 2. Examples of gaze plots

3.2 Bee swarm plots

While gaze plots allow analysis of the gaze of individual participants, bee swarm plots allow simultaneous replay of the gaze of multiple participants, thereby allowing between-subject comparison of a single stimulus.

Figure 3(a) shows a screenshot of a bee swarm plot where the visual stimulus was the writing process of plane figure 1, and Figure 3(b) shows the case where the visual stimulus was the completed diagram only. The circles indicate the gaze of each participant. Figure 3(a) was created immediately after drawing the three sides of triangle ABC and labeling vertices A and B. Participants' gazes were clearly concentrated in a limited area. In contrast, in Figure 3(b), where the writing process was not presented, participants' gazes were scattered about the image.

Analysis using bee swarm plots indicates that when the writing process is shown, all participants follow the writing in the same order and at the same location, whereas not showing the writing process results in varying viewing patterns among participants.

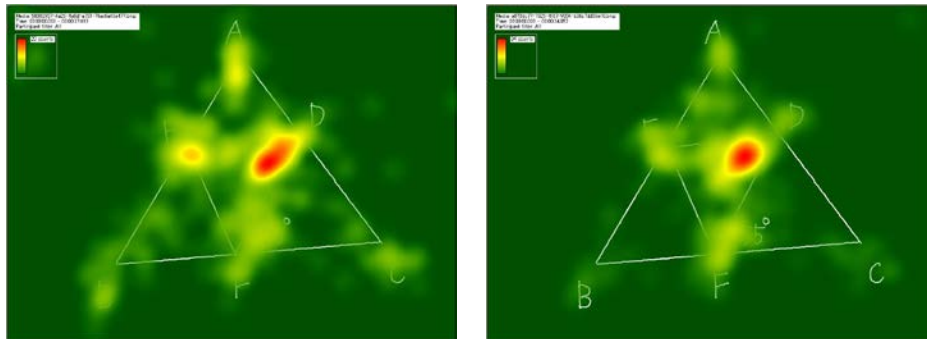


(a) Plane figure1 with writing process (b) Plane figure1 with the static image only
Figure 3. Examples of bee swarm plots

3.3 Heat map

Heat maps superimpose the eye movement of multiple participants to create a visualization resembling thermography. Figure 4(a) shows a heat map of the case where the visual stimulus was the writing process of plane figure 2, and Figure 4(b) shows the case where only the completed diagram was shown. In comparing the figures, Figure 4(a) shows higher interest in vertices A, B, and C.

Creation and analysis of the heat maps indicate that when figures were drawn, learners tended to examine vertices, intersections, and other points and places named with letters. In the case of equations, showing the writing process resulted in a tendency to view exponents.



(a) Plane figure2 with writing process (b) Plane figure2 with the static image only
Figure 4. Examples of a heat map

3.4 Clusters

In a cluster, the eye movements of multiple participants are superimposed to visualize common stopping places. Figure 5(a) shows a cluster for the case where the visual stimulus was the writing process of plane figure 1 was shown, and Figure 5(b) shows the case where only the completed diagram was shown.



(a) Plane figure1 with writing process (b) Plane figure1 with the static image only
Figure 5. Examples of a cluster

More numerous and fine areas are seen in the case where the writing process was shown, and gaze also moved to the semicircular area around the edge. In contrast, there were fewer divisions in the case where the writing process was not shown.

3.5 Reproduction test

Immediately after presentation of the stimuli, participants were asked to take a reproduction test in which they drew what they had just seen on a piece of paper. Figure 6 shows the results. Determination of the accuracy of reproduction of the presented plane figure or equation was made based on how accurately participants reproduced the form, without regard to the order that information was presented in.

Accuracy for plane figure 1 was 60% for both the case where the writing process was shown and where it was not. For plane figure 2, however, there was a significant gap in accuracy, 100% and 20% for the cases where the writing process was shown and where it was not, respectively. Scores on the reproduction test for plane figure 1 were the same, but in the case where the writing process was shown the reproduction error was consistently that semicircle AC centered at point D did not pass through point B; all other points were correct.

In the reproduction tests for equations, the cases of presented stimuli 1 and 2 had respective correct reproduction rates of 50% and 60% when the writing process was shown, and 75% and 80% when it was not; in each case, scores were higher when the writing process was not shown. Also, for equations there was little difference between the presented stimuli 1 and 2.

Video analysis of the reproduction test indicated that the reproduced procedure did not necessarily correspond to the procedure of writing that was presented. Of those participants who correctly reproduced the stimuli for which the writing procedure was shown, rates of reproduction in exactly the same manner as presented were 0% for plane figure 1, 40% for plane figure 2, 50% for equation 1, and 67% for equation 2.

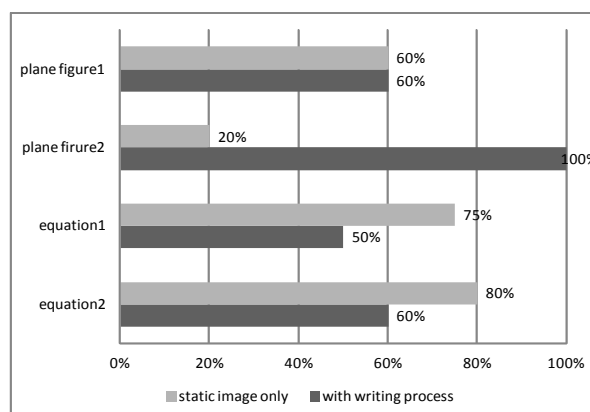


Figure 6. Results of reproduction test: The rate reproduced correctly

3.6 Questionnaire

To conclude the experiment, participants responded to a subjective questionnaire on a 5-point scale regarding the presence or absence of presentation of the writing process for plane figures and equations (Table 1). Regarding the plane figures, 8 of the 9 participants indicated positive opinions of seeing the process of writing. However, only 4 participants did so for equations.

Regarding the plane figures, representative positive comments regarding display of the writing process included statements such as “seeing the order in which to write makes remembering it easier,” “ABC and the other vertices left a strong impression,” and “without seeing the order to write things in, I’m not sure where to start from and what to memorize.” The negative comment was “It’s easier for me to remember when I can see everything at once from the beginning.”

Regarding the equations, a representative positive comment was “seeing the flow helps me to remember the equation.” Neutral and negative comments were along the lines of “I don’t need to see the equation written to understand the order of things,” and “When an equation gets long, the order that it’s written in becomes less important.”

Table 1: Questionnaire results

Writing process is helpful	Plane figures	Equations
Strongly agree	3	4
Agree	5	0
Neutral	0	5
Disagree	1	0
Strongly disagree	0	0

4. Conclusions and future research

We used an eye tracker to measure and analyze eye movement in cases where the writing process is shown and where static images are presented. Course content presentation that includes in-process writing of text is highly characterized by the sequential presentation of the writing processes. We believe that this presents a visualization of the thought process, and thus is far richer in educational information than simple presentation of results. We hope to elucidate the benefits of such display of thought processes, and use that knowledge for implementation into a presentation tool. As a fundamental experiment, we used plane figures and mathematical formulas in an analysis of the movement of learner gaze. The results of empirical data confirmed differences in gaze movement between cases where display of the writing process was present or absent. This study suggests that display of the process of writing information had positive effects, such as helping to retain learners' attention, and aiding learners' constitutive understanding.

Future research will include further experiments aimed at revealing the relation between thought processes and the presence or absence of display of the writing process. As part of that research, we will propose and implement new features for implementation into a presentation tool.

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