An eye tracking study of graphic representation in biology

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Abstract: This study aimed to investigate the role of graphic representations in the learning of biology domain. We examined 34 college students' eye movements while observing the plant tissues graphics through eye tracker. The students were divided into two groups: the biology group (N=17) and the non-biology group (N=17). Analyzing eye movement data and mental effort rating, we found that all college students had higher cognitive load and longer cognitive processes when they observed the textbook graphics compared with the authentic graphs. There were also differences in attention distribution in two graphs. Students in non-biology group had more fixations on text area than the other group. We considered that the two groups had dissimilar patterns in learning graphic representations.

Keywords: Eye tracker, Graph representation, Multimedia learning

1. Introduction

The famous proverb "a picture is worth a thousand words" means that graphic representations are very useful in delivering messages. In science education research community, research on graphic representations has received considerable attention recently (Cook, Wiebe & Carter, 2008; Patrick, Carter & Wiebe, 2005; Pozzer & Roth, 2005).When graphic representations combine various formats, such as text, together they will become even more powerful in instruction.

Graphic representations are widely used in biology, especially in microscopic world. In biology, it is very important to representing the microscopic representations, such as DNA model or animal tissues images, because learners cannot see microscopic scenes through their naked eyes. In Taiwan, almost every junior high school students have to take biology courses. Some of them will continue to study the biology-related courses in senior high school or in college. Realizing how the microscopic world works may help students learning physiology or the structures of cells better.

In biology, many concepts are often integrated in a complex manner and a correspondence between them is not obvious. For example, understanding of human body system or plant transport systems requires correlation of anatomy with physiology. These concepts are often represented in a way that the microscopic representations labeled with some proper nouns, but the functions of these nouns are seldom mentioned (see Fig. 1).

A completed cognitive process of representations always involves in construction of representations, and integration of external representations and internal representations. Many theories would discuss the relationship between external representations and internal representations, such as Paivio's dual coding theory (Paivio, 2006), or the research to explored mechanisms for effective integration of text with visuals leading towards construction of mental models (Schnotz, 2002).

Based on the above, we know that most knowledge and concepts in biology are constructed from graphic representations, and learners can improve their learning by graphic representations, especially in microscopic world. But we still found that many students get into trouble in learning by graphic representations. For example, Patrick, Carter and Wiebe (2005) examined students' interpretations of visual representations of DNA replication. They found that many students have difficulty to distinguish whether information is meaningful.

To make graphic representations refined, the purposes of this study are to investigate the observation process that college students with different backgrounds have in different graphic representations. We try to realize how eye movements and mental representations changed when college students observed two graphic representations. By eye-tracking technique, we can understand how students observe the microscopic representations. Data can be collected by eye movement measures to provide a view of how students acquire information from graphic representations. At the same time, we also investigate the mental effort when students observe graphic representations. Paas (1992) considered that cognitive load theory is a multidimensional concept, which can be distinguished to two components: mental load and mental effort. By measuring the mental effort, we can understand how much effort did participants made when they observed graphic representations.

2. Methodology

2.1 Participants

The participants were 34 undergraduate students from a public university in central Taiwan. Participants have normal or corrected to normal vision. All of the participants had taken college level biology courses that included the plant tissues and its basic component. The participants are assigned to one of two groups by their backgrounds: the biology group (N=17) and the non-biology group (N=17). And the students who major in biology had more training in biology domain.

2.2 Apparatus

The eye-tracking system we used in this study was MangoVision, it collected the position of the participants` gaze 60 times per second. The stimuli were presented by the software MangoVision Project on a 19-in Acer (1280×1024 pixels) monitor. Calculations using these data allowed points of perceptual fixation on the computer screen to be determined. Duchowski (2007) considered that fixations occur when a subject’s gaze is stabilized over an area of interest for at least 200 milliseconds. In this study, we collect the data of total fixation duration and total fixation counts, it is known that they can reflect the distribution of attention and the time of cognitive process.

2.3 Materials

The graphic representations in this study are represented in Fig. 1.Two biological graphic representations with both entirety region (left) and enlargement region (right). The authentic graph represents the stem of alfalfa, which was pictured by a Microscope Camera. The textbook graph represents the stem of sunflower, which was selected from a textbook used by participants when they studied biology in senior high school. The difference between two graphic representations is that the graphs in textbook are with labels. Heiser and Tversky (2006) found that students are used to drawing with arrows and labels to represent what they think. So we consider that the graphic representations with labels can enhance learning.

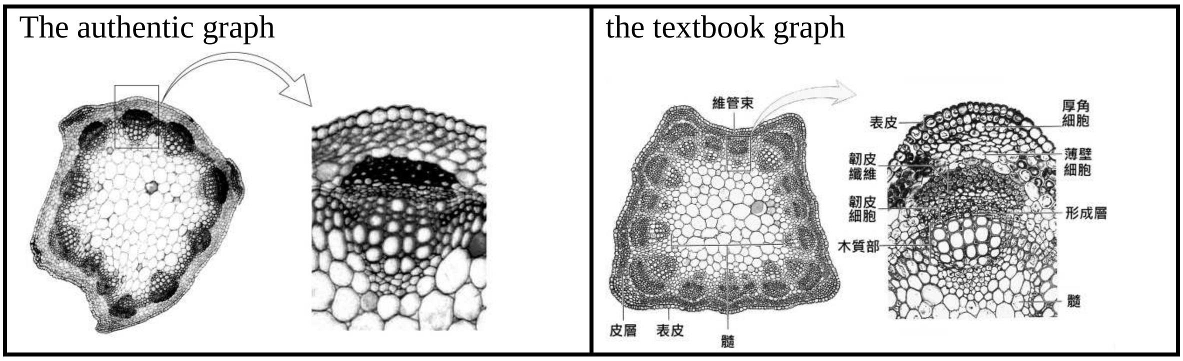

Fig. 1. The authentic graph and the textbook graph.

In this study, areas of Interest (AOIs) were defined the regions of interest in two graphic representations (refer to Fig. 2.), and fixations were recorded within these AOIs. In authentic graph, we defined two areas in this graph, entirety area (AOI 1) and enlargement area (AOI 2). In textbook graph, we defined three areas in this graph, entirety area (AOI 1), enlargement area (AOI 2) and text area (AOI 3).

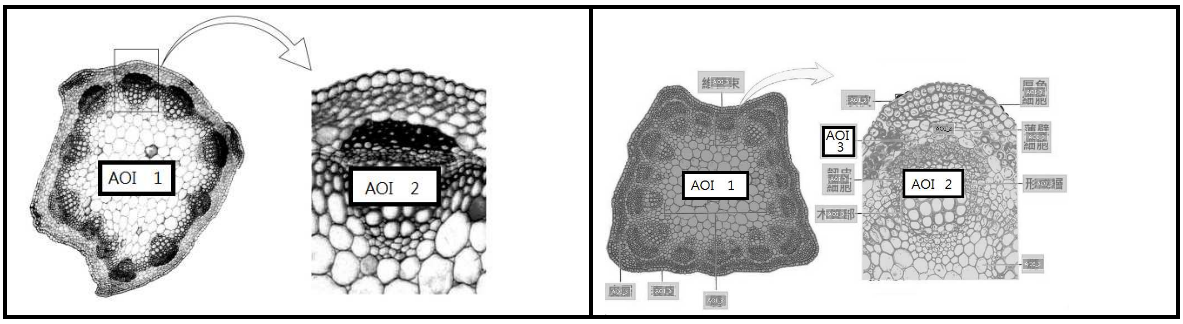

Fig. 2. The AOIs in authentic graph and textbook graph.

3. Research results

In Table 1, we show percentage of participants' fixation counts in AOIs in two graphic representations. We found that all the students had more fixation counts in the enlargement area of two graphic representations, and non-biology group students had more fixation counts in text area of textbook graph than biology group students.

Table 1 Percentage of participants' fixation counts in AOIs in two graphic representations.

Group	Graph	entirety	enlargement	text
Non-bio *(N*=11*)*	authentic	25.73%	74.27%	-
Non-bio *(N*=8*)*	textbook	26.24%	45.60%	28.19%
Bio *(N*=15*)*	authentic	40.80%	59.20%	-
Bio *(N*=12*)*	textbook	25.74%	55.29%	18.97%

Non-bio: participants major in physics or chemistry / Bio: participants major in biology

By paired sample t-test, we found that there are significant differences in total fixation duration between two types of graphs (see Table 2). Participants observed the textbook graph longer than authentic graph in both groups. Similarly, by paired sample t-test, we found that there are significant differences in mental effort rating between two types of graphs (see Table 2). Participants made more effort in observing the textbook graph than authentic graph in both groups.

Table 2 Comparison of participants' total fixation duration and mental effort rating between two graph representations.

Group	Graph	*M*	*SD*	*t*	*p*
total fixation duration					
Non-bio (*N*=17)	authentic	26.98	13.57	-6.09	.000***
	textbook	91.02	42.79		
Bio (*N*=17)	authentic	19.96	10.65	-7.12	.000***
	textbook	61.95	27.22		
mental effort rating					
Non-bio (*N*=17)	authentic	5.76	1.60	-4.92	.000***
	textbook	7.65	1.06		
Bio (*N*=17)	authentic	4.47	1.42	-2.97	.009**
	textbook	5.71	1.45		

**$p<.01$; ***$p<.001$

4. Conclusions

1. According to the analysis of the total fixation counts, we found that there were differences between non-biology group and biological group in the process of graphs observation. Non-biology group spend more time on dealing with labels. We also found that all of them spend the most time on the enlarged part of the graphic representations.
2. According to the *t*-test results of mental efforts rating and total fixation duration measurement, we found that participants had higher cognitive load and required more cognitive processing time observing textbook graphics.
3. With labels, biology graphic representations can help learners to gain a deeper understanding and identification of the various parts of the graphics. Graphic representations with labels can make participants' internal mental representations become more refined and enhance their learning.

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