EYE MOVEMENT PATTERNS OF CONCEPT MAP NOVICES: AN EXPLORATORY STUDY ON CHINESE TERTIARY STUDENTS

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Abstract: In recent years, the use of eye-tracking technologies has drawn increasing attention of educational researchers. However, there is still little research on the information processing patterns and consequences when learners reading concept maps based on eye movement data. This study is our initial attempt towards such direction. In this study we explored the eye movement patterns of concept map novices. Good concept maps are generally drawn with specified guidelines and students are always suggested to read the concept maps according to these guidelines. However, most of Chinese students have no experience of concept maps. Therefore, we are interested in their eye movement patterns when reading concept maps. Two layouts of concept maps (i.e., top-down layout and radial layout) were focused in the study. Eye movement data were captured by an unobtrusive eye-tracking device. 28 undergraduate students majored in economics and management in a famous Chinese university participated in the experiment. Results show that the top-down left-right pattern (i.e., text-transfer model) is dominated for Chinese tertiary students, no matter the layout of a concept map. Results also indicate that the visual attention of nodes and linking phrases are not evenly distributed, and the center and upper-left region of a concept map receives more fixations.
Keywords: Conceptual Maps, Eye tracking, information processing

1 Introduction

Educational researchers recently show increasing attention of the eye-tracking method, which has been intensively used in psychology and cognitive study. Compared to traditional interview and survey procedure, the eye-tracking method represents a promising way for tracking the cognitive process of learning (Adesope & Nesbit, 2013; Lai et al., 2013; Liu, 2014). Concept maps as graphical tools for organizing and representing knowledge have been proposed for more than 30 years. Guidelines to construct and read concept maps have been carefully designed. However there is little research on the real eye movement patterns when learner reading concept maps and we are not clear whether the eye movement patterns of concept map novices follow these guidelines. This study is an initial attempt to tackle the problem using an unobtrusive eye-tracking device in the context of Chinese tertiary students. Two typical concept map layouts (i.e., top-down hierarchical layout and radial layout) are focused in the study.

Prior studies have demonstrated the close link between eye movement patterns and human cognitive processes (e.g., Rayner, 1998). Thus, study on eye movement patterns on different layout of concept maps will help to understand the cognitive process of learning using concept maps, to differentiate the impacts of visual layouts on concept map comprehension, and to provide instructional suggestions for concept map design and teaching.

The remainder of the study is as follows: Section 2 provides the theoretical framework of the paper, Section 3 describes the research method used in the study, Section 4 discusses the results and Section 5 concludes the paper with future work.

2 Theoretical Framework

The theoretical framework of eye movement patterns of concept map novices roots in theories about eye movement and concept map.

2.1 Eye movement and the eye tracking method

According to eye-mind assumption (Just & Carpenter, 1980), eye gaze and attention have close relationship during the process of visual information presentation. People often use their eyes to explore external environments, and focus their eyes on an area of interest. Eye movement represents attentional shifts, which have been widely studied in the fields of usability and product design, assistive technology, and training simulations. Prior research has concluded that studying eye movements could help to understand pre-conscious mental operations, such as orienting, filtering, searching and semantic analysis. For example, study by Rayner (1998) reported that the patterns and measures of eye movement behaviors reflect the difficulty of information processing in the form of texts and images.

Visual perception falling within the normal range consists of three parts: foveal, parafoveal, and peripheral vision. Acuity is the greatest in the fovea, decreasing in the parafovea and periphery. In order to see things clearly, people frequently move their eyes to locate areas of interest in the region of fovea. Eye movement researchers have identified two general types of eye movement: fixations and saccades. Fixations refer to periods of 200 to 300 milliseconds in which eyes remain relatively still. Saccades are eye movements that occur between fixations. Studies have shown that different readers have different perceptual spans indicating areas of effective vision, and that new information is not acquired during saccades (Rayner, 1998).

The eye tracking method is basically developed based on the abovementioned characteristics of eye movements. It generally refers to a set of technologies which monitor and record the way a person looks at a particular text or image, and in what areas they fixed their attention, for how long and in what order. Such eye-tracking technology is used in educational research because it has potential to identify what information learners are attending to and the order of cognitive operations (Rayner, 1998; van Gog & Scheiter, 2010). Recently, Lai et al. (2013) reviewed 81 eye tracking papers in education and identified seven major research topics, i.e., effects of instructional strategies, patterns of information processing, individual differences, effects of learning strategies, reexamination of existing theories, social/cultural effects, and patterns of decision making.

Concept map as an effective knowledge representation medium can work as a visual stimulus to students. Thus, we believe that there is great potential in using the eye tracking method to analyze the eye movement patterns on and assess the impacts of concept maps. Recently, researchers have begun using eye movement data to build an understanding of how learners visually process concept maps. Nesbit, Larios, & Adesope (2007) found that participants gave early attention to nodes in the upper-left and central region of concept maps. Amadieu et al. (2009) used pupil dilation, fixation duration and navigational data to examine the effects concept map structure on disorientation, cognitive load, and learning from nonlinear documents. Bisra and Nesbit (2012) measured participants' eye movements while they were searching concept maps to gather information for argumentation. They found that participants' eyes fixated more on task-relevant nodes and more on nodes they later recalled correctly.

2.2 Eye movement patterns

Based on text reading patterns, prior research (Nesbit et al., 2007) suggests two possible eye-movement patterns: the text-transfer model and the hub-first model. Considering similar reading patterns of modern Chinese and western languages, we believe it is the truth for Chinese students.

The text-transfer model purports that learners tend to transfer text processing pattern to concept maps. Specifically, learners are likely to proceed concept maps from top to bottom, and from left to right. There would be an early saccade to the uppermost, leftmost node.

The hub-first model hypothesizes that concept map readers are seeking superordinate information. Hubs are nodes with a relatively large number of links to other nodes, which are likely to represent general information that is superordinate to information represented by other nodes. Hubs are generally centrally located in most concept maps. In a hub-first model, learners' earliest fixations are in the central region of the concept map, followed by nodes with a greater number of links.

2.3 Characteristics of a good concept map

Concept maps root in the Ausubel's assimilation theory. Decades of research and practice has demonstrated that concept maps can aid people of different ages to examine many fields of knowledge (Novak, 2010). They offer the flexibility of natural language and have the advantage of inducing their creators to organize their knowledge in a structured fashion, where concepts and their connections can be directly recognized.

Concept maps are composed of nodes that represent concepts and links that connect nodes to represent the relationships between concepts. Each node-link-node triplet forms a proposition with a meaningful statement about the object or event. These nodes and links are arranged in a hierarchical fashion with the most general concept at the top followed by more and more specific ones. The segments of a concept hierarchy represent different knowledge domains within the concept map. Links that cross segments, called cross-links, show how a concept in one knowledge domain is related to another and represent creative leaps on the part of the knowledge modeler.

The definition delineates several key characteristics of a good concept map: 1) A concept map usually stems from one main idea; 2) The main idea branches into related general concepts; 3) General concepts can be subdivided into more specific concepts branching from them in several tiers; 4) Specific concepts are elaborated by example; 5) Concepts are usually nouns, representing objects or events and each concept should be a single idea and appear only once in the map; 6) Relationships between concepts are shown by linking phrases and all concepts should be linked; 7) Cross-links are used to connect concepts in two different paths of the map.

To meet these characteristics, Novak and colleagues purported a top-down hierarchical layout (Novak & Gowin, 1984), whereas other researchers construct these visual representations in a radial configuration (Jonassen, Reeves, Hong, Harvey, & Peters, 1997) with the root node exists in the center of the map and the next level concepts spread around the central root node.

The eye movement pattern should match the layout of concept map to achieve good cognitive performance. Intuitively, top-down layout requires text-transfer model of eye movement and radial layout requires hub-first model. Accordingly in this study we are interested in concept map novices' real eye movement patterns when processing the two layouts of concept maps.

3 Method

To explore concept map novices' eye movement patterns, we conducted a controlled laboratory experiment. The whole experiment, including a briefing session, a reading session, and a test session, took approximately 15 minutes to finish. 28 undergraduate students from economics and management major in a famous university in China volunteered for the experiment. The participants were asked to carefully read two concept maps adapted from current well-designed concept maps. In this paper, we focused on the reading session and reported the eye movement patterns emerged from the session.

3.1 Experiment settings

The experiment settings are shown in Figure 1. The experiment took place in a room containing a desktop computer, mouse, keyboard, camera, and eye-tracking device. A Tobii T120 eye-tracker was used to collect eye movement data with the support of Tobii Studio software. Tobii T120 tracked participant's eye movement by using an infrared light source to illuminate the pupils and then captured the reflection. Tobii T120 could provide highly accurate and precise gaze-position data in real-life conditions and robust eye tracking capability ensures very low data loss regardless of a participant's ethnic background, age, use of glasses, or contact lenses.

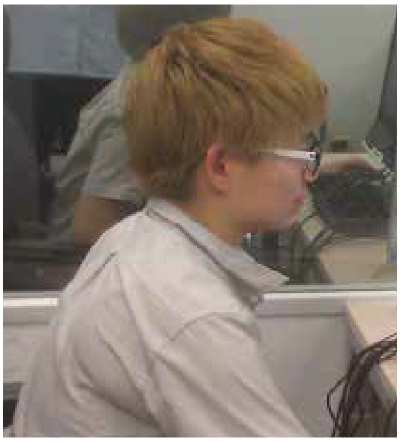

Figure 1. Experiment settings.

The eye-tracker was controlled by Tobii Studio software. This software offered a platform for recording eye movements, exporting raw eye gaze data, and multiple display visualizations such as video capture, gaze plot, and heat map. Along with gaze positions, mouse clicks and keystrokes were logged. Tobii Studio could also define areas of interest in order to filter the vast amounts of data into meaningful regions. In our settings, each node and linking phrase of a concept map was defined as an area of interest. Based on areas of interest, eye movement measures, such as fixation duration and fixation counts can be generated. The raw eye gaze data and eye movement measures can be exported to other commercial packages (e.g., IBM SPSS) for further analysis.

3.2 Concept maps and procedure

The two concept maps used in this study is adapted from the well-known Mars Exploration concept maps project. The focus question of one concept map is what capability advancements will result from a return to the moon, and another is what processes created asteroids. These topics are selected because the participants are generally not familiar with these topics while at the same time they are interested to know more about them. Due to the time constraints (less than 100 seconds) of one tasks in Tobii Studio, a few concepts in the original concept maps were deleted. Back-translation method was used to make sure the accuracy of translation from English to Chinese (Brislin, 1986). After translation, we redrew the two maps using CMapTools software. The top down layout and radial layout were prepared for the two concept maps respectively. Finally we got four concept maps as shown in Figure 2 ~ 5.

The experiment lasted for about 15 minutes and the time was determined by two rounds pilots study. The general procedure of the experiment was as followed: (1) a facilitator welcomed the participant, explained the facilities and tasks, and had him/her singed the consent form; (2) The participant conducted an eye-tracker calibration using the standard option in the Tobii Studio. The process took about 10 seconds by following moving red dots on the screen with eyes. (3) One top-down-layout concept map and one radial-layout concept map with different topics were randomly presented to the participants. Each map was shown for 100 seconds. The participants were asked to read and understand the two concept maps. (4) After reading the two concept maps, the participants were asked to complete a short quiz regarding to the content of concept maps and answer a questionnaire about experiences of reading concept maps with demographic information.

3.3 Experiment control

Prior studies have identified several sources of errors in concept mapping experiments, including variations in the participants' concept mapping proficiency, and variations in their prior domain knowledge. Accordingly, we have controlled these factors to minimize the influence of these sources of errors. Participants were carefully selected to make sure they have little knowledge about concept maps and domain knowledge about the two concept maps. Two items using 5-point Likert scale in the post-test questionnaire confirmed that these participants were general concept map novices (mean = 1.21, s.d. = 0.45) and they had limited knowledge of outer space (mean = 1.67, s.d. = 0.81).

4 Results with Discussions

As aforementioned, saccades and fixations are two general types of eye movement. Thus, to explore the novice's eye movement, in this paper we focused on the qualitative analysis of eye gaze plots and fixation heat maps generated during the concept map reading session of our experiment.

4.1 Results of gaze plots

A gaze plot displays movement sequence, order and duration of gaze fixations. Figure 2 exhibited a typical participant's eye gaze movement in the first 10 seconds on the top-down-layout concept map. In Figure 2, circles are labeled with fixation numbers before arrival and the diameters of the circles are positively related to fixation duration. The focus of the participant exists on the middle-left side of the concept map. We find that viewing begins with the top of the concept map, then moves on the second layer of the concept map. After that, the participant focuses its attention on the children nodes of the first node of the second layer, followed by the children nodes of the second node of the second layer. Such breadth-first pattern matches the hypothesized text-transfer model of eye movement.

Another typical participant's gaze plot is shown in Figure 3. The general pattern is similar to the above. However, the participant adopted a depth-first pattern, instead of the above-mentioned breath-first pattern. Further analysis on other participants' gaze plots of the two top-down-layout concept maps reveals similar conclusions. Although no prior training on concept maps, these novices could generally adjust their eye movements quickly and employ the breath-first or depth-first text-transfer model to traverse the top-down-layout concept maps.

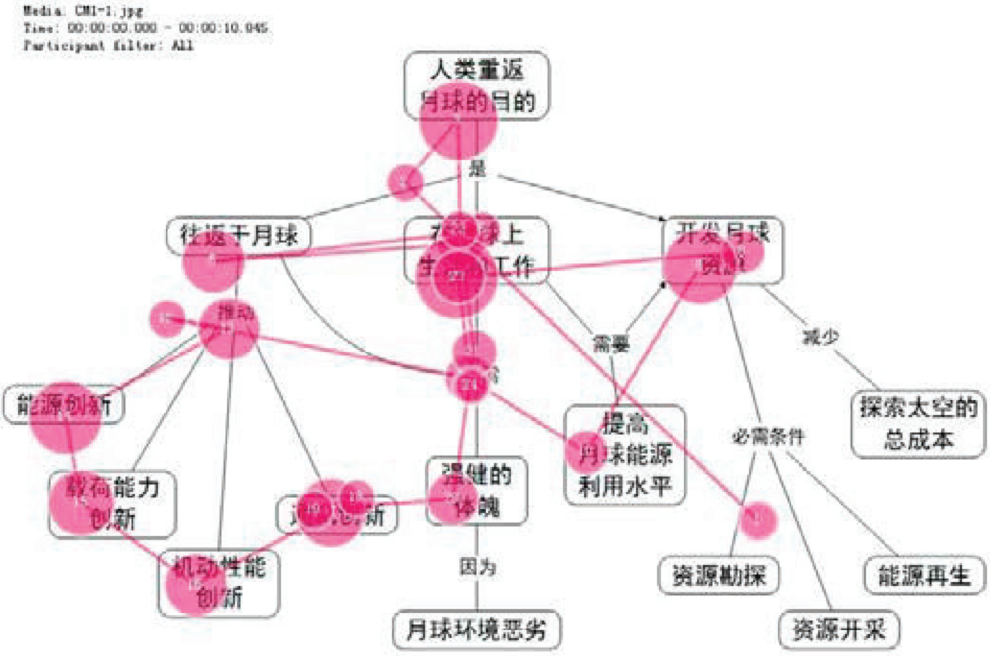

Figure 2: A typical gaze plot of the top-down-layout concept map 1.

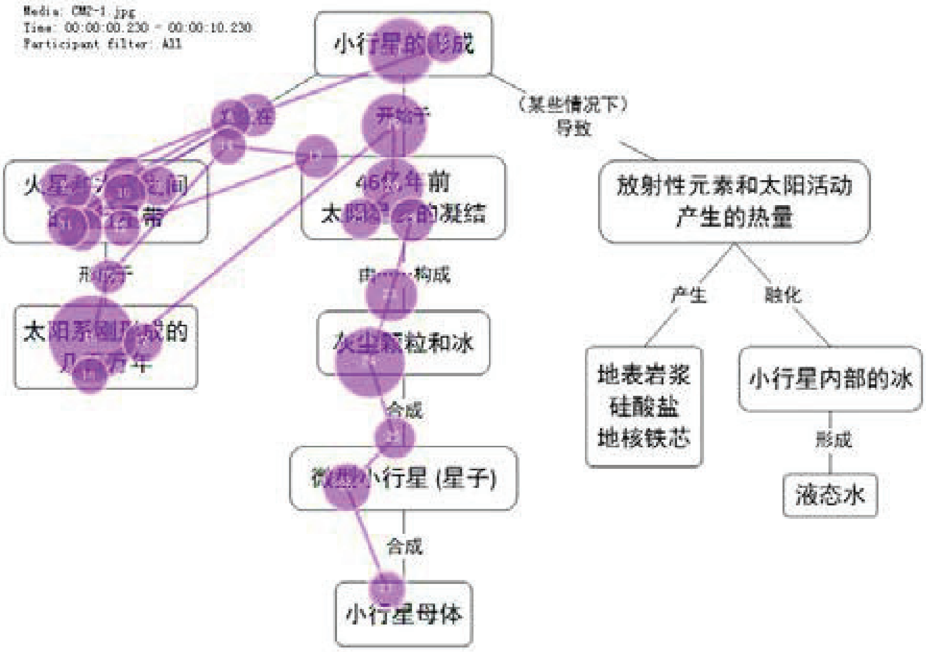

Figure 3: A typical gaze plot of the top-down layout concept map 2.

For the radial-layout concept map, the first fixation of participants generally falls into the upper-left of the map. It needs some time for participants to find the hub of the map. The general reading pattern still follows the top-down, left-right text-transfer model. Such finding mismatches with the hypothesized hub-first model of eye movement. The typical participants' eye gaze movements in the first 10 seconds on the radial-layout concept map 1 and 2 are shown in Figure 4 and 5.

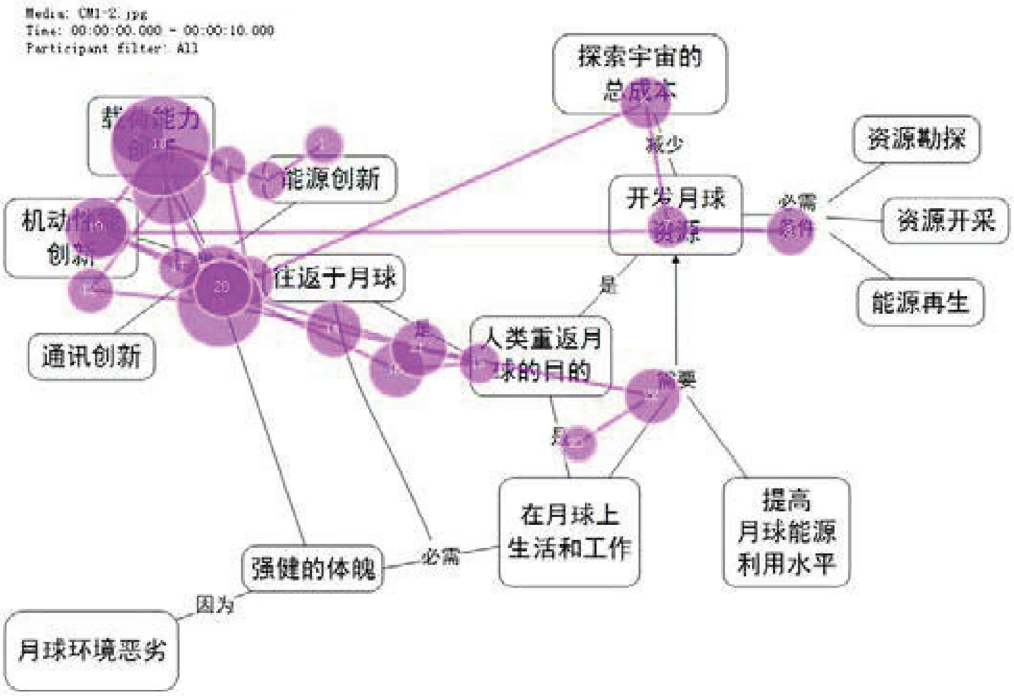

Figure 4: A typical gaze plot of the radial layout concept map 1.

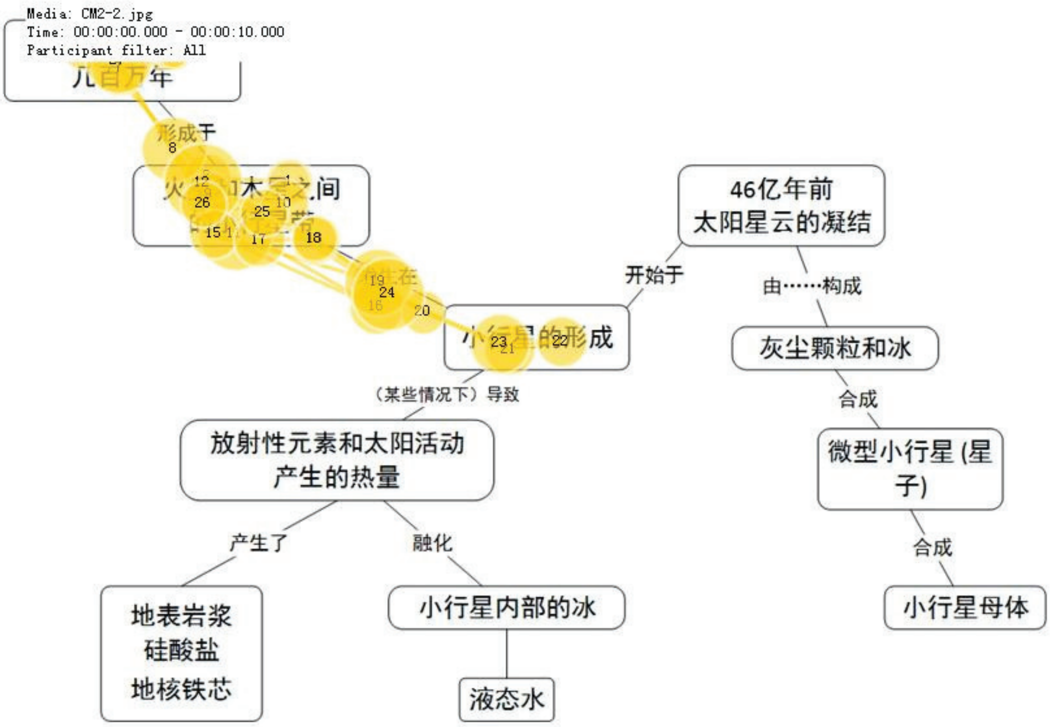

Figure 5: A typical gaze plot of the radial layout concept map 2.

Accordingly, we can conclude that the top-down layout can provide stronger cues, compared with radial layout, to guide the eye movement of a concept map novice. It may partially attribute to the education background of Chinese university students. They may not experience concept maps but they generally read tree diagrams in their past study.

4.2 Fixation heat map

Another output of the eye-tracking data is a representation of the areas of the screen receiving either more fixations or receiving the longest dwell times in a color-coded "hotspot" image of a concept map (see Figure 6 and 7). Specifically, the closer to red, the more fixations occur in an area of a concept map. Inspection of these heat maps reveals that on average the center of concept maps received the most fixations, and the bottom-right of concept maps received the least. In addition, people tended to pay more attention on nodes than linking phrases.

Figure 6. Fixation heat maps of top-down layout concept maps.

Figure 7. Fixation heat maps of radial layout concept maps.

Such findings are consistent with prior eye-tracking research on concept map (e.g., Nesbit et al., 2007). It indicates that the visual attention of nodes and links are not evenly distributed across the whole map. Concept map educators are suggested to consider the above issues when designing a good concept map.

5 Conclusions and Future Work

With the fast development of cognitive technologies, the education research begins to shift from behavioral perspective to cognitive perspective. In this study, we made an initial attempt to explore the eye movement patterns of concept map novices in the context of Chinese tertiary students. Results show that the top-down left-right pattern (i.e., text-transfer model) is dominated for Chinese tertiary students, no matter the layout of a concept map is top-down or radial. Results also show that visual attention of nodes and linking phrases are not evenly distributed, and center and upper-left region of a concept map receives more fixations.

We admit that the above conclusions are based on qualitative analysis of gaze plots and heat maps. In the future, we have planned to make quantitative analysis on the eye movement measures to support our arguments. Event though, we believe the conclusions of this study can disclose the eye movement patterns of concept map novices, and generate practical guidelines for concept maps design and learning to improve current instructional systems. The study also entails several interesting research directions. Our results show that concept map novices spent more time looking at concept nodes than linking phrases. It is of great interest to investigate the reasons at cognitive and neurological levels. Another promising direction is to identify the effects of individual differences (e.g., age and ethnicity) on eye movement patterns of concept map novices.

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