Cognitive Analysis of Experts’ and Novices’ Concept Mapping Processes: An Eye Tracking Study

Abstract

The goal of this study was to explore how designated experts (subject experts with extensive experience in science education and concept mapping) and novices (pre-service teachers) establish concept map (CM) development processes while considering their cognitive processes. Two experiments were conducted in which eye-tracking, written, and verbal data were collected from 29 novices and 6 subject matter experts. The results showed that despite some similar strategies, novices and experts followed different patterns during the CM development process. Both experts and novices embraced deductive reasoning and preferred hierarchical type CMs. Additional points studied during the process include filling out requested information in different orders, branch construction pattern, content richness and progress pattern. Furthermore, eye behavior patterns also differed among experts and novices. Expert participants differed from novices in all eye behavior metrics (fixation count, fixation and visit duration for specific actions). Novices’ fixation count (FC) numbers were higher than the experts’ during the entire process and in specific periods. In conclusion, these pattern differences affect the CM development process directly. Considering the patterns revealed in the study may help instructors guide learners more adequately and effectively.

Key words: concept map, eye tracking, cognitive process, debriefing protocol and expertise

1. Introduction

Concept maps (CMs) are valuable tools for researchers and practitioners because of how their structure visually represents verbal knowledge, and their effects and benefits have been examined in many research studies. Despite significant investigations into concept mapping, few have focused on the CM development process; instead studies have explored the potential of CMs as part of the assessment process as well as evaluating CMs themselves. Accordingly, the goal of this study is to understand the CM development process from the perspectives of experts and novices. This study is not interested in merely scoring the concepts and relations; instead, it investigated the process, which is much more than the end-product. Visual representation of information is the main focus, even though individuals may use inappropriate concepts or links resulting in correct relations among concepts in their map. The CM development process itself includes a chain of cognitive acts such as arranging, constructing, deleting, or changing concepts, all of which need to be investigated. The nature of the CM development process is not a well-studied issue for researchers, especially considering the perspectives of the experts’ and novices’ eye behavior.

At this point, exploring the CM development process becomes a critical issue that includes representing existing knowledge visually by forming relations among concepts and using links. This process is also crucial for determining reasons for ineffective CM usage: deficiencies of learners are explored more easily and effectively by considering causal factors. This case study is an important contribution to the field of education because it has the potential to improve these issues while introducing a combined perspective and integrating them under the same umbrella. One primary and three secondary research questions guided the current study:

- How do novices and experts establish their concept mapping processes?
  - How do concept map development processes differ between novices and experts?
  - What differences exist between novice and expert participants in terms of eye behavior (e.g. fixation count, visit duration, and fixation duration)?
  - Do novices and experts use specific strategies during the concept map development process?
2. Literature Review

Concept maps are graphical diagrams that are considered a good way to represent the organization of the knowledge of students (Novak & Gowin, 1984). The idea of concept mapping originated with Ausubel’s studies on meaningful theory, which emphasizes the importance of prior knowledge and the effect of advance organization on learning and retention (Ausubel, 1960, 1962; Ausubel & Fitzgerald, 1962). In order to support meaningful learning, evaluation strategies must be refined to relate new ideas to acquired knowledge (Novak & Canas, 2008). Concept mapping can also be considered a metacognitive tool, serving as an interactive link between existing schemata and new information (Kinchin & Hay, 2000). Numerous researchers in the field of science education have identified the potential benefits of CMs (Novak, 1990, 2005; Tekkaya, 2002, 2003; Novak & Canas, 2008). Novak and Gowin (1984) explained how CMs are a beneficial tool for teachers, enabling them to identify ways to organize meaning and discuss topics with students while simultaneously revealing misconceptions. According to Mintzes, Wandersee, and Novak (1998), CMs can also help students with knowledge organization. In recent years, the use of CMs has diversified widely, both in overall purpose and in specific subject matter.

Although CMs have been explored for various purposes, the overall development process has not been explored at a detailed level to assess underlying cognitive procedures. When CM development is considered as a whole element that includes numerous smaller decision making processes within it, the formation of CMs demonstrates similarities to the problem solving process, requiring active participation on the part of the mapper. Mintzes, Wandersee, and Novak (1998) have a parallel view: the concept mapping process reflects the perspective of the mapper during development. According to Howard and Barton (1986), the potential of the CM as a way of "thinking on paper" reveals indefinite relations and potential gaps in thinking mechanisms while showing contradictions among thoughts. The role of a CM as a spatial representation of knowledge captured the attention of the researchers. CMs are beneficial in that the knowledge structure of the mapper is translated from a mental picture to a spatial demonstration of concepts and the connections therein (Jonassen, Beisser, & Yacci, 1993). Jonassen (2011) has indicated that the effective problem solving process is necessary when constructing mental models by representing knowledge structures.

Several studies have been conducted regarding problem solving processes and revealing differences between experts and novices. Chi and Bassok (1989) investigated how skilled and poor problem solvers tackle problem solving processes. The role of knowledge structure and the difference between experts and novices could possibly be explained by the superiority of experts in terms of organizing knowledge meaningfully, as well as the successful utilization of chunking mechanisms (Larkin, McDermott, Simon, & Simon, 1980). This difference fascinated the researchers, compelling them to assess and compare novices’ knowledge with that of the experts in order to establish strategies for filling this gap (Ifenthaler, Masduki, & Seel, 2011). Although numerous studies have focused on the differences between novices and experts (Ericsson, 2009; Colins & Evans, 2007; Ericsson, Charness, Feltovich, & Hoffman, 2006; Chi, Glaser, & Farr, 1988; Ishii & Miwa, 2002; Carter, Sabers, Cushin, Pinnegar, & Berliner, 1987, Fiske, Kinder, & Larter, 1983; Law, Atkins, Karpas, Lomax, & Mackenzie, 2004), researchers have shifted investigations to possible reasons for the success of the experts during the problem solving process (Bialic, McLeod, & Gobet, 2008; Hegarty, Mayer, & Monk, 1995; Anderson, 1993; Koedinger & Anderson, 1990; Patel & Groen, 1991; Williams, Papierno, Makel, & Ceci, 2004). According to Goldstein (2005), expert knowledge is organized so necessary information is easily accessible, which, along with overall knowledge levels, is important in problem solving. Novices classify problems in terms of
similarities between objects, whereas experts tend to classify problems according to general principles (Goldstein, 2005). According to Mintzes et al. (1998), experts’ knowledge transfer from one domain to another is restricted, and they are capable of recognizing great meaningful patterns in their domain, allowing them to solve problems faster than novices. Experts generally possess a strongly hierarchical, cohesive framework of related concepts, and they represent those concepts at a "deeper more principled level" (Mintzes et al., 1998, p. 43). They tend to distinguish and solve fallacies through metacognitive skills. Mintzes, Wandersee, and Novak (2005) have highlighted the rareness of studies associating concept mapping and problem-solving expertise issues. They further indicated that the assumption of hierarchically related concepts is still being researched in many comparison studies. Stepich, Ertmer, and Lane (2001) explored coaching strategies for facilitating students practicing problem solving skills in the same manner as do experts in instructional design cases. Yeon-Lee (2002) explored the importance of expertise in complex cognitive tasks.

As cognitive structure gained attention, researchers began seeking different ways to explore the cognitive process. Recording eye movement and its potential for disclosing the fundamentals of the cognitive process are currently captivating the minds of researchers (Just & Carpenter, 1976, 1984; Rayner, 1995, 1998; Henderson, 2003; Liu, Lai, & Chuang, 2011). Many researchers have started to use eye movement metrics (number of fixations, average fixation duration, and total fixation time) during exploration of the cognitive process during actual task completion (Rayner, 1995, 1998; Jacob & Karn, 2003; Just & Carpenter, 1984). Liversedge and Findlay (2000) have indicated that an increase in fixation duration and numbers are connected with confronting a cognitive difficulty. Epelboim and Suppes (2001) explored the relation between longer fixations during difficult cognitive tasks such as geometry problems.

The connection between cognitive structure and eye behavior and a growing interest in exploring eye movements have also affected the field of education (Lowe & Boucheix, 2011; Hyöna, 2010; Jarodzka, Scheiter, Gerjets, & Van Gog, 2010; Mayer, 2010; Ozcelik, Karakus, Kursun, & Cagiltay, 2009; She & Chen, 2009; Patrick, Carter, & Wiebe, 2005; Grant & Spivey, 2003). Especially in science education, researchers have tried to examine eye behavior relationships (Wiebe, Slykhuis, & Annetta, 2007; Patrick, Carter & Wiebe, 2005). For example, Ariasi and Mason (2011) investigated the influence of text structure both on cognitive processes during the reading of a science text and also on conceptual learning gained from the text. In addition, eye tracking research provides a remarkable way for examining multimedia learning theories, thus increasing awareness of the link between the comprehension, learning, and thinking processes with the use of graphics (Mayer, 2010). Hyöna (2010) investigated the cognitive process of humans during multimedia learning and how eye tracking could be used to further understand this process. Eye tracking is also used for differentiating novices and experts (Van Gog, Paas, & Merrienboer, 2005; Jarodzka, Scheiter, Gerjets, and Van Gog, 2010). Different combinations of techniques like verbal protocol, eye tracking, and concept mapping have been used to reveal the cognitive process for both instructional and research purposes (Van Gog, Kester, Nievelstein, Giesbers, & Paas, 2009).

In this study, eye tracking was utilized for exploring cognitive processes during CM development activities while considering the expert or novice perspective. The study was aimed at understanding the CM development process in depth, leading to practical advice for practitioners and researchers while determining contributing reasons for the development of effective or ineffective CMs.

3. Methodology
Case study design was chosen to explore experts’ and novices’ cognitive processes throughout the CM development process. Yin (2009) defines the case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 18). Case studies do not adhere to a specific data collection or analysis method (Merriam, 2009) and might be considered a scientific investigation of a current problem when the details and context are vague (Yin, 2009). Since this research is striving to document a single unit within a holistic effort, it is a case study.

3.1. Sampling

Twenty-nine pre-service teachers (25 female and 4 male) as designated novices and 6 subject matter experts (5 female and 1 male) participated in this two stage study. The novices’ ages ranged between 21-23, and the experts’ ages ranged between 30 and 45. All participants were native Turkish speakers and fluent in English. They voluntarily took part in the experiment and were given a small stipend in addition to extra course credit. In the first experiment, 12 novice participants attended the study. In the second experiment, 17 novice participants and 6 experts attended the study. All novice participants had a science education background and were in their third and fourth years of study. The group selected as subject matter experts in the science education field had at least 5 years of experience in science education and with concept mapping. The experts were interviewed about their concept mapping experience before the study. According to their responses they had been using concept maps in their classes for a long time. All of the participants reported that they have developed their maps in science related subjects. In order to establish prior knowledge on selected concepts, pre-tests and an inventory were administered to the novices. Prior knowledge test scores of the novices for the concept of the cell ($M_{Cell} = 12.25, SD = 1.82; \text{Min} = 9, \text{Max} = 14$) and for the concept of matter ($M_{Matter} = 19.71, SD = 1.90; \text{Min} = 15, \text{Max} = 22$) showed that participants met knowledge requirements.

3.2. Procedures

All experiments were conducted in the Human Computer Interaction Research and Application Laboratory. Before the real experiments, pilot studies were conducted to review the questions and the procedure. While they were developing their CMs, participants’ eye tracking data were collected through the Tobii 1750 Eye Tracker device. Tobii Studio and Clearview software provided fixation duration (FD), fixation count (FC), and visit duration (VD) data. A free tool (CMap Tool, available at http://cmap.ihmc.us/) was selected for creating CMs. In order to make participants familiar with the tool, they attended a training session before the experiments. All participants were instructed about the tool’s usage and used the tool by themselves during tasks.

Experiment 1: Prior Experiences with the CM Development Process and Self Reporting

Purpose: The purpose of this experiment was to examine how novices conduct the CM development process over a specific concept. In order to investigate the CM development process in detail, participants were asked to develop a CM about the cell, and this process was analyzed both qualitatively and quantitatively. All participants took a prior knowledge test before the experiment on the selected biology concept (the cell).
Method and Procedures: In this experiment, 12 pre-service teachers in their third year of Elementary Science Education students participated. The gender distribution was 9 female and 3 male participants, whose ages ranged between 21 and 23 years. For this experiment, a concept from biology, the cell, was chosen. Before starting the experiment, participants took a prior knowledge test on the cell to establish required knowledge. Then, they were asked to fill out an inventory of 9 open-ended questions to examine their prior knowledge about and experience with the CM development process itself. In addition, in order to remind them about general ideas related to the cell, a handout was distributed. During the CM development process, however, participants were not allowed to refer to this handout. The participants were asked to develop a CM independently, and this process was recorded by the eye tracker device. After they completed their CMs, they completed another questionnaire, an interpretative essay including 8 open-ended questions regarding the CM development process. Both instruments were developed by the researcher and checked by an expert. (See Table 1)

Table 1

Sample questions from the prior knowledge tests

| Prior Knowledge Test (Cell) | Q1. Which of the following statements is incorrect for the cell membrane?  
|                           | a) Cell membrane provides chance to exchange with the environment.  
|                           | b) It does not exist in animal cells.  
|                           | c) It has a very fragile structure.  
|                           | d) It is semi-permeable.  |
|                           | Q2. Which of the following paired organelles are found in both plant and animal cells?  
|                           | a) Mitochondria-centrosome  
|                           | b) endoplasmic reticulum-plastid  
|                           | c) Golgi apparatus-mitochondria  
|                           | d) Cell membrane-cell wall  |

| Prior Knowledge Test (Matter) | Q1. Two students presented a project on physical and chemical changes in class. They conducted two separate experiments.  
|                              | 1st student evaporated some water.  
|                              | 2nd student transmitted electricity through the water to electrolyze.  
|                              | Please answer the following questions based on the experiments.  
|                              | Which student gave an example of which kind of change?  
|                              | a) 1st student: chemical change  
|                              | 2nd student: physical change  
|                              | b) 1st student: physical change  
|                              | 2nd student: chemical change  
|                              | c) Both students gave physical change examples.  
|                              | d) Both students gave chemical change examples.  |
|                              | Q2. Which one of the following entities is not a substance?  
|                              | I. sun light reaching Earth  
|                              | II. air in a bicycle tire  
|                              | III. a new born baby  
|                              | IV. hot air from a blow dryer  
|                              | V.  
|                              | a) Only I  
|                              | b) Only II  
|                              | c) Only III  
|                              | d) Only V  |

Experiment 2: CM Development Strategy and Debriefing Protocol

Purpose: In this experiment, the novices established CM on the concept of matter; in order to examine participants’ prior knowledge on the topic, a test was administered before the experiment. In addition to the novice group, experts were added to this portion of the study. The purpose of this experiment was to examine whether experts and novices differed in their CM development processes. In addition, with the aid of the information gathered from the experts, researchers could reflect upon how novices’ processes could be enhanced.
Method and Procedures: This experiment included two different groups of participants, novices and experts. The novice group was comprised of 17 pre-service teachers in their fourth year of science education. The gender distribution of the group was 16 female and 1 male, and their ages ranged between 21-25. The expert group was comprised of educators with at least 5 years expertise in science education and experience with concept mapping. This group consisted of 5 female participants and 1 male participant with ages ranging between 30-45.

3.3 Data Analysis

The prior knowledge test scores and CMs were analyzed. The researcher asked biology and chemistry experts to evaluate the CMs for quality and content richness. In addition, the eye movement data were quantified and analyzed by Tobii Studio and Clearview software to determine fixation count (FC), fixation duration (FD) and visit duration (VD) metrics. Participants’ eye behavior was analyzed frame by frame to identify patterns with an expert the validation of acts. Furthermore, open-ended questions from the CM inventory and interpretative essay instrument were analyzed using content analysis. In the data analysis process, the researcher first organized all the data, including the debriefing transcriptions, and controlled for any misunderstandings or incorrect transcriptions. Then, the researcher typed all documents collected from participants and arranged them into tables to present clearly organized data. In addition, the researcher generated codes and themes gathered from the data via debriefing sessions and document analysis.

The researcher tried to reveal the progress pattern of participants during the CM development process. Four periods were identified while considering progress as a basis for analysis. While determining these four periods of CM development (beginning, early-mid, late-mid, and final), the researcher set a percentage of constructed concepts as the basis for analysis instead of length of time, since the periods were extremely different based on the individual. Setting the completed percentage of concepts allowed the researcher to observe the completion process in an uninterrupted continuum while determining progress without limiting with the participant’s time. See Figure 2.

3.4 Validity Issues

To validate the results of this study, different techniques were used. Data were collected from different sources to minimize the subject characteristic effect and possible mortality threat. The methods were triangulated by collecting various types of data—verbal protocol, documental, observational, and eye-tracking as Creswell (2007) suggested as a strategy. The raw data were coded by the researcher twice at different times to check consistency between codes and themes. Furthermore, for peer examination the researcher asked a colleague to re-code part of the data to compare the generated codes and themes to ensure consistency. Moreover, as an external audit a subject matter expert’s help was sought to validate the determined acts (controlling and checking, reasoning, constructing a concept).

3.4.1 Limitations

In both experiments, handouts related to the selected concepts were given to the participants to clarify major points about the topics. Although the handouts were provided before the experiment and not allowed during the CM development process, participants’ later concept mapping may be affected, generating a potential limitation for this study. The gender imbalance may also be considered as a limitation for this study. Furthermore, the limited
number of experts might also be regarded as a limitation restricting the statistical analyses.

4. RESULTS

4.1. Experiment 1: Prior Experiences with the CM Development process and Self Reporting

The documental data on the prior experiences of the participants showed that most of the novice participants were familiar with CM development prior to this study, having developed 1 to 15 CMs. The most frequently expressed topics pertained to experiences in science and its various branches (N = 12), particularly biology, physics and chemistry. Some participants (N = 8) had developed CMs on education-related subjects like methods of education and classroom management. Some participants reported CM experience in both science and education-related subjects (N = 7). Two participants did not share their experiences. The experts were interviewed about their CM experience before the study. According to their responses they had been using CMs in their classes for a long time. Some of the experts also previously used CM techniques in their research studies. All participants reported having developed maps in science-related subjects.

Participants were also asked to identify subject areas appropriate for CMs and in which they would be compelled to use CMs in the future. Participants’ future selections were parallel to their prior experiences. The majority of the participants (N = 18) pointed to science-related subjects for CM development. Social science subjects (N = 10) were the second most preferred subject area by the participants. Although many participants (N = 12) had previous experience with CMs in the field of education (e.g., teaching methods), only a few participants (N = 2) indicated education specifically as a preferred area for CM development. Types of CMs participants had experienced included three main categories: hierarchical (N = 7), spider (N = 10), and mixed/both (N = 5). Seven participants did not explain their preferences.

4.2. Experiment 1 and Experiment 2: Eye behavior analysis

Exploring cognitive processes during CM development was the major focus for this study. For that reason, novice and expert eye behaviors were examined while comparing eye behavior metrics: fixation count, fixation, and visit duration. The results showed that novices had higher fixation counts (M_Matter = 59.43, M_Cell = 41.33) than experts (M_Matter = 20.08, M_Cell = 17.24) on their CMs independent from subject.

In addition, participants’ average fixation duration periods during CM development were compared. The results showed that novice participants’ average fixation duration period (M = 5.63 sec.) was shorter than the experts’ (M = 11.16 sec.) for the cell concept. On the other hand, for the matter concept, the fixation duration values for experts and novices were closer; novices spent 9.77 seconds on their CMs, while experts spent 10.85 seconds. In terms of visit duration values, periods were similar for the cell concept (M_Novices = 19.11, SD = 7.82; M_Experts = 22.02, SD = 6.98) but not matter (M_Novices = 22.27, SD = 10.21; M_Experts = 43.77, SD = 17.0), when novices recorded less time than experts. Furthermore, the frequently observed acts were determined during eye behavior analysis (See Table 2).

Table 2.

Frequently Observed Acts during CM Development
Constructing a concept  
- Constructing a blank concept  
Writing into a concept  
Constructing a link  
Erasing  
- Erasing a concept  
- Erasing a relationship  
- Erasing a branch/both concept and relationship  
Arrangement  
Reasoning  
Controlling checking  
Scrolling  
Cross-link  
Revising (Fixing a concept and relation)  
Tool box usage  
- Placing toolbox

<table>
<thead>
<tr>
<th>Acts</th>
<th>Type</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructing a concept</td>
<td>Primary</td>
<td>Double clicking generates a blank concept; double clicking inside the concept box allows for adding text. The act is whole and uninterrupted.</td>
</tr>
<tr>
<td>Constructing a blank concept</td>
<td>Secondary</td>
<td>It differs from constructing concept act as it proceeds with writing into relation or any other act instead of writing into concept box.</td>
</tr>
<tr>
<td>Writing into a concept</td>
<td>Primary</td>
<td>Completing a previously constructed concept.</td>
</tr>
<tr>
<td>Constructing a link</td>
<td>Primary</td>
<td>After developing a concept, clicking it generates an arrow; dragging the arrow creates a relationship and another concept box. Double clicking inside the box allows for entering text.</td>
</tr>
<tr>
<td>Erasing</td>
<td>Primary</td>
<td>Removing a concept or relationship by selecting the concept, link, or cluster of concepts and relationships, and then clicking delete.</td>
</tr>
<tr>
<td>Erasing a concept</td>
<td>Secondary</td>
<td>Deleting a specific concept; may be related to word choice or misspelling.</td>
</tr>
<tr>
<td>Erasing a relationship</td>
<td>Secondary</td>
<td>Deleting a specific relationship; may be related to word choice or to avoid repetition.</td>
</tr>
<tr>
<td>Erasing a branch/both concept and relationship</td>
<td>Secondary</td>
<td>Deleting both concept and relationship, replacing with something new or shifting the concept and relationship to a different location.</td>
</tr>
<tr>
<td>Arrangement</td>
<td>Primary</td>
<td>Placement of concepts, relations, and branches; includes changing locations of concepts or links or adding more information to a place.</td>
</tr>
<tr>
<td>Reasoning</td>
<td>Primary</td>
<td>A thinking process that usually continues into another act, like constructing a new concept, writing about a concept or relationship, constructing a cross-link, or adding/deleting something; easily observed via eye tracking.</td>
</tr>
<tr>
<td>Controlling checking</td>
<td>Primary</td>
<td>Checking for errors, leading to revisions or adjustments of the map. During this act, eye movements are fast and result with either no movement or only corrections as necessary.</td>
</tr>
<tr>
<td>Scrolling</td>
<td>Primary</td>
<td>Moving through the CM to control information.</td>
</tr>
<tr>
<td>Cross-link</td>
<td>Primary</td>
<td>Developing a meaningful relationship between two branches.</td>
</tr>
<tr>
<td>Revising (Fixing a concept and relation)</td>
<td>Primary</td>
<td>Correcting mistakes by changing or adding words to a concept or relationship.</td>
</tr>
<tr>
<td>Tool box usage</td>
<td>Primary</td>
<td>Includes tasks such as changing arrow direction, color, box style, and font style or size.</td>
</tr>
<tr>
<td>Placing toolbox</td>
<td>Secondary</td>
<td>Location of the tool box.</td>
</tr>
</tbody>
</table>

Specifically, three main acts - cross-link, controlling and checking and reasoning—were selected for gathering additional information about the cognitive processes of participants. In order to observe differences between expert and novice participants for these acts, their fixation count, fixation duration, and visit duration values were compared. During comparison, the topics of the CMs were also taken into consideration. For the cell concept, experts’ fixation duration periods were longer than those of the novices. Specifically, cross-link act fixation duration periods were considerably longer for experts (M = .97, SD = .17) than novices (M = .28, SD = .25). Along the same lines, experts’ fixation duration periods for controlling and checking (M = .48, SD = .11) and reasoning (M = 52, SD = .03) were fairly longer than the novices’ (M_{CC} = .16, SD_{CC} = .12; M_{R} = 35, SD_{R} = .11.).
The results for matter also showed differences in fixation duration periods: Experts' fixation duration periods were longer than the novices' for all three assessed areas. Cross-link fixation duration was considerably longer for the experts ($M_{Experts} = .67$, $SD = .63$) than the novices ($M = .47$, $SD = .38$), while reasoning times ($M_{Experts} = .50$, $SD = .07$; $M_{Novices} = .45$, $SD = .13$) and controlling and checking were closer ($M_{Experts} = .37$, $SD = .02$; $M_{Novices} = .33$, $SD = .15$).

### 4.3. Experiment 1 and Experiment 2: General CM Development Patterns

As a general strategy, novices ($N = 29$) and experts ($N = 5$) followed a similar, deductive strategy, starting with a general concept and continuing by constructing sub-concepts and links while keeping relations to the main concept in mind. The underlying reasons for preferring a deductive strategy were structuring relations more easily and smoothly, prior experiences with deductive strategy, the similarity of the structured image on a subject in mind, and the suitability of the chosen subject. Although novices and experts followed the same strategy during their CM development process, most novices declared that they did not have a deliberate plan in mind before starting but tended to write the information which came to mind first. Verbal and eye behavior data showed that while they may not have planned to follow a strategy, they practiced deductive strategy during their CM development.

Other patterns revealed during this portion of the study included filling out requested information in a particular order, preference towards use of hierarchical type maps, and constructing branches in multiple ways. In terms of filling out information in order, most of the novice ($N = 25$) and expert ($N = 5$) participants preferred to write the linking word and then the concept. In addition, a majority of novices ($N = 21$) and experts ($N = 6$) preferred hierarchical type maps over the spider type. (See Figure 3)

![Figure 3 is about here=](image)

Unlike the other patterns revealed, experts and novices followed different patterns during branch constructing. Novices ($N = 24$) followed a synchronized pattern; if they started to give an example or mentioned a feature from one branch, they tended to give similar information about the equivalent branch concurrently. This apparently synchronized act of writing information about the various branches is referred to by the researcher as “mirror image.” Comparatively, most of the experts ($N = 5$) showed a reverse pattern; they completed an entire branch first as opposed to writing equal information about each subsequent branch. This difference might be related to the knowledge of organization structures and the strategies embraced by the experts and novices. (See Figure 4)

![Figure 4 is about here=](image)

### 4.4. Experiment 2: CM Development Progress Pattern Analysis

In order to understand the progression of the CM development process, measures regarding content richness and the frequency and pattern of observed acts (i.e., constructing a concept, cross-link, reasoning, erasing) were examined. Content richness was measured with the aid of predetermined criteria drawn from the literature (number of concepts, links, cross-links, and examples; Trowbridge & Wandersee, 1998) while considering the subject matter and ensuring a standard procedure for analyzing every map. The results showed apparent differences between experts and novices in terms of content richness for both the Cell and Matter subjects. The number of concepts presented by experts for the Cell subject ($M_{Cell} = 32.67$, $SD = 7.64$) was higher than for the novices ($M_{Cell} = 23.5$, $SD = 4.17$). Likewise, for the
Matter subject, expert map concept numbers were higher (M_{Matter} = 30.33, SD = 12.42) than those of novices (M_{Matter} = 17.4, SD = 3.85). In terms of the number of links in the CMs for both subjects, expert scores were higher (M_{Cell} = 38, SD = 4; M_{Matter} = 30, SD = 9.64) than the novices’ (M_{Cell} = 22.5, SD = 6.86; M_{Matter} = 19.4, SD = 6.07) as well. Moreover, for the Cell subject, the number of cross-links (M_{Cell} = 6, SD = 0) and examples (M_{Cell} = 6, SD = 2.65) were greater for experts than novices (M_{Cell} = 1.83, SD = 1.85; M_{Cell} = 1.67, SD = 3.5). Likewise, the number of cross-links (M_{Matter} = 2.33, SD = 2.08) and examples (M_{Matter} = 7, SD = 4) were higher for experts than novices (M_{Matter} = 2.13, SD = 2.17; M_{Matter} = 1.46, SD = 2.53) for the Matter subject. As a result, experts’ CMs were more qualified than the novices’ according to all measures in both subjects. In terms of total time spent concept mapping and the total number of acts observed, experts invested more minutes (M_{Cell} = 22.02; M_{Matter} = 43.77) than novices (M_{Cell} = 19.11; M_{Matter} = 22.72) on both subjects. However, novices completed more total acts (M_{Cell} = 655.25; M_{Matter} = 1040.75) than experts (M_{Cell} = 164.25; M_{Matter} = 265.5) for both subjects. Demographic information regarding the differences between experts and novices in terms of the content richness in their maps is given below (See Table 3).

Table 3.

<table>
<thead>
<tr>
<th>Cell</th>
<th>N</th>
<th>Number of concepts</th>
<th>Number of links</th>
<th>Number of cross-links</th>
<th>Number of examples</th>
<th>Time in minutes</th>
<th>Number of total acts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts</td>
<td>3</td>
<td>32.67</td>
<td>38</td>
<td>6</td>
<td>6</td>
<td>22.02</td>
<td>164.25</td>
</tr>
<tr>
<td>Novices</td>
<td>12</td>
<td>23.5</td>
<td>22.5</td>
<td>1.83</td>
<td>1.67</td>
<td>19.11</td>
<td>655.25</td>
</tr>
</tbody>
</table>


**Matter**

| Experts | 3 | 30.33              | 30             | 2.33                 | 7                  | 43.77           | 265.5              |
| Novices | 17 | 17.04             | 19.4           | 2.13                 | 1.46               | 22.27           | 1040.75            |

In order to understand the progression of the CM development process, the frequency and pattern of observed acts (i.e., constructing a concept, cross-link, reasoning, erasing) were examined. During analysis, specific periods were identified: beginning, early-mid, late-mid, and final. The results showed that for the cell concept, the highest total number of acts performed by all participants during CM development was during the final period (M_{Novices} = 78, SD = 39.81; M_{Experts} = 75.67, SD = 36.91). The beginning and final periods’ total numbers of acts were much closer to each other than the other periods for novices (M = 48, SD = 19.83) and experts (M = 43, SD = 14.53). In the late-mid period, a substantial difference appeared between novice and expert participants’ total number of movements (M = 39.75, SD = 15.46; M = 55.33, SD = 10.41).

Table 4.

**Total Number of Acts for Novices and Experts during Each Period and Concept (Cell)**

<table>
<thead>
<tr>
<th>N</th>
<th>Period</th>
<th>Cell</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novices</td>
<td>12</td>
<td>Period</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 (Beginning)</td>
<td></td>
<td>48.00</td>
<td>19.83</td>
</tr>
</tbody>
</table>
Unlike with the cell concept, results for the matter concept showed that experts and novices differed in almost every period, especially during the early-mid period (M_{Novices} = 57.59, SD = 39.08; M_{Experts} = 81, SD = 38.16) and final period, where the total number of movements were higher for experts than novices (M_{Novices} = 100.82, SD = 58.33; M_{Experts} = 131, SD = 66.09). For the matter concept, the highest number of movements for both groups occurred during the final period, similar to the results for the ell (M_{Novices} = 100.82, SD = 58.33, Min = 55, Max = 280; M_{Experts} = 131, SD = 66.09, Min = 57, Max = 207).

Table 5.

**Total Number of Acts for Novices and Experts during Each Period (Matter)**

<table>
<thead>
<tr>
<th>N</th>
<th>Period</th>
<th>Matter</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Novices</td>
<td>1 (Beginning)</td>
<td>32.29</td>
<td>20.55</td>
</tr>
<tr>
<td></td>
<td>2 (Early-mid)</td>
<td>57.59</td>
<td>39.08</td>
</tr>
<tr>
<td></td>
<td>3 (Late-mid)</td>
<td>54.18</td>
<td>29.21</td>
</tr>
<tr>
<td></td>
<td>4 (Final)</td>
<td>100.82</td>
<td>58.33</td>
</tr>
<tr>
<td>Experts</td>
<td>3 (Beginning)</td>
<td>44.67</td>
<td>9.29</td>
</tr>
<tr>
<td></td>
<td>2 (Early-mid)</td>
<td>81</td>
<td>38.16</td>
</tr>
<tr>
<td></td>
<td>3 (Late-mid)</td>
<td>73</td>
<td>39.89</td>
</tr>
<tr>
<td></td>
<td>4 (Final)</td>
<td>131</td>
<td>66.09</td>
</tr>
</tbody>
</table>

Additionally, some of the other acts (controlling and checking, cross-link, reasoning and revision) were examined in terms of frequency across the previously defined periods. For controlling and checking, novices preferred to control their maps in every period of the CM development process, while experts tended to exhibit control mostly in the early-mid and final periods. Experts did not control their CMs in the beginning period, while novices controlled their maps at a lesser frequency than during other periods. Furthermore, the frequency of the controlling and checking act for novices was higher than for experts in the beginning, late-mid, and final periods. For constructing cross-link, a similar pattern was observed for novices. Novices tended to construct cross-link during every period, while experts constructed cross-link in every period except the beginning. The results also showed that experts constructed more cross-link than the novices. One potential reason for this difference is the extent of the knowledge of the experts; their experience with CMs may have also directly caused an increased tendency to construct additional cross-link.

In regard to the act of reasoning, both novices and experts tended to show a higher frequency of reasoning than any other act during any period. The results showed that both novices’ and experts’ frequencies developed according to a similar pattern except during the early-mid period, where novices showed a leap. Experts tended to reason across multiple periods and more frequently than the novices. As for the revision act, it was most frequently observed in the final period for both groups. However, a slightly different pattern was
observed for novices, who tended to revise their maps more frequently than experts and across the entire range of periods. In sum, the findings showed that the frequency of these acts varied in different periods for novices and experts (See Figure 5).

=Figure 5 is about here=

5. DISCUSSION

This two staged study used eye tracking for exploring the cognitive processes of novices and experts throughout the CM development process in a qualitative manner. The limited number of studies on integrated approaches to the CM development process led the researchers of this study to explore a unique perspective with regard to the expertise issue.

5.1. Eye Behavior Analysis

The eye behavior analysis aimed to disclose the cognitive process of experts and novices. The results showed that novices had higher fixation counts than experts on their CMs, independent from subject. Moreover, when fixation duration and visit duration periods were compared, novice fixation duration periods were shorter than the experts’ for the cell concept. On the other hand, for matter, the fixation duration values for experts and novices were closer. In terms of visit duration periods, novices invested less time during their CM development process when compared to experts.

The findings on differences between novices and experts according to visit duration periods have a parallel view with the literature, in which experts are considered the slower thinkers (Goldstein, 2005). During the problem solving process, for instance, experts are slower because they are focusing on comprehending a problem instead of trying to solve it (Goldstein, 2005). This strategy led to better overall CM production, although it was more time consuming than the strategy embraced by the novices. Novices had higher fixation counts than experts for both concepts (cell and matter). This difference might be associated with the difficult nature of constructing a map while simultaneously trying to provide all knowledge for the structure. According to Schau and Mattern (1997), “map generation imposes a high level of cognitive demand, both spatial-visual and verbal, on the student. Demand is higher when the assessment task requires students to create an entire map including the concepts” (p. 173). Additionally, the literature supports the view of the increase in fixation count as a possible indicator of cognitive process or a particular interest in that area (Holmqvist, Nystrom, Andersson, Dewhurst, Jarodzka, & Van de Weijer, 2011; Doherty, O’Brien, & Carl, 2009).

Three specifically selected acts (reasoning, controlling-checking, and cross-link) were also compared according to the eye behavior metrics. The findings showed differences between experts and novices in terms of fixation duration periods. Experts’ fixation duration periods for all selected acts were longer than those of novices in cell and matter concepts. For the cross-link act, experts demonstrated drastically higher periods of time engaged than the novices for both subjects. The time spent controlling and checking was also longer for experts than novices. For the reasoning act's the fixation duration, experts spent similar lengths of time on both subjects, while novices spent more time on the matter concept than the cell. This difference in fixation duration could be related to one particular expert's lengthy CM development process. According to Liversedge and Findlay (2000), the increase in fixation duration and number can be considered a connection to a cognitive difficulty. The experts clearly represented a different pattern during the whole process as well as individual phases. This difference might be related to the different thinking structure of the experts. Comparison
eye tracking studies on chess (Gobet & Simon, 1996; Charness & Reingold, 1992) support this view, highlighting how experts have fewer fixations since they focus on the big picture instead of small elements. Medin, Ross and Markman (2001) have a parallel view: unlike novices, experts use a group of meaningful information which includes many more pieces. As the eye movement metrics showed, experts and novices exhibited different eye behavior patterns for both the entire process and within the selected acts. For the reasoning act, experts’ fixation duration was higher in both academic subjects than that of the novices. The difference in the selected acts (reasoning, controlling-checking, and cross-link) might be associated with the difference in their knowledge organization and routines that they embraced, plus the complexity of the acts themselves. Additionally, experts tended to construct more cross-link than novices, but the attempts of novices increased their total spent time in the cross-link act. The difference between cross-link actions could be related to the difficulty of constructing cross-links for novices, since it requires bringing together information from different branches. According to Goldstein (2005), the knowledge organization of experts differs from novices, who classify problems in terms of similarities of objects; experts tend to classify problems by considering general principles.

5.2. General Patterns Revealed During CM Development

The verbal, eye behavior, and written data results proved that a deductive strategy was commonly embraced by both novices and experts during CM development. Three underlying reasons were determined for this preference: relations and concepts were structured more easily and smoothly, participants considered deductive thinking a learned habit, and the selected academic subjects were topics that participants felt lent themselves well to CM construction. In the literature, experts and novices differed in regards to competencies (Davidson & Sternberg, 2003) and reasoning strategies as well as the frequency with which they used those strategies (Patel & Groen, 1986). Conversely, the findings of this study showed that experts and novices followed a similar pattern of deductive reasoning, which might be related to the nature of the academic subjects selected for the study. Furthermore, the novices might have imitated their instructors, thus affecting their reasoning strategies. Although they did not differ in their general strategy during CM development, the knowledge organization and included information in the maps did differ between novices and experts.

Moreover, the results demonstrated that novices did not declare an initial strategy at the early steps of their CM development process, which may explain missing points and the overall poor quality of their maps. Instead of embracing a plan, they tended to write information as it came to mind in a stream-of-consciousness manner. However, eye movements and debriefing protocol data showed that novices did indeed follow a strategy of deductive reasoning without being aware of its presence. Kuhn and Dean (2004) emphasized the importance of metacognitive development and explained how to support it. One way is to have learners “reflect on and evaluate their activities” (p. 270). This act of reflection may help to focus the attention of the learners on an activity. Kuhn and Dean (2004) also proposed that facilitating a communication platform, including asking probing questions about the reasons for participants’ actions, might help learners question themselves during independent CM construction. Modeling these processes could help the learner to construct a better, more deliberate initial image and start map creation in a more structured manner.

The higher quality CMs produced by expert participants were due not only to their greater grasp of knowledge but also their increased understanding of organization strategies used to display knowledge effectively. This finding might be a clue for instructors to guide students throughout the process and use metacognitive support. The importance of guidance and appropriate instruction were also emphasized by Sternberg and Grigorenko (2003). They
suggested that without appropriate guidance or support provided by a coach, poor performers cannot advance to higher levels. Monitoring learners and guiding them through their processes by asking questions helps them develop awareness about their thinking strategies.

Moreover, other observed patterns included embracing hierarchical type maps and constructing branches in different manners. Preferring hierarchical maps could be related to embracing deductive reasoning, a top-down strategy, as well as the suitability of the academic subject for hierarchical mapping. The importance and practicality of using hierarchical mapping has been emphasized in literature as well. Novak and Gowin (1984) argued that CMs need to be presented in a hierarchical manner. They expressed how hierarchy enables the mapper to add new concepts and links, construct new branches, or alter existing branches (Novak & Gowin, 1984). According to Quillian (1968), hierarchical structure is similar to the CM structure; hierarchical structure consists of nodes and links, much like CMs show relationships among concepts with links while specifying the meaning of the concept as a whole. The importance of cognitive structure for meaningful learning is related to the organization of concepts in the mind. This idea was explained by Ifenthaler et al. (2011). Guiding students to develop hierarchical mapping might be beneficial in that it helps them to arrange the information in their minds, and then adequately visualize it.

In terms of filling out requested information, both novices and experts followed a deductive order; first they filled in the concept boxes, then they pointed out the related word, and finally they continued to the next concept box. Filling out the information by following a specific pattern might be related to the processing order of the mind. The participants might have filled out the CM in this manner because of unrealized groupings in the mind or previously learned behavior. This method for completing a CM might have also been taught by their instructors.

While constructing branches in CMs, novice participants tended to follow a different branch construction pattern than the experts. Novices preferred to act in a synchronized manner, constructing branches simultaneously in the aforementioned "mirror image" style, while experts showed a reverse pattern, completing one branch entirely before moving to the next. According to Goldstein (2005), novices differ from experts in terms of classifying the problems regarding their similarities, whereas experts tend to classify problems in terms of general principles. According to Hoffman and Militello (2008), instead of using special reasoning processes, experts are distinguished from novices in their knowledge organization and the way that they use this knowledge. Hoffman and Militello (2008) explained that the expert's knowledge is specific to their domain of study, and thus is broad and well organized. The difference between novices and experts could be related to differences in knowledge organization structures and embraced strategies during reasoning. In terms of branch construction pattern, novices need to be guided to complete an entire branch instead of addressing different branches at the same time. This adjustment might help them focus on relevant information, which might also prevent misconceptions.

5.3. CM Development Progress Pattern Analysis

In order to identify recognizable patterns among participants in terms of their progress during the CM development process, four periods during their progress were examined. The findings showed patterns among experts and novices in terms of the frequency of determined acts across a specific period. According to the results, the highest total numbers of acts for both experts and novices were during the last period for both the cell and matter concepts. The beginning and final periods’ total numbers of movements were closer to each other than the other periods for novices and experts. In the late-mid period, there was an appreciable difference between novices’ and experts’ total numbers of movements. The results for the matter topic showed
that experts and novices differed in every almost period, unlike the cell topic. Especially in the early-mid and final periods, the total number of movements was higher for experts than novices.

The increase in the total number of movements towards to the final stage might be related to participants’ constructing fewer concepts and their efforts checking errors or revising their maps. Experts had done more controlling and checking of their maps than the novices in every period, especially in the final period, generating fewer misconceptions than novices. Experts’ extended knowledge and experience could also be a reason for fewer misconceptions in CMs. Although experts generally spend more time in the problem solving process than novices, this strategy yields more effective results (Goldstein, 2005). One critical suggestion for novices, therefore, is to control their maps frequently in every period (beginning, early-mid, late-mid and final).

In terms of the reasoning act, experts had a higher frequency in the first period than the novices, although the total time spent on this act in the third and last periods showed a similar pattern. This finding might be related to the experts' and novices' different knowledge organization during problem solving. As Goldstein (2005) expressed, experts are slower thinkers who prefer to comprehend the problem instead of attempting to solve it; they spend more time in the problem solving process than novices.

### 6. CONCLUSION

The results of this study suggest that CMs are valuable tools for visualizing information in the mind and they provide gateways to meaningful learning. Researchers provided a different angle to concept mapping, investigating participants' cognitive processes. Analyzing the CM development process from beginning to end prompts consideration of critical points. This study offers valuable information on the cognitive processes of pre-service teachers during CM development and may help them to regulate the process of teaching while considering differences between learners in terms of CM development patterns.

In order to understand how novices and experts establish CM processes, verbal and written data were collected. The results showed that novices and experts exhibited different patterns both throughout the process and within selected acts. Novices and experts also differed in eye behavior metrics, fixation count number, and fixation and visit duration periods. In terms of specific strategies, it was proved that both novices and experts embraced deductive behavior during their CM development. It was also demonstrated that novices and experts have different initial strategies and branch construction patterns. According to the general patterns, experts and novices differed in almost every phase of CM development.

The following suggestions are introduced for practical and effective usage of CM: instructors need to consider the unique knowledge structure of the participants; instructors need to give special attention to the CM development process during instruction; learners need to be better guided about their misconceptions; and learners need to be directed in specific progression periods on specific actions. Before and after the CM development process, special attention needs to be given to several specific points—better preparations on the topic, checking information constantly, looking for cross-link opportunities, and constructing cross-link at adequate periods. Furthermore, in order to provide a better CM experience for the learners, computer-based instant feedback mechanisms should be developed. In addition to individual concept mapping, group concept mapping processes need to be established. New developments in technology require adapting to the learner instead of the environment or tool, and in this respect, materials need to be designed considering modern users' needs.
Although this study was conducted in an institution where the mode of instruction is English, the practical suggestions for these kinds of diagrams could also be applicable for teachers who teach in Turkish. The results of the study may also provide clues for both researchers and teachers, as they can authorize the process of increasing map quality and preventing misconceptions with adequate feedback and support while maintaining the perspectives of the learners as a priority. This study faced some limitations outside the control of the researchers. The limited sample size of experts can be considered a limitation that affected analysis methods. Because of the limited number of experts, statistical analysis could not be employed. Furthermore, gender imbalance might be considered a limitation. In further studies, such limitations could be handled by including enough experts to apply statistical analyses. Similarly, the gender imbalance could be addressed by equalizing the sampling in terms of gender.

REFERENCES


Ifenthaler, D., Masduki, I., & Seel, N. M. (2011). The mystery of cognitive structure and how we can detect it: tracking the development of cognitive structures over time. Instructional Science, 39, 41-61.


