HOW LEARNERS VISUALLY NAVIGATE CONCEPT MAPS: AN ANALYSIS OF EYE MOVEMENTS

by

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ABSTRACT

This research examined the eye movements of students who were instructed to use computer-based concept maps to complete an argument and identify argument-relevant information. Fifty participants were shown the same three concept maps and asked to use them to construct arguments. Fixation frequencies, durations, and sequences for nodes and links were analyzed. Eye movements were compared between participants as well as across concept maps. The results indicated that the participants actively processed nodes longer than links, and moved their gaze from one node to a connected node more often than to an unconnected node. In most cases, participants did not preferentially follow the direction indicated by the arrowhead. These findings have implications for classroom and textbook deployment of concept maps as learning resources.

Keywords: eye movements, concept maps, argumentation, eye-tracking

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CHAPTER I: OUTLINE OF THE THESIS

Previous research has indicated that concept maps can support a learner's understanding of the relationships between concepts (Novak & Gowin, 1984; Novak, 1993; O'Donnell, Dansereau, & Hall, 2002; Novak & Canas, 2006). There is theoretical and empirical support for the idea that students learn structural knowledge, the arrangement of connections between concepts (Beissner et al., 1993), by studying and creating concept maps. Argumentation has been recognized as a process of acquiring and representing one's structural knowledge. Building arguments requires a student to identify relevant concepts, rearrange and organize the concepts, and synthesize a coherent, reasoned assertion. An inference from these theories is that when students are asked to construct an argument from the information presented in concept maps, they will cognitively process the relationships between concepts in the maps.

Eye movement tracking has become a widely accepted technique in educational research (Rayner, 1998; Rayner, Li, Williams, Cave, & Well, 2007; Rayner, 2009; Findlay & Gilchrist, 2003). Eye-tracking equipment is able to provide researchers with fixation duration and frequency measures that can be analyzed to reveal detailed information about a student's cognitive processing (Hodgson, Bajwa, Owen & Kennard, 2000).

Amadieu, van Gog, Paas, Tricot and Marine (2009) explored the effects of prior knowledge and concept map structure on participants' disorientation and cognitive load. Eye-tracking equipment collected pupil dilation and fixation duration data while students studied concept maps. Their conclusion suggested that eye movement data could provide an understanding of the cognitive processes underlying studying from concept maps.

In this study, participant's eye movements were tracked to explore how they mentally processed relationships while using a concept map in an argumentation task. Students were given the task of constructing an argument from evidence embedded in concept maps. The measures included participant fixation counts and fixation durations on the nodes and links in the concept maps.

1.1 Research Aims

Concept maps are assembled from nodes and lines. The nodes represent concepts, and the lines between the nodes represent relationships. Each line has a label (the link) that describes the relationship between the two nodes it connects. The visual properties of a line can encode supplemental information about the relationship between two nodes. For example, arrowheads may be attached to lines to denote the directionality of the relationship (Wiegmann, Dansereau, McCagg, & Rewey, 1992).

Conventionally, concept maps have been understood to comprise fundamental units, or node-link-node segments, called propositions (Novak & Gowin, 1984, p. 15). By connecting propositions, concepts are organized into a larger framework that allows learners to understand the presented structural knowledge.

Although concept maps represent relationships between concepts, prior research has not determined how students construct knowledge about these relationships when they read a concept map. It is unclear whether the visual elements designers implement to illustrate relationships are guiding learners in their understanding of the concept map. As well, it is unknown whether the visual properties of lines that represent supplementary information about propositions have utility for comprehension or only contribute needlessly to concept map complexity (Wallace, West, Ware, & Dansereau, 1998).

There are three premises that form the foundation of the research questions in this study: (1) Constructing an argument will require participants to understand how nodes and links relate to form relationships, thereby inducing participants to expend cognitive resources on nodes and links. (2) Participant eye movements will focus on the elements of the concept map that reveal information about the relationship between concepts. (3) Concept maps are constructed from propositions and therefore participants will view the concept map in terms of node-link-node units in order to comprehend the relationship between nodes.

This research was guided by the following research questions:

Research question 1: Do participants fixate longer on nodes or links during an argumentation task?

Hypothesis 1: Participants will fixate equally on nodes and links during the argumentation task. The argumentation task will require participants to identify and understand the relationships in the concept maps. Since relationships are expressed in node-link-node segments, fixations need to be equal in order for participants to completely ascertain the proposition.

Research question 2: Do the lines that connect nodes guide eye gaze as learners study concept maps?

Hypothesis 2: The lines that connect nodes will guide eye gaze as learners study the concept map. Learner eye movements will reflect the goal of understanding the relationship between nodes. Therefore, participants will use the lines to guide their eye gaze through the concept maps.

Research question 3: Do arrowheads guide eye gaze as learners study concept maps?

Hypothesis 3: Arrowheads will guide eye gaze as a learner studies a concept map, because they encode the directions of the relationships between nodes.

Research question 4: Do eye gaze patterns support the understanding that learners view concept maps in terms of propositional units?

Hypothesis 4: Gaze patterns will be consistent with the theory that learners view concept maps in terms of propositional units. The most common transition sequence found in eye gaze data will follow links connecting two nodes.

1.2 Approach and Assumptions

This research uses eye-tracking to understand the process of learning from concept maps. Although the use of an eye tracker to collect data has been used to investigate many teaching and learning phenomena (Rayner, 2009; Findlay & Gilchrist, 2003), I could only find one paper pertaining specifically to eye-tracking while studying a concept map. Therefore, the results of this study will provide valuable methodological insight for future eye-tracking research on the process of learning from concept maps.

As this is one of the first eye-tracking studies to investigate learning from a concept map, it is especially important to validate three assumptions. The first assumption is that the eye-tracking equipment will function properly. Alternate sources of data should corroborate the eye-tracking data results to ensure bias was not introduced when eye movement was measured. Second, participants will be engaged with the argumentation task and therefore will selectively focus on parts of the concept maps that are related to the argument. It is important to validate this assumption, because otherwise the eye gaze data will not inform our understanding of how participants search the concept map for information pertaining to relationships between concepts. The third assumption is that participants will use a similar ability to complete tasks across the three maps. Eye-tracking data from the maps will be used to replicate results. Therefore, confirming that a similar ability is needed to complete the map tasks is important.

1.3 Findings

Participants consisted of 50 undergraduate and graduate students from a mid-sized university in Canada. They were provided with an argument and asked to search three concept maps for evidence that could be used to support the claim. Their eye movements were tracked while they studied the concept maps, selected task-relevant information, and entered information supporting an argument.

Analysis of the eye-tracking data revealed that participants actively processed nodes longer than links. They were more likely to move their gaze between connected nodes than unconnected nodes. When moving their gaze from one node to a connected node, in most cases they showed no preference for following the direction indicated by the arrowhead. Therefore, the arrowheads provided in the map did not guide the participants' analyses of the presented relationships or synthesis of the argument. The fact that participants did follow lines, however, shows that they obtained relationship information from this key feature of the maps.

Transition sequences found in eye gaze data showed that participants did not traverse the concept maps strictly according to propositional units. Instead, the most common transition sequence consisted of a participant fixating on a node, then fixating elsewhere, and then returning to the node of origin. It was also found that the lines that connected nodes guided participant eye gaze. Therefore, participants obtained relationship information from this key feature of the maps.

1.4 Structure of the thesis

Chapter 2 reviews research literature on structural knowledge, concept maps, argumentation, and the use of eye tracking in the domain of educational research. First, I review the nature of structural knowledge and the difficulty of learning relationships between concepts. The theoretical framework of concept maps is presented to justify their use in educational settings. Furthermore, the visual properties of nodes and links and how they represent relationships in concept maps are discussed. Support for the use of argumentation to promote understanding of relationships is provided. Finally, the chapter concludes with previous literature on how eye tracking has been used in three areas of educational research: reading, problem solving, and information searching.

Chapter 3 lists information about participant recruitment and demographics. This chapter provides a detailed account of the study procedures, learning materials given to participants and the apparatus and software used to track eye movements. A description of the task performance data, eye-tracking data, and individual difference variables is included. The task performance data consist of the relevant node selection scores, post-test fill-in-the-blank concept maps scores, and time on task values. Eye-tracking data are in the form of fixation durations and counts, whereas the individual difference variables are scores on the Need for Cognition Scale and Vocabulary I test.

Chapter 4 is divided into two main sections that contain: (a) an analysis of task performance and (b) an analysis of the eye-tracking data. Descriptive statistics and strength of relationships (correlation coefficients) tests from task performance are presented. Finally, the analysis of the fixation duration and counts on nodes and links was reported in the eye-tracking data section. Paired t-test results between fixation durations and transition frequencies are presented.

Chapter 5 contains discussions of the research question results, as well as implications for teaching and learning. This chapter closes with the limitations of the present study and proposes possible future research directions.

CHAPTER II: LITERATURE REVIEW

2.1 Structural Knowledge

"Meaning does not exist until some structure, or organization, is achieved" (Mandler, 1983, p. 4).

Concepts are mental representations that allow us to perceive similarities and distinguish between ideas, images or words. They are abstract in nature and can be used to aid in characterizing knowledge as being relevant or irrelevant to a particular purpose. Bruner (1990) argues that concepts are formed when we attach meaning to the world and internalize observed phenomena. Without connecting concepts to each other and the world, they are hollow, orphaned pieces of information. A person's "explicit awareness" of the interrelationships among concepts is termed structural knowledge (Jonassen, Beissner & Yacci, 1993, p. 4).

Structural knowledge is the pattern of connections between concepts (Beissner et al., 1993) and can be viewed as a person's cognitive structure (Preece, 1976). Researchers have conceptualized structural knowledge as being the organizational dimension of declarative knowledge (Jonassen et al., 1993, p. 5; Mitchell and Chi, 1984). Yet, others may argue it is separate from but required when declarative knowledge is transformed into procedural knowledge (Tennyson & Cocchiarella, 1986).

Understanding the nature of structural knowledge is helpful when teaching and learning. The act of organizing concepts or mental representations facilitates comprehension, recall and transfer (Beissner et al., 1993) and is essential to learning. In order for mental constructs to be created and described, they require unique identities separating and situating them within related concepts. Students with a poor understanding of an area's structural knowledge do not have the foundation to position newly acquired concepts nor can they make inferences in order to solve problems (Jonassen et al., 1993, p.8). A well-developed knowledge structure in a specific domain can increase problem solving ability (Chi & Glaswer, 1985). Expert problem solvers tend to represent solutions as abstract patterns instead of focusing on the details of specific problems, thereby exhibiting a well developed knowledge structure (Larkin, McDermott, Simon, & Simon, 1980).

There are several challenges to representing structural knowledge. First, it is a multi-dimensional, non-linear construct and therefore is difficult to convey using conventional text. As well, an underlying property of structural knowledge is that concepts are semantically separated by "distance" (Jonassen et al., 1993, p.15). Although concepts are interconnected, not all connections are equally as robust and therefore this "distance" corresponds to the strength of the relationship. In addition, not only are the relationships incongruent in strength, they vary in type. Lastly, an individual's structural knowledge is dynamic and can be rearranged into multiple perspectives.

In response to the challenges listed above, several structural knowledge representations are visual in nature. Spatial layouts of information can illustrate the proximity of concepts, type of relationships, as well as multiple processing routes (Lambiotte & Dansereau, 1992). A few examples of visual representations that express structural knowledge are matrices and classification tables (Beissner et al., 1993). Each format differs in the types of relationships it can communicate (hierarchal, causal, example of, and so on). In educational settings, a commonly used visual representation of structural knowledge is a node-link diagram.

2.2 Concept Maps

Node-link diagrams, in which the nodes represent concepts, and the lines between the nodes represent relationships, can represent structural knowledge. Each line has a label that describes the relationship between the two nodes it connects. This label will be referred to as a link. The fundamental unit of a concept map is a node-link-node segment called a proposition (Novak & Gowin, 1984, p. 15). Propositions form phrases or meaningful statements - for example “Bali tigers are extinct”.

These visual displays are referred to by many names in the literature (Milam, Santo, & Heaton, 2000), such as network maps (Beissner et al., 1993) knowledge maps (O'Donnell, Dansereau, & Hall, 2002), cognitive maps (Grasha, 1996; Miles & Huberman, 1994) and concept maps (Novak & Gowin, 1984; Novak, 1980; Novak, 1981; Novak, 1993). However, this thesis will use the most commonly cited term, concept map, to refer to all node-link visual displays in which nodes are labeled with nouns or noun phrases (Nesbit & Adesope, 2006).

There has been growing interest in the efficacy of creating and learning from concept maps. Nesbit and Adesope (2006) estimate that over 500 peer-reviewed articles have been published which reference node-link diagrams or concept maps. They have been used in various business, science and education fields to facilitate communication creativity, and collaboration (Novak, 1998; Watters & Wu, 1999). Specifically, in education, students and instructors have used them to organize concepts, convey information, and problem solve (Novak, 1993).

Although the outcome measures from creating and studying concept maps are well documented in the literature, it is not yet fully understood how learning from concept maps affects cognitive processing. Currently, ideas from the theory of constructivism and research on human information processing are cited to support the use of concept maps.

2.2.1 Theoretical Framework

Novak and his colleagues first developed concept maps in the 1970s. They drew on Ausubel's assimilation theory (Ausubel, 1968) in developing a visual knowledge representation technique for science students (Milam et al., 2000). Ausubel argued that learners incorporate new concepts into preexisting cognitive structures and consequently he stressed the importance of anchoring new material to prior knowledge (Ausubel, 1968; Plotnick, 1997). He emphasized the role advance organizers, or other materials that provide an organizational cue in preparing students for upcoming concepts, could play in this assimilation process (Estes, Mills, & Barron, 1969).

The epistemological theory of constructivism has been traditionally linked to the investigation and use of concept maps (von Glasersfeld, 1991). Constructivists believe that learning is an active process taken upon by the student as she situates new information with previous experiences and constructs her own understanding (Nicoll, Francisco, & Nakhleh, 2001). Furthermore, constructivists have used concept maps to study how learners model their understanding (Cliburn, 1990).

Current information processing theories (Ashcraft, 2006) about the human memory system also offer support for the use of concept maps to facilitate meaningful learning (Novak & Cañas, 2006). While there are several models of human memory, many draw upon Atkinson & Shiffrin (1968) ideas of working memory and its interplay with long-term memory.

Working memory is the component of human memory that organizes and processes incoming information (Baddeley & Hitch, 1974). It has a limited capacity and can only hold and manipulate a few units of information at any given time. Typically, a person can retain five to seven pieces of information, whether they be numbers, letters, or concepts (Miller, 1956). In contrast, long-term memory stores large quantities of knowledge and its retention is practically unlimited (Baddeley & Hitch, 1974). It is the interactions between the new information in working memory and the prior knowledge loaded into working memory from long-term memory that result in learning (Novak & Cañas, 2006).

When a learner is rote memorizing, fewer connections are made between the incoming information and the preexisting structural knowledge, and therefore, newly acquired information can be easily and quickly forgotten. On the other hand, meaningful learning integrates incoming knowledge with information already stored in long-term memory (Novak & Cañas, 2006). This allows for ease of recall and potential for use of the newly acquired concepts in problem solving (Novak, 2002). It is this iteration of information processing between working and long-term memory that results in meaningful learning (Anderson, 1992).

There are two implications from the memory system literature that pertain to our theoretical understanding of the cognitive effects of concept maps. First, because the memory system organizes knowledge into a framework, information presented with special attention to structure will be easier to assimilate. Various sources suggest that teaching techniques which organize concepts into frameworks result in meaningful learning (Bransford, Brown, & Cocking, 1999; Tsien, 2007). These types of techniques provide a template for learners to organize the new information. Second, concept maps arrange and structure knowledge allowing for conceptual units to be manipulated in working memory. By grouping information into propositions, concept maps allow the learner to increase her working memory span (Novak & Cañas, 2006).

Concept map designers connect propositions to represent structural knowledge. However, design decisions regarding the visual properties of the map can alter a learner's perception of the presented relationship information. There are three visual components of a concept map, layout, node, and line, and their properties are discussed in the following section.

2.2.2 Visual Display

Concept map layouts vary throughout the literature, as nodes can be arranged in several spatial configurations (Lambiotte, Dansereau, Cross, & Reynolds, 1989). For example, Novak (1993) describes a top-down hierarchical structure, whereas other researchers construct these visual representations in a circular or cluster configuration (Jonassen, Reeves, Hong, Harvey, & Peters, 1997). Concept maps can also be created without a specific pattern, in which case the nodes can be heterarchical. Highly organized concept maps can guide a learner's attention and support their navigation (Amadieu, van Gog, Paas, Tricot, & Mariné, 2009). However this organization may restrict the types of relationships that can be made between the concepts.

The visual properties of a node -- shape (commonly circles and rectangles), size and colour -- are often used to signify importance or category (Milam et al., 2000). The visual properties of connecting lines sometimes encode supplementary information about the relationship between concepts (Lambiotte et al., 1989). Lines may be straight, curved, solid, dotted, barbed, or transparent. Such variations may differentiate among relationships that are primary or secondary, strong or weak, causal or correlational, implicit or explicit, and so on. (Milam et al., 2000; Wiegmann, Dansereau, McCagg, & Rewey, 1992). Arrowheads at one or both ends may be used to denote the directionality of the relationship (Wiegmann et al., 1992). There are two classifications of lines, unembellished (straight) and embellished. An embellished line encodes additional relationship information by varying its line properties (arrows, fill, shape).

Prior research has not determined whether altering the visual properties of lines to represent supplementary information about a relationship has utility for comprehension or learning or only contributes needlessly to concept map complexity (Wallace, West, Ware, & Dansereau, 1998). Two elements to be considered when determining line properties are the prior knowledge structure and working memory of the learner.

2.2.2.1 Prior knowledge structure and links

Structural knowledge that is consistent with prior knowledge can be assimilated into a person's schema, whereas novel or inconsistent organization may require a modification of a person's existing understanding of how concepts relate to each other. Instructional materials exhibiting a high level of organization impose specific structural knowledge on the learner. Such an imposition can be either beneficial or detrimental to the student, as a conflict between incoming and prior knowledge can lead to misconceptions and cognitive dissonance.

Concept maps with embellished lines are more highly organized than concept maps with unembellished lines and therefore may conflict with the prior knowledge structure of a learner. For example, Tsai, Lin, & Yuan (2001) discuss the importance of appropriately scaffolded computer assistance while creating concept maps. The 'free construction' version of the concept mapping software allowed students to create their own concepts and links, while a second version would insert a link from a pre-programmed concept map when students typed in the node. Students in the 'free construct' group had the flexibility to organize and represent their knowledge structure. However, this version places a greater emphasis on the student already having and then drawing correctly on the relevant conceptual knowledge. On the other hand, students using the partially constructed version may learn higher-order conceptual organization, but have to reconcile differences between their prior knowledge and the connections the software created for them.

As well, unembellished lines may trigger the learner to generate questions about two concepts where the relationship is not explicit. Thereby, preventing the learner from becoming disoriented in the map and burdened with too much information (Gurlitt & Renkl, 2008).

2.2.2.2 Working memory and links

Various studies resulted in the drawing of contradictory conclusions over the impact links have on a learner's working memory. Some research has shown that links alleviate the cognitive burden placed on students to generate their own relationships, while other research has shown that links increase extraneous processing. Two such studies are discussed below.

Lambiotte & Dansereau (1992) argue that learning materials need links in order to alleviate ambiguity and reduce the load on working memory. University students from a biology class were given a concept map, an outline, or a list of key terms alongside the lecture notes. Free-recall tests found that students with low prior knowledge learned most with concept maps, because the relationships between concepts were clearly stated. By explicitly labeling relationships, a learner is not left to deduce connections that may or may not be correct. This reduces the working memory load that might be incurred if the learner had to create her own relationships.

On the other hand, Wiegmann et al.'s (1992) Experiment 3 results imply that there is variation in how individuals process concept map lines and links, and that the specific properties of the lines and links affect how this processing occurs. Instead of decreasing cognitive load, an individual has to decipher the verbal information encoded in links and lines. In Experiment 3, university students were provided with a concept map about the human autonomic nervous system and then asked to complete a fill-in-the-blank and multiple-choice test. One group of students was given the concept map with embellished lines, while the other group received the concept map with unembellished lines. Students with high verbal ability performed better when they learned from concept maps with link embellishments, whereas low verbal ability students did not.

The study suggests that high verbal ability students were able to semantically process the concept map quickly, whereas the embellished lines stalled low verbal ability students. Consequently, when given the map with unembellished lines, low verbal ability students could focus on the nodes, thereby making it easier to manage the main ideas. Simpler connections alleviated extraneous processing.

2.2.3 What Makes a Good Map?

The creator of a concept map, whether a learner or teacher, must decide the specific salient characteristics of the layout, nodes, and, perhaps most importantly, lines. Berg (1999) acknowledged that there is no one "correct" algorithm when creating a concept map (as cited in Milam et al, 2000). Rather, since various learning activities elicit specific cognitive processes, a concept map should be evaluated upon how well its intended purpose is fulfilled.

2.2.4 Learning Activities

The cognitive and metacognitive processes activated when working with concept maps depend on the requisite learning task (Gurlitt & Renkl, 2008; Hauser, Nückles, & Renkl, 2006). Several examples of learning tasks include memorizing, summarizing, evaluating, differentiating, and building an argument.

Chang, Sung, & Chen (2001) compared biology pre and post-tests of students who created their own concept maps. They randomly assigned seventh grade students to three separate treatments. One group was asked to construct a concept map on a computer ("free-construction group"), another group was asked to construct a concept map with paper and pencil ("free-construction by paper-and-pencil"), whereas the third group was asked to complete a partially constructed concept map ("construct-on-scaffold"). Each student was provided a list of biological concepts and their relationships. It was concluded that different learning tasks involving concept maps led to disparities in learning outcomes.

A think-aloud study was conducted by Gurlitt, Renkl, Motes & Hauser (2006) exploring how prior knowledge is triggered during concept map assembly (as cited in Gurlitt et al, 2008). Learners were asked to complete two learning tasks while describing their thoughts aloud. First, students were given nodes and asked to draw the lines and label the links between them. Second, students were given another concept map with lines already present and instructed to label the links. The think-aloud protocols revealed an organizational process when students were asked to draw lines and label links, whereas labeling alone led to elaboration. The organization process includes specifying interrelations between concepts and higher order structure. In contrast, the elaboration process involves connecting new knowledge with previously existing knowledge.

These findings indicate that different learning tasks involving concept maps can cause various cognitive and metacognitive processes to be activated. One such learning task may be writing out an argument from the information provided in a concept map.

2.3 Argumentation

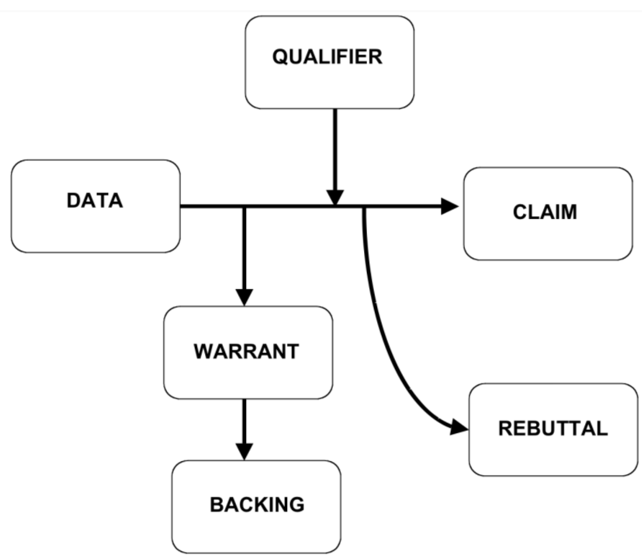
Considering and constructing opinions is an important skill in social, educational and vocational activities. When deciding between various options (i.e., which university major to study, which car to purchase) it is important to be able to critically evaluate the pros and cons and anticipate consequences. As well, group decisions are made such as which project to fund, course of treatment to provide, or person to hire. In all these spheres, it is an important asset to be able to logically defend your position. Therefore, argumentation skills (logical reasoning, critical thinking, and effective communication) are essential for students to learn (Nussbaum, 2008).

Argumentation is the process of using logic and evidence to reach a conclusion (Nussbaum, 2008). The product or argument is a logical conclusion deduced from premises, while the process is the act of constructing and evaluating these arguments (Kuhn & Udell, 2003). It has been repeatedly shown that directly teaching students about argumentation improves the quality of their arguments (e.g., Osborne, Erduran, & Simon, 2004; Zohar & Nemet, 2002) and their understanding of the argued concepts (Jimenez-Aleixandre & Pereiro-Munoz, 2002; Leach, 1999)

The teaching of argumentation skills has been investigated in many academic areas such as science (Osborne et al., 2004; Driver, Newton, & Osborne, 2000), law (Verheij, 2003) and history (Paz, 2005). A common argumentation structure used to teach these skills is Toulmin's argument model (Clark, Sampson, Weinberger, & Erkens, 2007; Toulmin, 1958). Toulmin (1958) states that an argument has several components that logically fit together (Figure 1). For example, the claim is the assertion a person is making, data/evidence supports this claim and a warrant links the data/evidence with the claim. It is thought that the greater the number of Toulmin's model components that used in an argument, the higher the level of sophistication and quality (Simon, 2008). Therefore, arguments that include rebuttals, or contradictory support, are more complex.

Written arguments express one's understanding of relationships between pieces of data because they involve organizing and formulating coherent proposals (Kelly, Regev, & Prothero, 2007, p. 137). As opposed to other tasks, such as free recall, students must draw upon their conceptual and structural knowledge in order to build a well thought out argument (Halliday & Martin, 1993).

Figure 1 Toulmin's argument pattern (Toulmin, 1959)



2.4 Eye Movement

Eye gaze is related to a person's motivation and goals (Hodgson, Bajwa, Owen, & Kennard, 2000), and therefore may be seen as a "window to the mind" (Just & Carpenter, 1984; Grant & Spivey, 2003; She & Chen, 2009). Eye movements have been studied in fields of usability and product design, assistive technology, and training simulations.

Eye gaze is comprised of two actions: short rapid movements (saccades) and stoppages (fixations). A saccade is the movement of the eyes, while a fixation is the maintenance of the fovea on a location (Rayner, 2009). The fovea is the part of the retina responsible for sharp vision, which is involved in reading, playing video games, and driving. Surrounding the fovea are the lesser acute parafoveal and peripheral regions. New information is obtained during fixations, while under normal circumstances, information appears as a blur during a saccade (Rayner, 2009). Therefore, in order to see clearly, a person will move her eyes until her foveal region aligns with the desired stimulus.

Fixations become longer and occur more frequently as the complexity of a task increases (Chi, Lin, & Lan, 2003; Hegarty et al., 1992; Rayner, 1998). For example, fixation duration increases as students are provided with gradually more difficult relational math word problems and classic mechanics physics problems (Hegarty & Just, 1993; Hegarty et al., 1992) and long words are more likely to be fixated on than short words while reading text (Brysbaert, Drieghe, & Vitu, 2005; Drieghe, Brysbaert, Desmet, & Baecke, 2004; Kliegl, Grabner, Rolfs, & Engbert, 2004).

2.4.1 Eye Movement Research in Education

Eye movement tracking has become a widely accepted technique in studying various topics in the education realm (Rayner, 1998; Rayner, Li, Williams, Cave, & Well, 2007; Rayner, 2009; Findlay & Gilchrist, 2003). These tasks include reading (Frenck-Mestre, 2005; Rayner, Chace, Slattery, & Ashby, 2006; Rayner, 1998), problem solving (Crowe, Averbeck, Chafee, Anderson, & Georgopoulos, 2000; Tai, Loehr, & Brigham, 2006), visual search (Najemnik & Geisler, 2005; Zelinsky & Sheinberg, 1997), and scene perception (Henderson, 2003; Rayner & Pollatsek, 1992). Eye movements can be studied to reveal step-by-step learner cognition during a given task. A thorough investigation of the education eye-tracking literature is beyond the scope of this thesis. However, three topics that are of particular relevance to concept maps and argumentation will be discussed below: reading, problem solving, and information seeking.

2.4.2 Eye-tracking and Reading

Eye-tracking has been used to study the process of reading since Javel, in 1879, described eye movements as being short movements and stoppages, instead of a continuous movement along a line (see Huey, 1908). Reading is a complicated cognitive process of deciphering symbols and translating them into verbal information. Eye-tracking studies have investigated second-language acquisition, comprehension, silent reading, and other reading-related phenomena (Frenck-Mestre, 2005; Rayner et al., 2006; Rayner, 1998).

There are two main decisions to be made while reading, when to move the eyes, or fixation duration, and where to move the eyes, or saccade length (Tsai & McConkie, 2003, p.160). The duration of a fixation typically lasts about 200-250 milliseconds and a saccade size is seven to nine letter spaces during silent reading (Duchowski, 2007, p. 213).

Fixation duration is a function of the specific task given to a participant. For example, fixation duration during silent reading is shorter than during other tasks such as oral reading, visual search and music reading (Rayner, 1998). As stated above, longer words are more likely to be fixated on than shorter words (Brysbaert, Drieghe, & Vitu, 2005; Drieghe et al., 2004; Kliegl et al., 2004). As well, readers demonstrated longer fixations when they read complicated sentence structures, difficult words (e.g., low-frequency words), or ambiguous syntax (Rayner et al., 2006; Frazier & Rayner, 1982).

The investigation of saccade length has produced several well-understood tendencies of readers. First, readers do not fixate on every word; in fact, most readers skip about one-third of all words (Rayner, 1998) - especially short or high-frequency words (Radach & Kempe, 1993; Brysbaert et al., 2005). Second, the location of the fixation also depends on word length. If the word is between four and ten letters, the fixation location is at the beginning or middle of the word, whereas words with longer than ten letters tend to have two fixations. These occur at the beginning and at the end of the word (Hyönä, Niemi, & Underwood, 1989; Rayner, 1998; Vitu, 1991).

Ten to fifteen percent of the time, readers will make a backwards saccade while reading text (Rayner, 1998). This is called a regression in the literature and is often induced by comprehension failure (Kliegl, Olson, & Davidson, 1982; Blanchard, & Iran-Nejad, 1987; Frazier & Rayner, 1982).

In summary, insightful temporal information about the process of reading is obtained through collecting eye movement data. Rayner (2006) asserts that eye-tracking technologies provide a researcher with a measure of the “moment-to-moment comprehension processes”. It has been repeatedly shown that as text increases in difficulty, fixation duration increases, saccade length becomes shorter, and the number of regressions increases.

2.4.3 Eye-tracking and Problem Solving

Researchers use think-aloud protocols, retrospective reporting, and decision analysis when trying to understand the minute details of problem solving. However, none of these analyses are free of participant bias and it is unlikely that a person is fully and consciously aware of her own cognitive processes. Eye movements permit researchers to make conjectures about the cognitive processes underlying problem solving (van Gog, Paas, Merrienboer, & Witte, 2005).

Eye movements have been studied during problem solving tasks that require eye movement strategies or visuospatial planning (Hodgson & Golding, 2003, p. 49). These types of problems include card sorting and the Tower of London. Kaller, Rahm, Bolkenius, and Unterrainer (2009) used eye-tracking to assess adult cognitive processes while solving Tower of London problems. This type of problem requires a person to mentally plan the shortest sequence of moves to rearrange a set of balls, and then to enter her solution on a computer. Kaller et al. found that independent of the problem information that was presented, participants tended to fixate initially to the left side. As well, the duration of the final fixation before the execution of a ball movement correlated highly with the difficulty of the problem. Therefore, this last fixation indicates a clear-cut separation between internalization and planning processes. The importance of their experiment was that it established that different phases of problem solving could be identified using eye-tracking equipment.

Diagram-based problem solving has also been studied using eye-tracking equipment (Grant & Spivey, 2003; Rosenblit et al., 2002; Epelboim & Suppes, 2001). Often, the specific aspects of a diagram draw attention and aid in the problem solving process. Grant et al. (2003) found that as they changed the nuanced details of the problem diagram by adding in animation, the probability of a student fixating on these changes and solving the question correctly also changed. As well, this study linked eye movement patterns with higher-order cognition. Grant et al. were able to distinguish between unsuccessful and successful problem solvers by analyzing eye movements.

Various cognitively demanding tasks are coupled with specific gaze-shifting approaches (Hayhoe, Bensinger, & Ballard, 1998; Hodgson et al., 2000). Eye movement patterns (i.e., the number, density, and clustering of fixations) have been linked to specific problem solving strategies in geometric reasoning (Epelboim & Suppes, 1997), mechanical systems (Rozenblit, Spivey, & Wojslawowicz, 2002), and spatial reasoning problems (Cook, Mitchell, & Goldin-Meadow, 2008). Furthermore, it has been demonstrated that experts and novices differ in their eye movement patterns when asked to solve problems.

Tai et al. (2006) presented pre-service science teachers with multiple-choice questions from the fields of biology, chemistry, and physics, while having their eye gaze tracked and recorded. A graph, table or image accompanied each question. Self-reports stated varying degrees of expertise in the three science areas. Eye gaze patterns were contrasted between experts and novices, and it was found that experts made shorter fixations, and that these shorter fixations were on different elements of the question. Tai et al. concluded that eye gaze data could be used to characterize participants and analyze approaches.

2.4.4 Eye-tracking and Information Searching

Visual search is a daily task that includes looking for cars keys, scanning webpages, and picking out your friend in a crowd. There are two factors that affect the direction of a subsequent saccade during visual search: the participant's viewing strategy and peripheral stimuli (Duchowski, 2007, p. 224). The viewing strategy is coupled with the given task, and attention capturing peripheral stimuli may include the onset of movement, coloured or bright stimuli (Todd & Kramer, 1993).

In an education setting, students may be asked to search within text, pictorial representations, and diagrams for specific pieces of information. Researchers have used eye-tracking equipment to study this behavior and have found various ways that prior knowledge affects eye gaze during information seeking.

One phenomenon attributed to prior knowledge that may influence how a person searches for information is the Einstellung effect. This is when a person is prevented from searching for a better solution because of their predisposition to choosing the answer that has already occurred to them (Luchins & Luchins, 1954). A recognizable feature of the problem may prompt the first solution.

Bilalic, McLeod, and Gobet (2008) explored this effect by tracking the eye movements of chess players. Expert and novice chess players were shown board configurations and asked for the optimal solution (least number of moves until checkmate). The problems were set-up to have two solutions. One solution was a familiar sequence taught to all skilled players, while the other solution was a shorter, less familiar sequence. Expert chess players claimed to be seeking alternative solutions; however, their eye movements indicated that they were focusing on the squares related to the first solution sequence. This bias led to skilled chess players performing below their skill level.

This study emphasizes the notion that people seek information that is congruent with their prior knowledge (McKenzie, 2006; Nickerson, 1998). Amadieu et al., (2009) also studied the effects of prior knowledge by tracking eye movements. They conducted a 2 X 2 factorial design where one of the factors was prior knowledge, and the other factor was type of information stimuli. Two groups of students were provided with concept maps about the HIV virus infection process. One group was provided with training about how a retrovirus replicates (high prior knowledge), while the second group was not provided with this training (low prior knowledge). There were also two types of concept maps, one that had a hierarchical structure (HS), and one that had a network structure (NS). Each map had one introductory information node, eleven anatomic information nodes, and thirteen functional information nodes. Pre- and post-tests revealed that low prior knowledge participants had higher conceptual knowledge gains when given hierarchical concept maps to study.

The researchers collected eye movement data to provide information about the cognitive load imposed by the cognitive processes required to navigate and learn from the concept maps. Each node in the maps was identified as a “LookZone”, or “Area of Interest”, in order to filter the fixation durations into meaningful regions. The percentage of time spent fixating on a “LookZone” was considered the attention allocated to understand the material.

The results showed that the low prior knowledge participants had higher fixation durations on the HS map. As well, for the NS map, the mean percentage of time spent fixating on the anatomic nodes was greater for the higher prior knowledge participants. Therefore, the eye-tracking data showed high prior knowledge subjects were able to focus on the elements of the network map necessary to understand the concepts better than students with low prior knowledge. They concluded that when given a less structured concept map, high prior knowledge students were able to recognize elements that were familiar to them and that helped guide them through the understanding process.

2.5 Summary

An important consideration when designing and using teaching materials is whether the learner will interpret the materials as intended. If the materials are vague or unspecific, the learner may have trouble comprehending the information, leading to misconceptions or gaps in understanding. However, cognitive overload or dissonance may occur if the presented information is in conflict with prior knowledge. A strain on working memory will result in learners avoiding components of the materials intended to be of use. Therefore, insight into a learner's cognitive processes while studying can be a valuable asset when teaching and learning with materials.

Our understanding of the cognitive processes underlying searching and acquiring information from a concept map is full of gaps. One such gap is the role nodes, links, lines and arrowheads play in a learner's comprehension of presented relationships. It is unclear whether the conceptual unit of a concept map (proposition) and the accompaniments that support it (links, lines and arrowheads) are effective conveyers of relational information or increase map complexity to result in cognitive overload or dissonance.

A current trend in literature is for studies, such as the one conducted by Amadieu et al. (2009), to use eye-tracking equipment to investigate cognitive processing. Eye movement data are an objective measure of processing (Duchowski, 2003; Rayner, 1998), as fixation duration has been shown to provide a "good index of ease of processing" (Ball, 2003; Liversedge, Paterson, & Pickering, 1998), and fixation count indicates greater interest or complexity of the target (Poole, Ball, & Phillips, 2004). Specific eye gaze shifting approaches have been analyzed to identify problem solving strategies and phases (Kaller et. al., 2009), expert and novice behaviors (Tai et.al., 2006), high and low prior knowledge learners (Amadieu et. al., 2009), and viewing strategy (Duchowski, 2007, p. 224). Therefore, eye-tracking techniques can differentiate moment by movement learner motives and priorities while working her way though a task.

Different learning tasks draw upon specific cognitive processes, and therefore lead to patterns in eye gaze. A theoretical understanding of the cognitive processes required to complete the task can inform detection of these patterns from the raw eye gaze data. For example, a key operation in building an argument is to realize the relationships between pieces of evidence. As such, eye gaze patterns while searching for information and constructing an argument will be distinct. These patterns can be isolated from the data and fuel our detailed analysis of the cognitive processes involved in completing the task.

The following chapter outlines the methodology used to categorize such patterns from the eye gaze data collected as participants studied concept maps. They were asked to construct an argument from the information provided in the concept map so that they would focus on the relationships between ideas.

CHAPTER III: METHOD

3.1 Participant Recruitment

Advertisement for this study took place over a two-week period (September 8, 2009 – September 18, 2009). Posters in print advertising the study (see Appendix A) were displayed in classrooms, hallways, and the bus loop of a mid-sized Canadian university. As well, ten classroom announcements were made, and approximately fifteen messages were left on classroom chalkboards. Each announcement and message included a brief description of the study, contact information (email: edpsychstudy@gmail.com), and the amount of financial remuneration that would be provided. Participants expressed their interest via email, providing their availabilities for the month of September 2009.

3.2 Participants

Fifty university students (33 women and 17 men, *M* = 22.59 years old, *SD* = 4.15) volunteered for a one-hour session, and were paid $15 for participating. Identification numbers were assigned to all participants and data records to respect anonymity. Of the 50 volunteers, 41 were studying in an undergraduate program, 7 were working on a master's degree, and 1 participant was a Ph.D. candidate. As shown in Table 1, the majority of the participants were enrolled in either the Faculty of Arts and Social Sciences or the Faculty of Science.

Table 1 Faculty enrollment

Faculty	Number of participants
Applied Science	5
Arts and Social Sciences	18
Business	5
Education	7
Environmental Sciences	1
Health Sciences	1
Sciences	13
Total	50

3.3 Materials and Instruments

3.3.1 Purpose of Study and Consent Form

Print-based information (see Appendix B) detailed the purpose and goals of the study, risks, payment, and a statement of confidentiality, as required by the university's Office of Research Ethics. A consent form was provided along with the research study information (see Appendix C) for the participant to read, review, and sign.

3.3.2 Questionnaire

The "Participant Questionnaire" (see Appendix D) was created and administered digitally by the Tobii Studio software. The questionnaire requested information about age, gender, number of years studied in English, level of education completed, and current faculty and program of study.

3.3.3 Instructions Set

Participants were provided with a set of instructions on concept maps (Appendix E) and argumentation (Appendix F). The concept map instructions included a definition of concept maps and an explanation of how the combination of nodes, links, and arrows form meaningful propositions.

The argumentation instructions first described the advantages of constructing arguments from several points of view, rather than focusing solely on one side of a debate. As well, the parts of an argument (claim, support, and rebuttal) were defined along with examples. Finally, the instructions stated that arguments could be represented in concept maps.

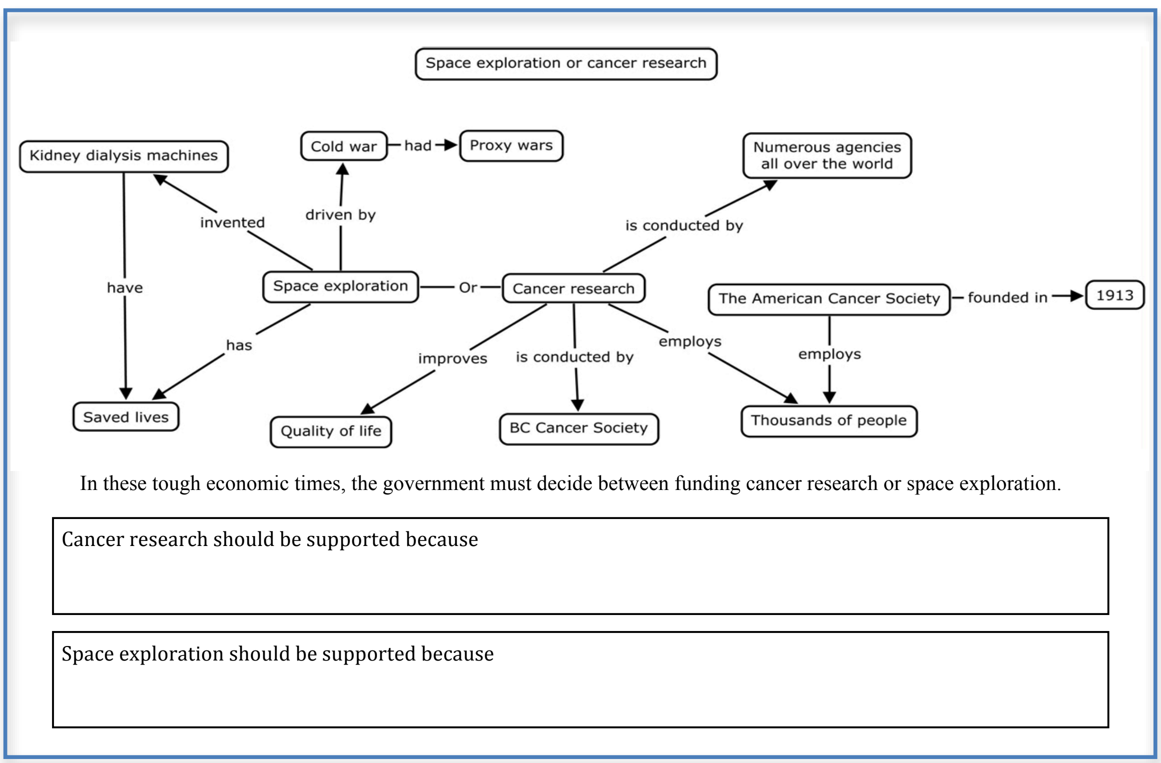
3.3.4 Practice Task

The practice task was built into a locally-stored webpage presented on the eye-tracker computer monitor. The page contained an embedded .swf ("Shockwave" or "Small Web Format") of an interactive concept map and two text boxes. The page also contained the statement: "In these tough economic times, the government must decide between funding cancer research or space exploration." In the first text box, students were asked to complete the statement, "Cancer research should be supported because". The second text box asked students to complete the statement, "Space exploration should be supported because".

Created using Adobe Flash and Aptana IDE, the interactive component of the concept map was the colour of the node outlines. These outlines would change from "black" to "red" when a participant moved the cursor over a node and "clicked" on it.

CmapTools software (available for download at http://cmap.ihmc.us) was used to construct the concept maps. This program was developed at the Institute for Human and Machine Cognition, and was chosen because of its simple display and features. The structure of the map did not conform to a radial or hierarchical design, and did not signal that the map should be read in left-to-right, top-to-bottom or centre-to-edge order. There were twelve propositions (node-link-node combinations), eight of which were related to the argument presented above, and four of which were extraneous to the argument. This concept map consisted of thirteen nodes that were connected by twelve links and unidirectional arrows (see Figure 2).

Figure 2 Practice task

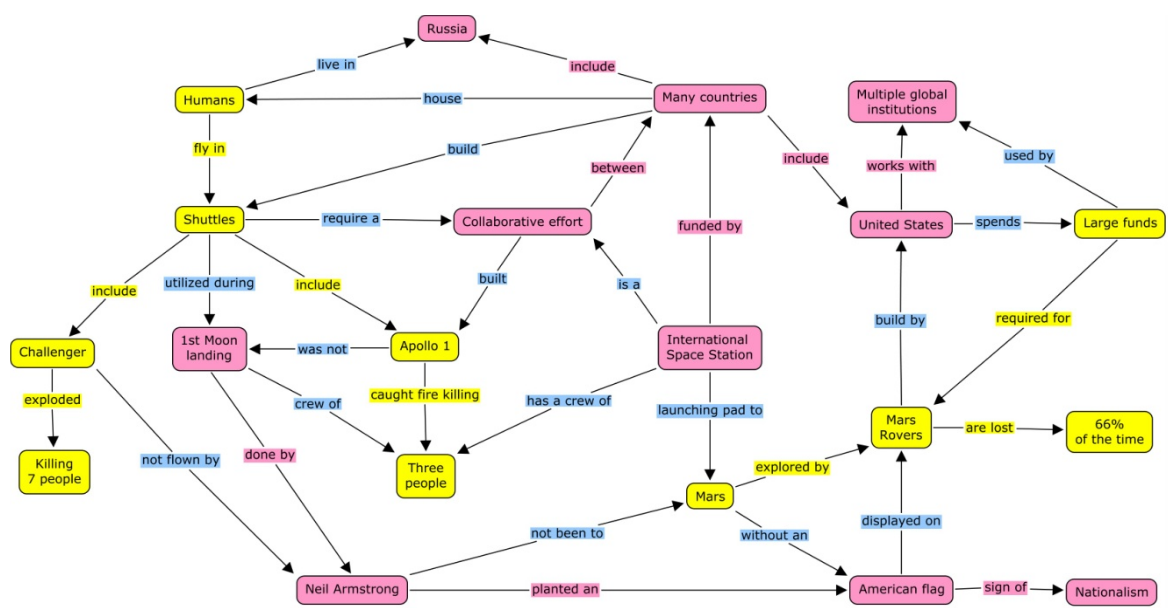


3.3.5 Map Task

The map task had participants interacting with three webpages. Each webpage contained a concept map (Map A, Map B, and Map C), two textboxes and two buttons. As above, the webpages were made using Adobe Flash and Aptana IDE and offered the same interaction features.

Evidence for two arguments were embedded into all three concept maps: "Should we support human space exploration or robotic space exploration?" (Argument 1) and "Is American space exploration fueled by nationalism or human curiosity?" (Argument 2). Each node could be categorized as belonging to Argument 1 or Argument 2. The outgoing arrows from each node went equally to Argument 1 nodes and Argument 2 nodes. Therefore, there were "within" argument lines (connecting two nodes from the same argument) or "between" argument lines (connecting two nodes from different arguments) as shown in Figure 3.

Figure 3 Colour coded Map A



The three types of propositions presented in the concept maps were: Argument 1, Argument 2, and “between” arguments (see Table 2).

Table 2 Composition of webpage concept maps

			Propositions		
Webpage	Nodes	Links	Argument 1	Argument 2	Between arguments
Map A	20	34	8	8	16
Map B	26	44	11	11	22
Map C	22	36	9	9	18

Immediately below the concept map, there were two textboxes. Below the textboxes, there were two buttons. The labels on the buttons were “Start” and “Submit”, and they controlled the textboxes. Using JavaScript, the contents of the textbox were written to an external text file when the “Submit” button was clicked, or were retrieved when “Start” button was clicked. Therefore, each participant could recover their response from Map A and add to it while working with Map B.

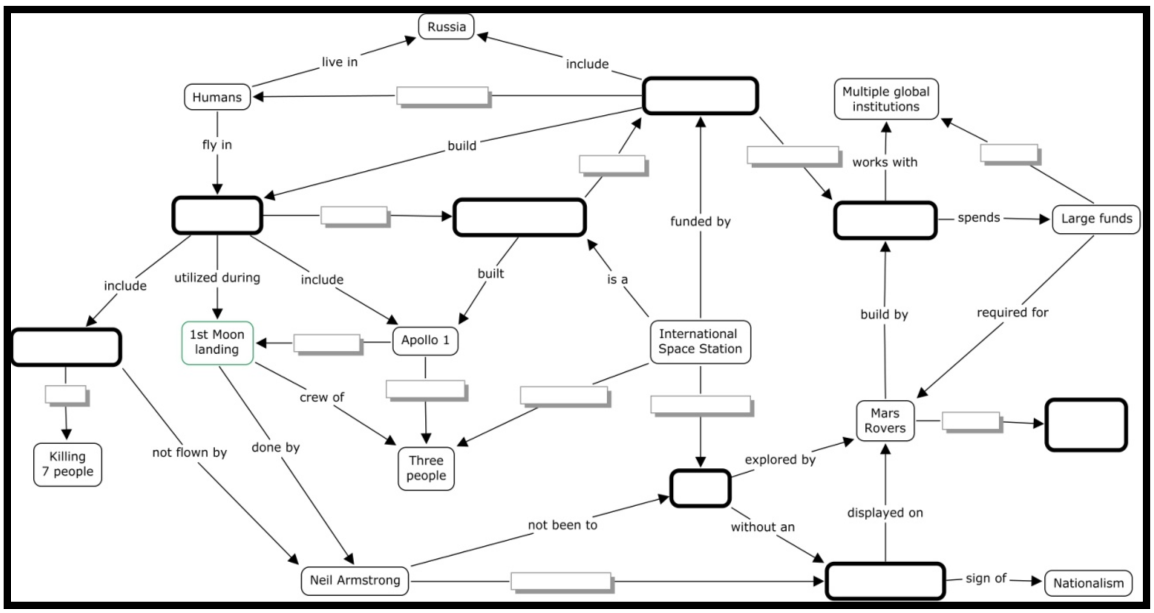
3.3.6 Fill-in-the-blank Concept Maps

Maps A, B and C were printed on three 8.5 X 11 inch sheets of paper. Each concept map was partially filled-in and created using the software program CmapTools (see above). As shown in Table 3, there were an even number of missing nodes from each of the two arguments, and an equivalent number of links missing within arguments and between arguments. Figure 4 is the Map A fill-in-the-blank image.

Table 3 Composition of fill-in-the-blank concept maps

	Blank nodes		Blanks links		
Sheet	Argument 1	Argument 2	Argument 1	Argument 2	Between arguments
Map A	4	4	3	3	6
Map B	5	5	5	5	10
Map C	4	4	4	4	8

Figure 4 Map A fill-in-the-blank



3.3.7 Need for Cognition

Cacioppo, Petty, & Kao (1984) authored the Need for Cognition Scale (NCS) that consisted of 18 items and measures "an individual's tendency to seek, engage in and enjoy effortful cognitive activities" (Zhou, 2008, p.48). The responses to each of the items are answered on a 7-point scale ranging from 1 (not at all true of me) to 7 (very true of me). Participant responses were combined over all items as the conceptualization of need for cognition (NFC) is a one-dimensional construct (Cacioppo, Petty, Feinstein, & Jarvis, 1996).

3.3.8 Factor Referenced Cognitive Tests - Vocabulary I

The Educational Testing Service (ETS) Factor Kit was first developed in 1954 (see Ektrom & Bejar, 1990) as a manual for researchers to obtain information about various cognitive factors. The current version contains 72 tests marking 23 cognitive factors.

The Vocabulary I test was chosen as a measure for the factor verbal comprehension. This factor is defined as the “ability to understand the English language” (Carroll, 1974). It is a 36-item test where the participant is given a word and asked to select the synonym from four choices.

3.4 Apparatus

The experiment took place in a room containing a desktop computer, mouse, keyboard, and eye-tracking equipment. A Tobii T120 eye-tracker was used to collect eye movements during display of the Windows XP desktop using Tobii Studio Analysis software (v 2.0.6) with “screen” as the stimulus option. Both the display and eye-tracker server ran on a 2.6 GHz Intel Pentium M Dell Inspiron 9300 desktop equipped with 2 GB RAM and an nVidia 6800 Go graphics card.

3.5 Eye-tracking Software

The eye-tracking system was controlled by Tobii Studio analysis 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. This system tracked what the participant was looking by using an infrared light source to illuminate the pupils and then captured the reflection. Along with gaze positions, mouse clicks and keystrokes were logged.

Tobii Studio allowed a researcher to define Areas of Interest (AOI) in order to filter the vast amounts of data into meaningful regions. Each node and link was defined as an AOI and measures, such as total time spent, number of fixations, and duration of fixations were recorded. To reduce the margin of error, the AOIs were defined to be larger than the actual outlines of the nodes and links.

3.6 Procedure

1. Participants were booked for an hour-long experimental session and paid $15. Fifty participants were given appointments, and all participants completed the session. Upon arrival, students were given print-based information about the study and a written consent form.

2. A "Participant Questionnaire" was administered on the computer in Tobii Studio software. Each participant was assigned a Tobii Studio identification number to track his or her eye gaze and responses to the questionnaire.

3. Each participant conducted an eye-tracker calibration using the standard automatic option in Tobii Studio. This process involves following moving red dots on the screen with the eyes and takes about 10 seconds. After the calibration, the program reported that the calibration had been successfully completed or recommended that the participant be recalibrated.

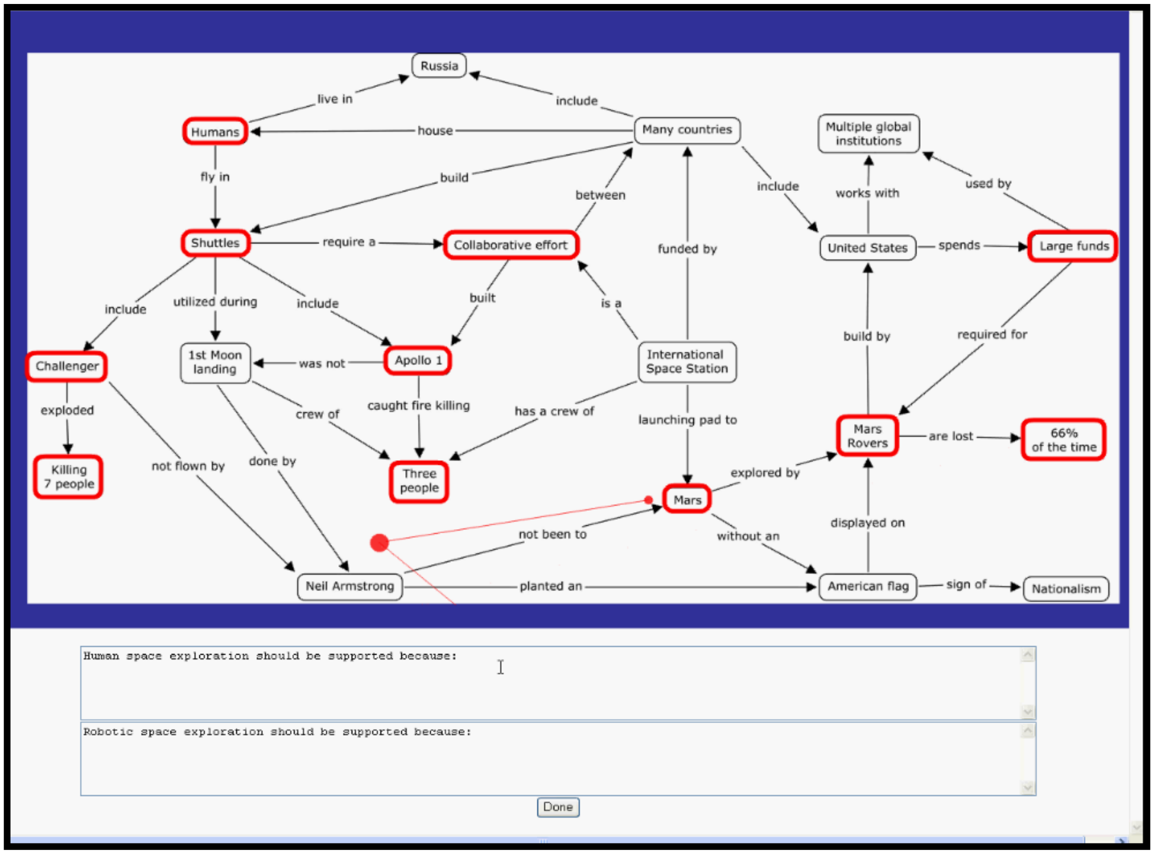
4. Once students completed the calibration, they were handed the instruction set. After the students read the instructions, the researcher orally reiterated the information

and asked the participants if they had a clear understanding of the various elements of concept maps and arguments.

5. Next, the participants completed the practice task. They selected argument related nodes on the screen and typed out the evidence for both sides of the argument in the text boxes. Once the student informed the researcher that they had completed the task to the best of their ability, the researcher and participant verbally discussed the participant's responses. Any misunderstandings of what the task required were clarified. Next, participants were provided with the answers to the practice task, including a sample written argument and a key identifying the correct relevant nodes.

6. The researcher presented Argument 1 to the participants and brought up the webpages containing the concept maps (Map A, Map B, and Map C) on the scren. The participants "clicked" on the nodes relevant to Argument 1, and typed out the argument in the textboxes below (see Figure 5). Students were given unlimited time to complete the task for each map.

Figure 5 Map A with selected nodes



7. After the map task was completed, three fill-in-the-blank concept map sheets and a pen were given to the participant. The participants were informed that there would be no time limit on this section and encouraged to attempt empty nodes and links, even if they could not recall the specific wording used in the original map.

8. Finally, the NCS and Vocabulary I instruments were administered to the students in print form. The NCS questionnaire was not timed. Participants were given eight minutes to complete the Vocabulary I test (as recommended by ETS Cognitive Tests Manual).

CHAPTER IV: RESULTS

The goal of this research was to understand how learners process concept maps as they complete a semantic task. Eye-tracking data were analyzed to answer the following questions:

(1) Did participants fixate longer on nodes or links during the argumentation task?

(2) Did the lines that connect nodes guide eye gaze as learners studied the concept map?

(3) Did arrowheads guide eye gaze as learners studied the concept map?

(4) Did eye gaze patterns support the understanding that learners view concept maps in terms of propositional units?

Before the eye-tracking data could be analyzed, it was necessary to establish that participants engaged with the concept map to extract meaning and complete the argumentation task. Therefore there are two main components of the results: (a) a section that reports an analysis of task performance and individual difference variables and (b) a section that reports an analysis of the eye-tracking data that directly addresses the research questions. The task performance and individual difference variables section deals with four types of data: (1) selection of relevant nodes on-screen; (2) post-test performance on fill-in-the-blank concept maps; (3) time on task for each map; (4) Need for Cognition Scale and Vocabulary I scores.

The later section deals with three types of eye-tracking data for Map A only: (1) Area of Interest (AOI) fixation count and duration; (2) single transitions; (3) multiple transitions. The analysis was restricted to Map A because a large portion of this investigation was methodological in nature and involved exploring a variety of methods for analyzing the eye-tracking data. For the purpose of publication in a scholarly journal I will apply the same methods reported here to Maps B and C as a way of replicating the results of the investigation reported here.

4.1 Task Performance and Individual Difference Variables

4.1.1 Selection of relevant nodes on-screen

Each map node was assigned a unique code representing its map location and corresponding argument (Argument 1 or 2). The number of participants that identified each node is presented in Table 4.

Table 4 Number of participants who selected a node

Argument 1 Nodes	Participants selecting node	Argument 2 Nodes	Participants selecting node
A11	44	A21	24
A12	45	A22	5
A13	28	A23	30
A14	40	A24	18
A15	42	A25	22
A16	35	A26	25
A17	27	A27	20
A18	50	A28	17
A19	42	A29	11
A110	40	A210	11
B11	38	B21	24
B12	41	B22	11
B13	36	B23	25
B14	36	B24	24
B15	25	B25	16
B16	19	B26	14
B17	18	B27	5

Argument 1 Nodes	Participants selecting node	Argument 2 Nodes	Participants selecting node
B18	36	B28	3
B19	45	B29	3
B110	49	B210	7
B111	20	B211	16
B112	42	B212	13
B113	21	B213	17
C11	33	C21	16
C12	35	C22	3
C13	26	C23	8
C14	18	C24	17
C15	10	C25	36
C16	24	C26	4
C17	18	C27	5
C18	45	C28	25
C19	41	C29	29
C110	35	C210	26
C111	42	C211	24

Table 5 shows the means and standard deviations of the number of participants who correctly identified the relevant nodes. Independent two-sample *t*-tests indicated the Argument1 nodes were identified significantly more than Argument 2 nodes in the maps ($p < 0.001$).

Using group means and standard deviations, a standardized mean difference effect size (Cohen's *d*) was calculated for each map. A large effect was found for each of the maps, indicating that the number of participants who selected Argument 1 nodes was at least one standard deviation greater than the number of participants who selected Argument 2 nodes (Cohen, 1969).

Table 5 Mean, SD, t-tests, and effect sizes for selected nodes

		Mean	SD	*t*	*p*	Cohen's *d*
Map A	Argument 1	39.3	7.3	6.31	.001	2.81
	Argument 2	18.3	7.6			
Map B	Argument 1	32.8	10.8	5.18	.001	2.03
	Argument 2	13.7	7.8			
Map C	Argument 1	29.7	11.3	2.16	.001	1.08
	Argument 2	17.5	11.3			

Three scores were calculated for each participant: Score on Map A Nodes (SAN), Score on Map B Nodes (SBN), and Score on Map C Nodes (SCN). One point was assigned for each correctly selected and correctly unselected node. The mean and standard deviation for these scores is shown in Table 6.

Table 6 Relevant node selection scores

Score	Max score	Mean score	SD	Mean percentage
SAN	20	14.20	3.42	71.0%
SBN	26	17.96	4.06	69.1%
SCN	22	13.68	2.83	62.2%

The relationships between the scores were analyzed and the Pearson correlation coefficients (*r*) are listed in Table 7. Strong correlations were found among the three scores indicating that a participant's performance tended to be similar across the three maps.

Table 7 Correlation coefficients between relevant node section scores

	SAN	SBN	SCN
SAN	1	0.452**	0.503**
SBN	0.452**	1	0.606**
SCN	0.503**	0.606**	1

** p < 0.01

4.1.2 Post-test performance on the fill-in-the-blank concept maps

Two researchers marked fifteen percent of the fill-in-the-blank maps. One point was assigned to each correctly written blank, and the points were summed to produce a score for each paper map. The interrater reliability for the raters was found to be Kappa = 0.93 (p <.0.001), 95% CI (0.90, 0.96). Since the interrater reliability was high, one researcher scored the remaining maps. Each participant received a Map A fill-in-the-blank score (SAF), Map B fill-in-the-blank (SBF) score, and Map C fill-in-the-blank score (SCF). Table 8 summarizes these results by providing the mean score, standard deviation, and mean percentage for each map.

Table 8 Participant scores on fill-in-the-blank task

	Max score	Mean score	SD	Mean percentage
SAF	20	8.84	3.91	44.2%
SBF	31	9.50	6.23	30.6%
SCF	27	12.58	5.02	46.6%

The relationships between the fill-in-the-blank scores were analyzed and the Pearson correlation coefficients (r) are listed in Table 9. Strong relationships were found among these three scores.

Table 9 Correlation coefficients between fill-in-the-blank scores

	SAF	SBF	SCF
SAF	1	0.610**	0.591**
SBF	0.610**	1	0.666**
SCF	0.591**	0.666**	1

** $p < 0.01$

4.1.2.1 Brief discussion

The results for the relevant node selection task verified the assumption that the learners were purposefully engaged with the task. If no statistically detectable difference had been found, then it would have been unclear whether or not the participants understood the instructions. Accurate identification indicated that participants were selective and not random in their choices.

On average, participants scored between 30-50% for the fill-in-the-blank task. This result was consistent with expectations as participants were instructed to only concentrate on the nodes that were relevant to Argument 1. This verified that participants were engaged with the concept maps for the purpose of analysis and synthesis, rather than memorization of information.

Two results verified the assumption that tasks across maps were similar. First, strong correlations were found among scores for the selection of relevant nodes. Second, strong correlations were found among the fill-in-the-blank concept maps scores. Weaker relationships would have indicated the set of three map tasks lacked internal consistency.

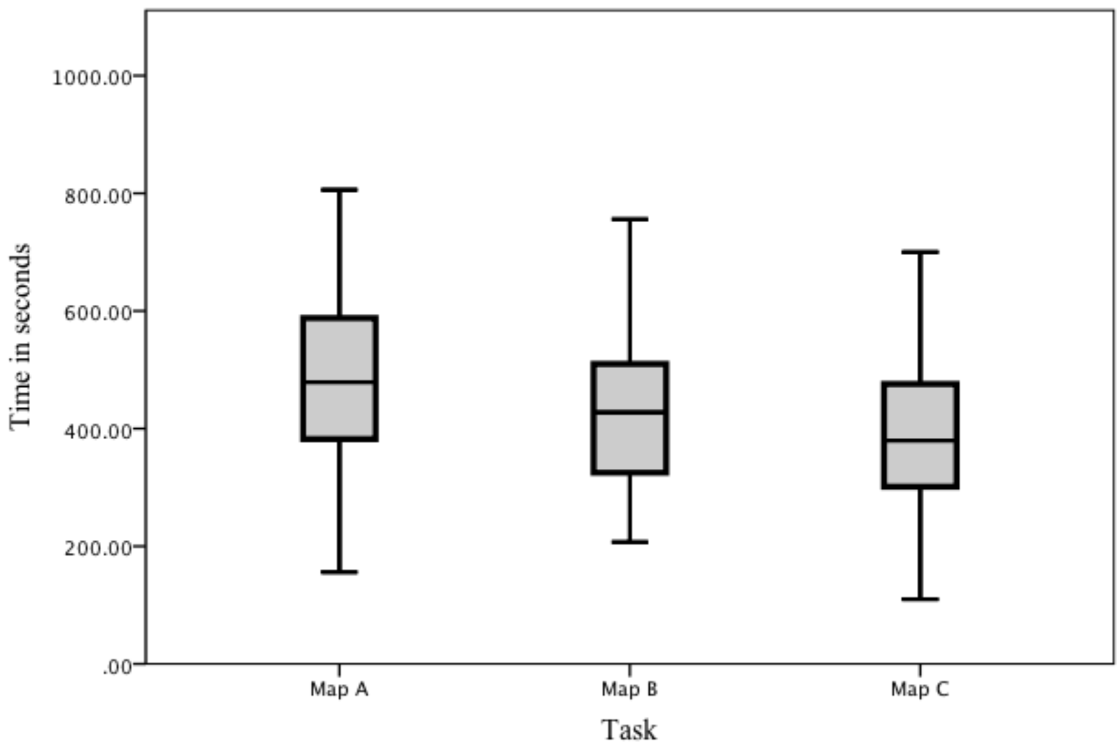
4.1.3 Time on task

Table 10 shows that, on average, participants spent less time on each successive map.

Table 10 Mean and SD for total time on task

Map	Mean (seconds)	SD
A	494.4	174.1
B	425.9	122.3
C	394.1	123.9

Figure 6 Boxplot of time on task



Strong relationships were found among time on task for the maps. The Pearson correlation coefficients (*r*) are listed in Table 11 and were found to be significant ($p < 0.01$).

Table 11 Correlation coefficients between times on task

Map	A	B	C
A	1	0.610**	0.496**
B	0.610**	1	0.545**
C	0.496**	0.545**	1

** $p < 0.01$

Table 12 shows that no relationships were statistically detected between time on task and relevant node identification scores. Relationships were detected between time on task and fill-in-the-blank concept map scores for Maps B and C, but not for Map A.

Table 12 Correlation coefficients between time on task and map tasks

Tasks / Time	SAN	SBN	SCN	SAF	SBF	SCF
Map A	-0.277	0.014	0.030	0.173	0.164	0.179
Map B	0.008	-0.008	0.054	0.081	0.303*	0.203
Map C	-0.047	0.014	0.094	0.067	0.308*	0.384**

** $p < 0.01$
* $p < 0.05$

4.1.3.1 Brief discussion

One emerging trend was that participants spent less time viewing each subsequent map. This may have resulted from increasing routinization or fatigue from previous tasks.

Weak relationships were found between time on task and fill-in-the-blank concept maps. These results verified the assumptions that participants were engaged with the argumentation task and therefore selectively focused on potions of the concept maps that they thought were related to the argument.

4.1.4 Need for Cognition Scale and Vocabulary I

Table 13 displays the mean and standard deviations of scores on the Need for Cognition (NFC) and Vocabulary I (VI) scales. The NFC was comprised of 18 questions, each requiring participants to express their answers on a seven-point scale. Nine of the questions used positive phrasing, while nine used negative phrasing. A score for each participant was calculated by inverting the responses to the negative questions and then summing across all questions. The scale showed a high internal consistency (Cronbach's alpha = 0.87). The VI test contained 36 questions, and the scores were calculated by summing the correct responses. Frequency distributions of participant NFC and VI scores can be found in Figure 7 and Figure 8 respectively. A statistically detectable relationship was found between the NFC and VI scores ($r = 0.50$, $p < .001$).

Table 13 Mean and SD of NFC and V1 scores

Measure	Mean	Standard Deviation
NFC	86.2	16.1
V1	22.5	8.3

Figure 7 Distribution of NFC scores

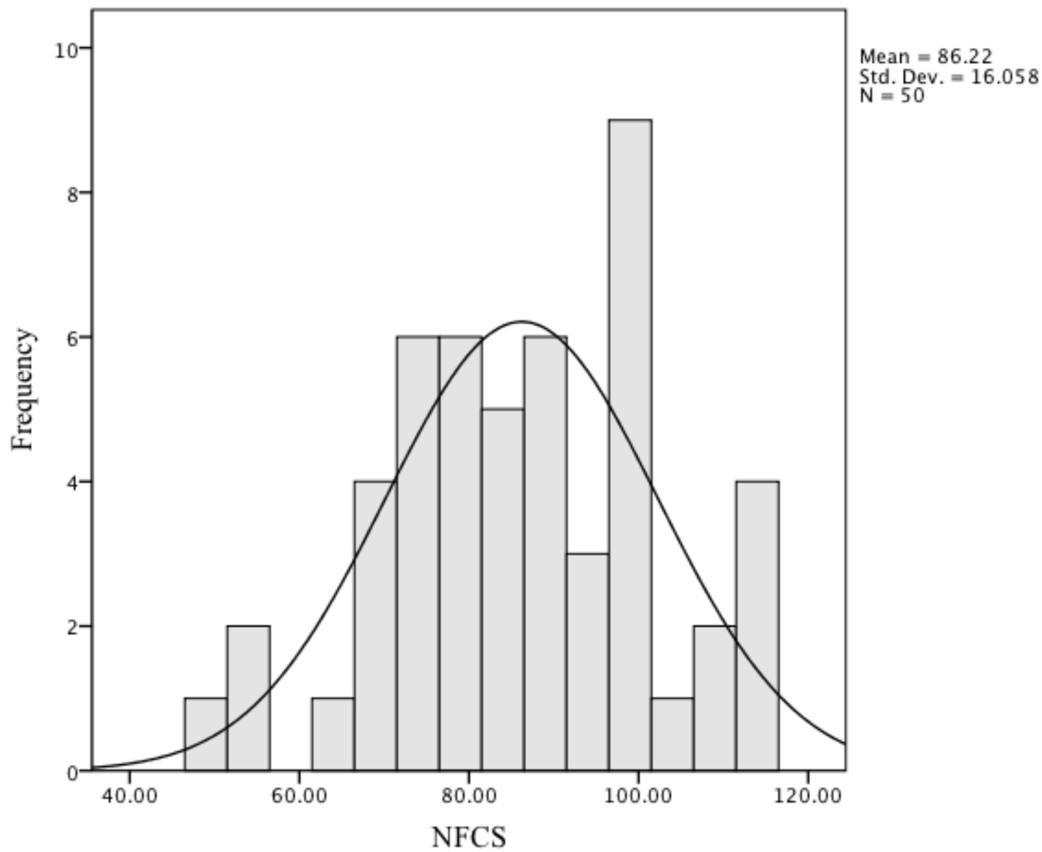
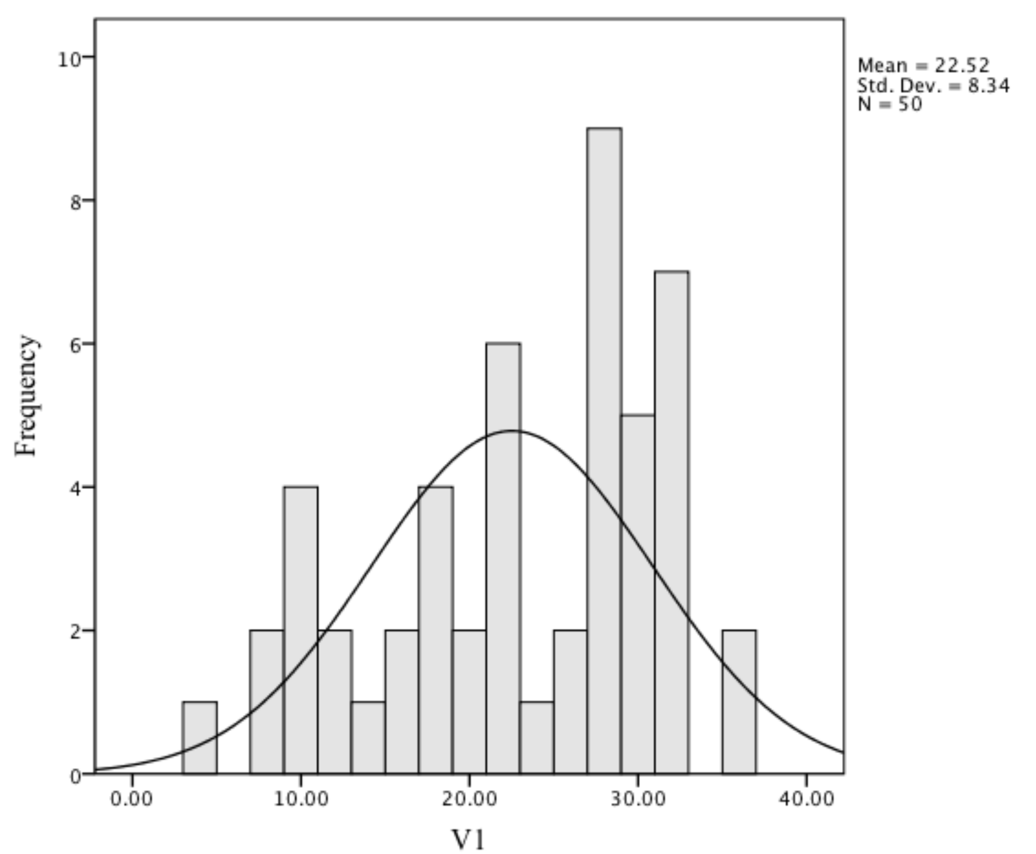


Figure 8 Distribution of V1 scores



The fill-in-the-blank concept map scores seemed to correlate more strongly with the V1 scores than with the NFC scores (the V1 scores accounted for more than 40% of the fill-in-the-blank variance).

Table 14 Correlation coefficients between fill-in-the-blank and NFC/V1 scores

Measures \ Maps	SAF	SBF	SCF
NFC	0.332*	0.185	0.395**
V1	0.483**	0.422**	0.413**

** $p < 0.01$
* $p < 0.05$

4.2 Eye-Tracking Data

4.2.1 AOI Fixation Duration and Count

Each node and link was defined as an AOI (see methods). Fixation duration (FD) and fixation count (FC) were measured for each AOI. A measure calculated "per participant per map" was shortened to PPPM.

4.2.1.1 Selection of relevant nodes on screen

PPPM total fixation duration and fixation count were computed for the selected and unselected nodes (Table 15).

Individual differences in eye gaze, fixation duration, and fixation counts suggested that the eye movement data should be treated as dependent or related samples. Therefore, data from the same participant were paired and each subject acted as his or her own control. Paired samples *t*-tests were used to test the null hypothesis that the differences between two measures have a value of zero. This test is quite robust if groups of equal sample size are compared, even if they exhibit unequal variances (Hinkle, Wiersma, & Jurs, 2003, p. 264).

In this case, FD totals for selected and unselected nodes for each participant were paired. The paired samples *t*-test between the FD totals revealed fixation duration was longer on the selected nodes for each of the maps ($p < 0 .001$). Fixation frequencies were also statistically detectably greater on the selected nodes ($p < 0.001$).

Table 15 FD and FC of selected and unselected nodes with t-test results

		Selected Node		Unselected node		*t*	Sig. (2-tailed)
		Mean	SD	Mean	SD		
Fixation duration (seconds)	Map A	62.14	37.34	33.03	21.83	5.78	<0.001
	Map B	41.48	23.75	23.54	12.17	4.00	0.001
	Map C	59.18	42.97	31.43	22.07	4.48	<0.001
Fixation Count	Map A	200.68	130.73	112.00	70.74	4.81	<0.001
	Map B	142.80	79.03	96.46	56.86	4.69	<0.001
	Map C	163.62	87.00	96.42	60.38	4.90	<0.001

4.2.1.2 Post-test performance on the fill-in-the-blank concept maps

Each blank on the fill-in-the-blank concept maps was marked correct, incorrect, or empty. PPPM fixation durations and fixation counts were averaged in each of these three categories (mean scores shown in Table 16). A one-way analysis of variance (ANOVA) revealed a statistically detectable difference among the three categories for all three maps (see Table 17).

Table 16 Mean for FD and FC for fill-in-the-map categories

		Correct		Incorrect		Blank	
		Mean	SD	Mean	SD	Mean	SD
Fixation duration (seconds)	Map A	3.23	1.72	2.20	2.77	1.63	1.28
	Map B	1.92	1.48	1.31	1.95	1.00	0.65
	Map C	2.69	1.59	1.07	1.18	1.01	0.75
Fixation count	Map A	10.64	6.26	7.54	8.50	5.72	4.25
	Map B	5.97	3.83	4.26	6.14	3.64	2.14
	Map C	8.54	4.69	3.74	4.08	3.61	2.58

Data analysis included conducting multiple comparisons. In order to control the family wise error rate for groups of hypothesis tests, the sequential Bonferroni procedure suggested by Holm was used to adjust the critical value thresholds required to reject the null hypotheses.

The p-values were ranked from lowest to highest. For the smallest p-value within the group of tests, $\alpha = 0.05$ was divided by the number of tests required to establish statistical significance (e.g. where there were 3 tests, the lowest p-value was compared to $0.05/3 = 0.0167$). If significance was established, that hypothesis could be rejected. Then, the next smallest p-value was compared to the number of tests minus 1, or $0.05/2 = 0.025$, and so forth, until the critical level was no longer met and all remaining hypothesis could not be rejected. Research suggests that the Holm-Bonferroni method is less conservative than the traditional Bonferroni correction procedure, while controlling alpha abuse.

Using the Holm-Bonferroni method, I was able to reject the null hypotheses that there were no differences between the fixation duration on correct, incorrect and empty blanks in the three maps with 95% confidence. I was also able to reject the null hypotheses that there were no differences between fixation count on correct, incorrect and empty blanks in the three maps with a 95% confidence. The Holm-Bonferroni results are shown in Table 17.

Table 17 ANOVA results with unadjusted and adjusted p-values

		F	*p*-value (unadjusted)	Holm-Bonferroni *p*-value (adjusted)*
Fixation duration (seconds)	Map A	7.98	0.001	0.025
	Map B	5.09	0.007	0.050
	Map C	30.35	<0.001	0.017
Fixation Count	Map A	7.16	0.001	0.025
	Map B	3.83	0.024	0.050
	Map C	26.04	<0.001	0.017

*value for significance

4.2.1.3 Brief discussion

These results verified the assumption that the eye-tracker was functioning properly, since participant fixation durations and frequencies were greater on nodes selected as relevant and on AOIs correctly recalled on the post-test.

4.2.2 Research Question 1

Did participants fixate longer on nodes or links during the argumentation task?

Total fixation duration upon all nodes (FDN) and the total fixation duration upon all links (FDL) were calculated PPPM (coded as FDN-A, FDL-A, FDN-B, FDL-B, FDN-C and FDL-C). Table 18 contains the descriptive statistics for each map. Paired *t*-tests within each map revealed that the total fixation durations for nodes were statistically different than the fixation durations for links (see Table 18).

Table 18 Mean and SD of node and link fixation durations with t-test results

	Mean	SD	*t*	Sig. (2-tailed)
FDN-A	95.17	49.72	11.62	<0.001
FDL-A	36.61	22.49		
FDN-B	74.82	41.00	10.41	<0.001
FDL-B	26.60	12.54		
FDN-C	90.60	52.42	9.62	<0.001
FDL-C	32.00	17.29		

4.2.2.1 Number, size, and observation count of AOIs

FDN and FDL sums were normalized by dividing by the relative number of AOIs in each category. For example, since Map A has 20 nodes and 34 links, 20 divided the FDN-A total, and 34 divided the FDL-A total. The results were expressed as an average fixation duration per node (AvgFDN) and an average fixation duration per link (AvgFDL) PPPM. A paired samples *t*-test was conducted per map and it was determined that AvgFDN was statistically detectably greater than AvgFDL. This demonstrates that after the difference in the number of nodes and links was accounted for, the fixation duration was still greater on the nodes.

Table 19 Descriptive statistics and t-test results of average FD on nodes and links

	AOI	Number	Average fixation durations	Mean	SD	*t*	Sig. (2-tailed)
Map A	Nodes	20	AvgFDN	4.76	2.49	12.85	<0.001
	Links	34	AvgFDL	1.08	0.66		
Map B	Nodes	26	AvgFDN	2.88	1.58	11.76	<0.001
	Links	47	AvgFDL	0.57	0.27		
Map C	Nodes	22	AvgFDN	4.12	2.38	10.75	<0.001
	Links	37	AvgFDL	0.82	0.44		

Tobii Studio expressed the area of each AOI as a percentage of the total screen (Table 20). The FDN and FDL sums were divided by total node area and total link area, respectively, producing Area-FDN and Area-FDL (Table 21). A paired samples *t*-test was conducted within each map and it was determined that Area-FDN was statistically detectably different than Area-FDN. In conclusion, even when the variable area is held constant, node FD is greater than link FD.

Table 20 Percentage of screen area for AOIs

	AOI	Percentage of screen area
Map A	Nodes	9.49%
	Links	5.82%
Map B	Nodes	9.38%
	Links	6.41%
Map C	Nodes	10.05%
	Links	6.14%

Table 21 FD per percentage of screen area mean, SD and t-test results

	Area-FD	Mean	SD	*t*	Sig. (2-tailed)
Map A	Area-FDN	10.03	5.24	11.62	<0.001
	Area-FDL	6.29	3.87		
Map B	Area-FDN	7.98	4.37	10.41	<0.001
	Area-FDL	4.15	1.96		
Map C	Area-FDN	9.02	5.21	9.62	<0.001
	Area-FDL	5.21	2.81		

Tobii Studio provided the AOI observation counts (number of visits to an AOI). Total node observation counts and total link observation counts were calculated PPPM. Paired samples *t*-tests revealed that participants visited nodes more often than links.

Table 22 Descriptive statistics and t-test results of observation counts

	AOI	Mean (counts)	SD	*t*	Sig. (2-tailed)
Map A	Nodes	271.44	141.77	11.39	<0.001
	Links	127.10	73.06		
Map B	Nodes	202.98	97.47	11.26	<0.001
	Links	93.16	39.79		
Map C	Nodes	220.72	96.78	12.46	<0.001
	Links	106.16	49.86		

4.2.3 Single Transitions

Map A raw eye gaze data contained all the fixations and the corresponding AOIs. The eye gaze data were converted into sequences of strings. The conversion from the raw data to the strings involved removing fixations on the text boxes and empty spaces. Each string represented the order in which a participant visited AOIs. Transition matrices were created and populated by counts of transitions between AOIs. A portion of a matrix is shown in Figure 9.

Figure 9 Portion of transition matrix for all participants

	A11	A12	A13	A14	A15	A16
A11		123	5	38	24	2[illegible]
A12	165		5	16	37	10[illegible]
A13	1	7		6	6	14[illegible]
A14	35	23	5		164	1[illegible]
A15	11	43	7	194		5[illegible]
A16	15	101	128	15	60	
A17	31	151	24	92	175	17[illegible]
A18	48	53	8	77	51	2[illegible]
A19	10	8	5	20	11	[illegible]
A110	2	4	1	11	5	[illegible]
A21	3	12	28	25	133	14
A22	2	5	62	6	4	1[illegible]
A23	1	7	66	7	11	4[illegible]
A24	2	2	6	4	1	[illegible]
A25	1	5	1	5	8	[illegible]
A26	6	7	7	117	92	2[illegible]
A27	3	3	0	32	12	[illegible]
A28	10	3	3	14	8	1[illegible]

4.2.4 Research Question 2

Did the lines that connect nodes guide eye gaze as learners studied the concept map?

There were 54 AOIs in Map A: 20 nodes and 34 links. Starting from any given AOI, 53 destinations were possible. Therefore, Map A contained 2862 possible transitions. The total number of transitions each participant made was calculated (M = 794.28; SD = 413.75).

Transitions between two connected nodes were isolated from the matrices. As there were 34 links, 68 node-to-connected node transitions (NCN) were possible. NCN and node-to-unconnected node (NUN) transition counts were calculated per participant. Although NCN transitions accounted for only 2.4% (68/2862) of all possible transitions, on average, participants made this type of a transition 14.9% of the time. Table 23 contains the mean number of total, NCN, and NUN transitions.

Table 23 Descriptive statistics for transitions

Transitions	Number of possible transitions	Mean	SD	Skewness	Kurtosis	Percentage of transitions
Total	2862	794.28	413.75	0.945	0.337	100%
NCN	68	118.58	66.74	0.322	-0.389	14.9%
NUN	312	163.26	80.77	0.429	0.020	20.4%

NCN and NUN transitions were normalized by dividing by the number of possible unique transitions in each category. A paired samples *t*-test revealed that participants made the NCN transitions more often than NUN transitions ($t = 11.09$, $p < 0.001$).

Table 24 Normalized NCN and NUN transitions with t-test results

Transitions	Mean of normalized transitions	SD	*t*	Sig. (2-tailed)
NCN	1.74	0.98	11.09	<0.001
NUN	0.52	0.24		

A second analysis of this data was conducted by grouping NCN and NUN transitions according to node of origin. For each originating node, the total number of NCN (T-NCN) and total number of NUN (T-NUN) transitions by all participants were summed. A paired samples *t*-test between the 34 sets of T-NCN and T-NUN transitions was conducted. It was found that the number of transitions between connected nodes was significantly higher than between unconnected nodes ($t = 4.77$, $p <0.001$).

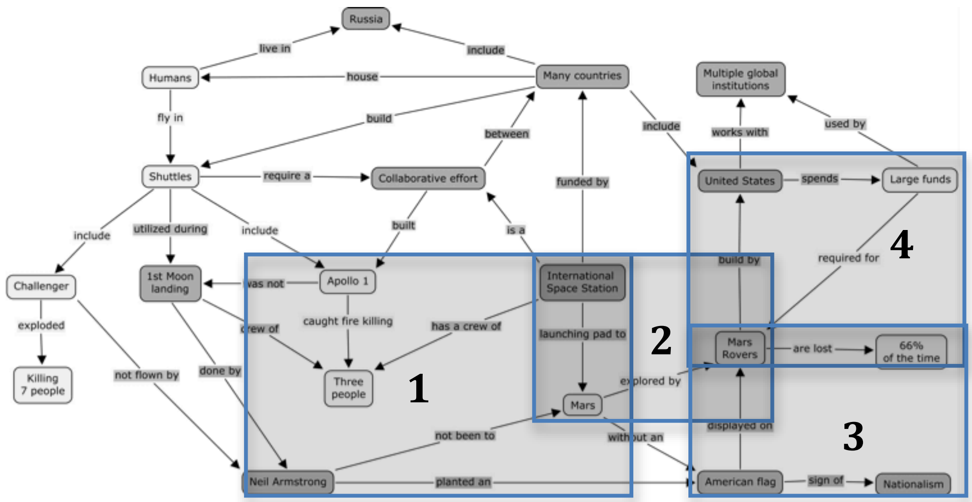
Table 25 NCN and NUN transitions from origin node and t-test results

Transitions	Mean for all nodes	SD	*t*	Sig. (2-tailed)
NCN	294.95	140.62	4.77	<0.001
NUN	145.20	67.74		

4.2.4.1 Distance between nodes

Four areas were selected based on node-to-node distance. In these areas, linked and unlinked nodes were generally the same distance apart.

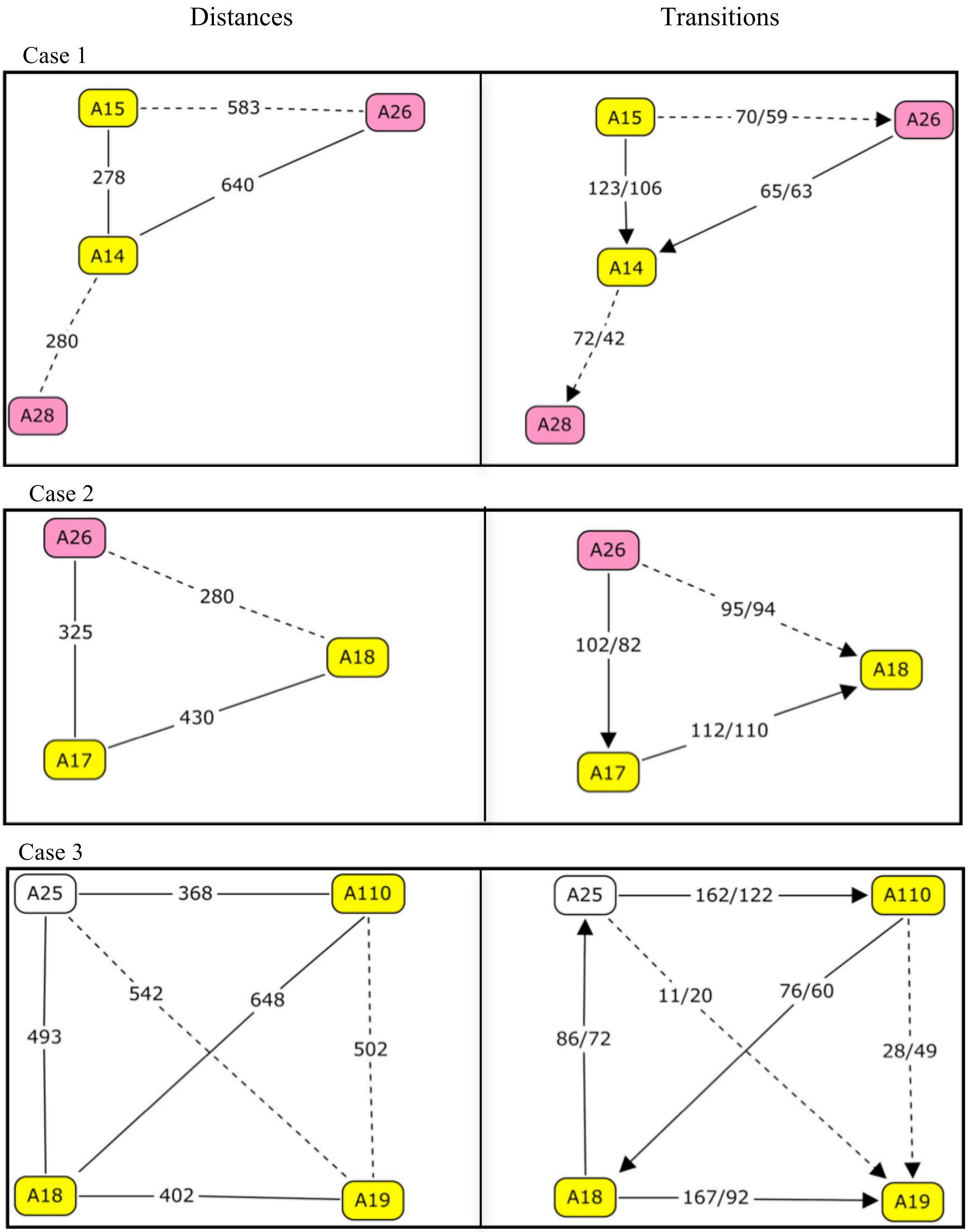
Figure 10 Map A with 4 cases highlighted



For each of the areas, two schematics are presented. The first schematic outlines the distances between nodes in pixels, and the second schematic outlines the number of total transitions that participants made between the nodes. A solid line represents a connection between the nodes, whereas a dotted line indicates the absence of an arrow. For each transition, there are two numbers separated by a colon: the number of transitions in the forward direction (along the arrowhead) and the number of transitions in the backwards direction (against the arrowhead).

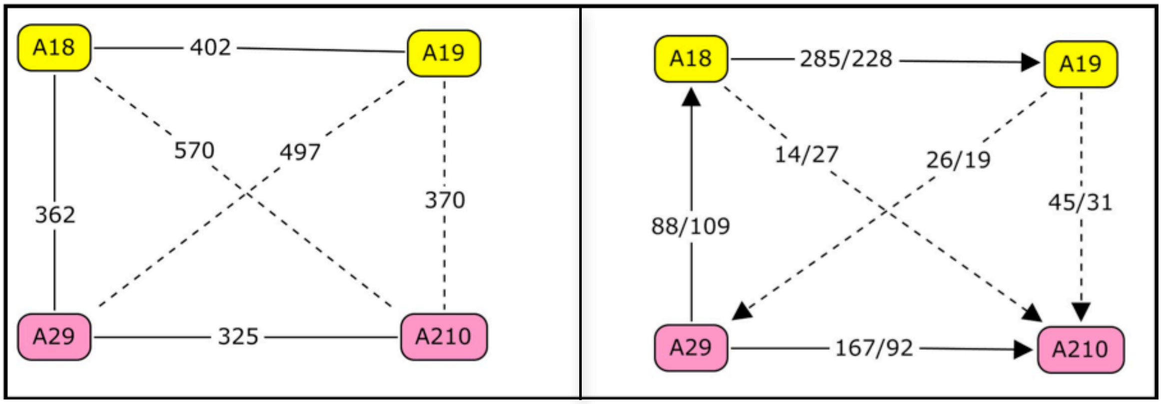
In case 1, the distance between A15 and A14 and A14 and A28 was approximately the same, but only A15 and A14 were connected in the map. However, the number of A15-A14 transitions was greater in both the forward and backward direction. This pattern was repeated in all of the selected areas.

Figure 11 Schematic of the four cases



Distances Transitions

Case 4



4.2.5 Research Question 3

Did arrowheads guide eye gaze as learners studied the concept map?

Transitions between connected nodes were characterized as following one of four paths. Participants either observed the intervening link in the forward (Path 1) or backward (Path 3) direction or bypassed the link in the forward (Path 2) or backward (Path 4) direction. These paths are graphically illustrated in Figure 12.

Figure 12 Pathways from node to connected node

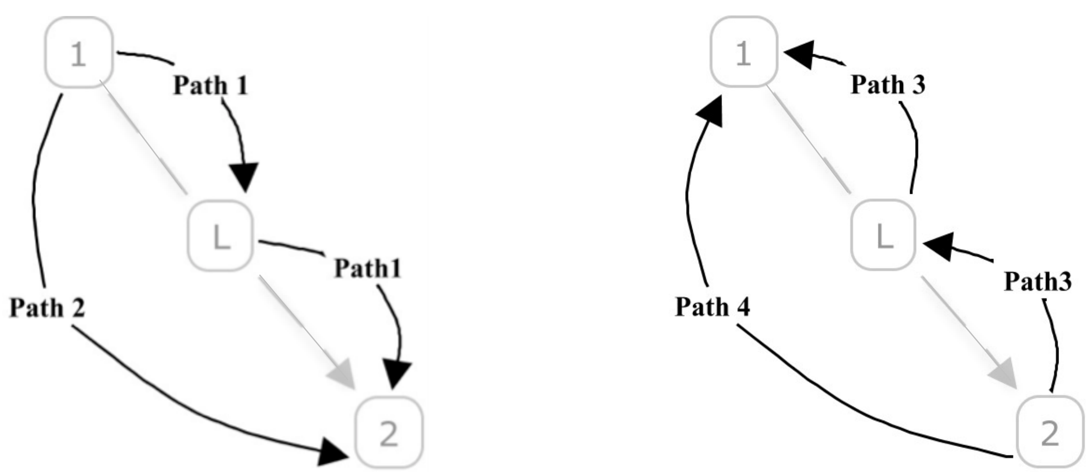
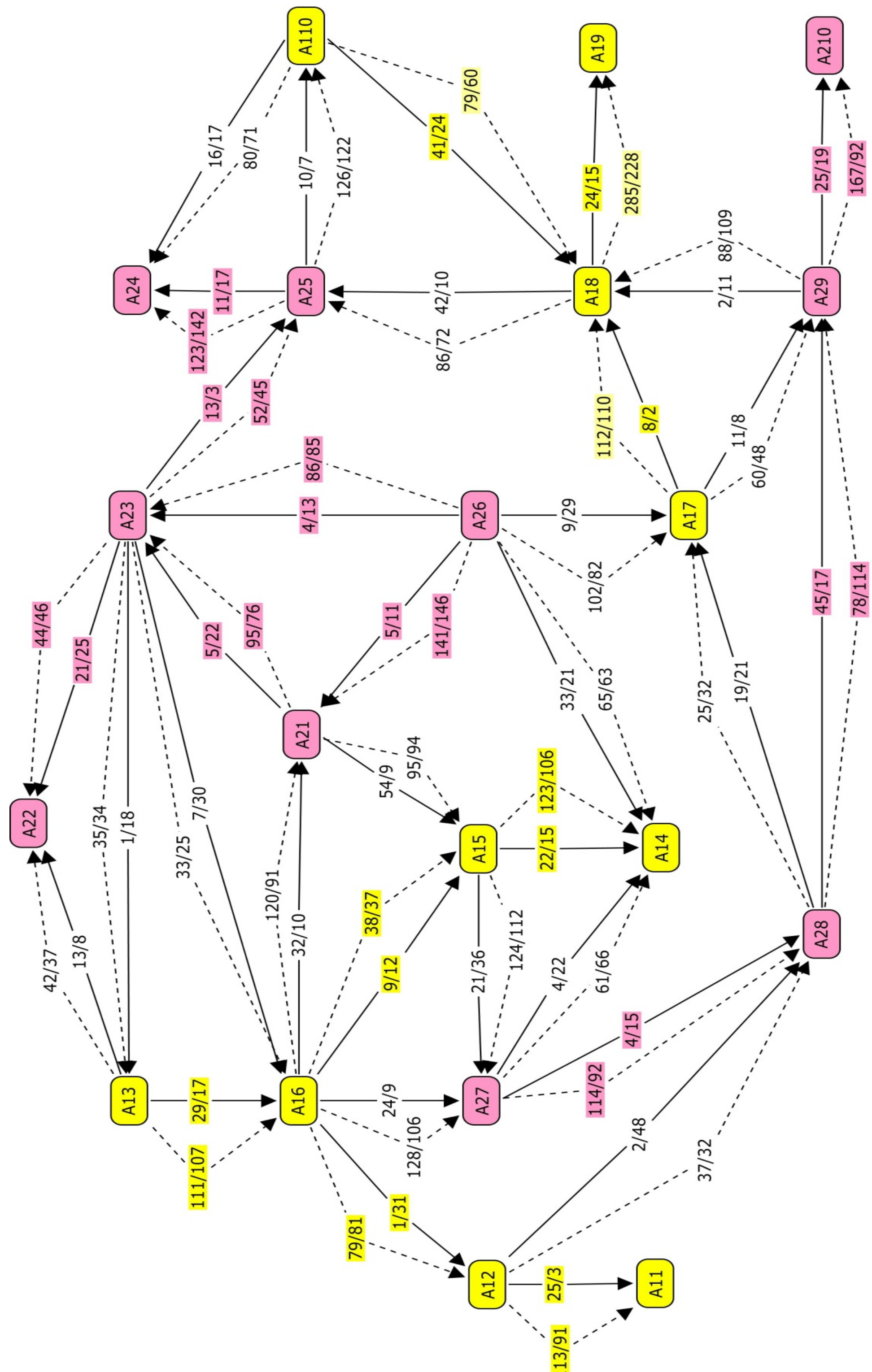


Figure 13 shows the number of times each of the four transition paths appeared in the eye gaze data. A solid line represents transitions that included the link, while a dotted line represents transitions that bypassed the link. Two counts accompany each arrow; the first number is forward direction count, while the second number is the backwards direction count. In the diagram, the nodes from Argument 1 are indicated by yellow fill, and the nodes from Argument 2 are indicated by pink fill. Arrows between Argument 1 nodes are highlighted in yellow, while arrows between Argument 2 nodes are highlighted in pink.

Figure 13 Total transitions for Map A



Two connected nodes were referred to as a "pair" (e.g. A12 and A11). Map A contained 34 arrows, and therefore 34 pairs. Each participant had two transition counts for each pair: the number of forward transitions (Path 2), and the number of backward transitions (Path 4). The two transition counts between each pair were defined as a "set". Missing sets (which occurred when the participant did not make a forward or backward transition) were removed from the data. Table 26 lists the number of participants who made each transition.

34 paired *t*-tests were conducted comparing forward and backward transition counts for each of the pairs. Out of 34 *t*-tests, eight of them had $p < 0.05$, of which seven had forward transitions significantly greater than backward transitions, and one of which had backward transitions significantly greater than forward transitions (A28-A17). The results of each test are graphically depicted in Figure 14. For the remaining 26 pairs, the numbers of forward transitions were not statistically distinguishable from the backward transitions.

Table 26 Mean and SD of transitions per arrow direction

Origin node	End node	No. of participants	Forward Mean	Backward Mean	Forward SD	Backward SD
A12	A11	48	2.31	1.85	1.81	1.77
A12	A28	29	0.79	0.52	1.05	1.02
A16	A12	28	2.11	2.14	2.59	2.66
A16	A27	40	2.53	2.08	2.80	2.43
A16	A15	24	1.25	1.13	1.59	1.70
A16	A21	37	1.89	1.41	2.26	1.94
A13	A16	41	2.20	2.12	2.39	2.72
A27	A14	28	0.93	0.79	1.09	1.34
A27	A28	38	1.21	1.39	2.00	1.64

Origin node	End node	No. of participants	Forward Mean	Backward Mean	Forward SD	Backward SD
A15	A14	40	2.10	1.85	2.32	2.53
A15	A27	43	2.35	2.19	2.58	3.17
A13	A22	42	2.71	2.48	2.46	2.61
A28	A29	36	1.44	0.94	1.70	1.39
A28	A17	27	0.41	0.70	0.64	0.72
A21	A15	37	1.89	1.86	2.28	1.97
A21	A23	38	1.63	1.42	1.89	1.46
A23	A22	28	0.61	0.75	1.61	1.11
A23	A25	31	0.77	0.58	1.18	1.15
A23	A16	21	0.43	0.10	0.68	0.30
A23	A13	28	0.79	0.82	1.26	1.25
A26	A23	41	1.51	1.68	1.98	1.56
A26	A21	44	2.98	3.07	3.07	3.02
A26	A14	39	1.18	1.10	1.39	1.07
A26	A17	42	3.45	1.93	3.01	2.03
A17	A18	37	2.57	2.27	3.11	2.61
A17	A29	31	0.97	0.74	1.30	1.34
A18	A29	39	1.54	1.92	1.88	2.09
A29	A210	42	3.45	1.93	3.01	2.03
A18	A19	49	5.79	4.65	4.38	4.72
A18	A25	41	1.65	1.21	1.68	1.89
A110	A24	35	1.46	1.40	1.56	1.83
A110	A18	35	1.49	1.20	1.65	1.69
A25	A110	40	2.37	2.42	2.55	2.76
A25	A24	42	2.48	2.81	2.85	2.59

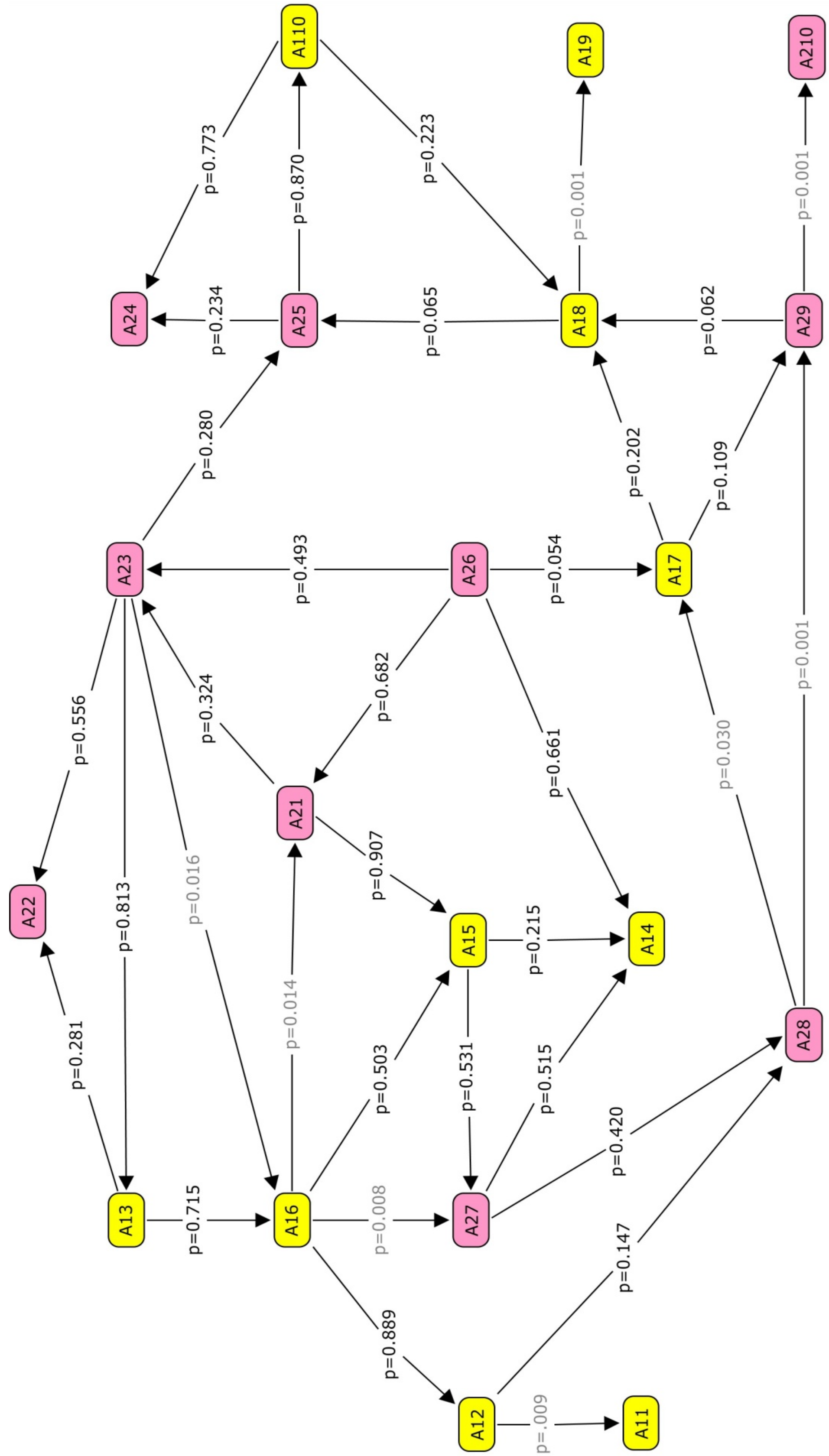
Using the Holm-Bonferroni method, for only three of the pairs was I able to reject the null hypotheses (that were no differences between the forward and backward transitions) with a confidence level of 95% ($\alpha = 0.05$). These pairs were: A18-A19, A29-A210, A28-A29. In these pairs, there were statistically detectably more forward transitions than backward transitions. I was unable to reject the null hypothesis for the remaining pairs. The results for the four pairs with the smallest *p*-values are displayed in Table 27.

Table 27 Results of unadjusted and adjusted p-values for 4 pairs

Pair	*p*-value (unadjusted)	Holm-Bonferroni *p*-value (adjusted)*
A18-A19	0.001	0.0015
A29-A210	0.001	0.0015
A28-A29	0.001	0.0016
A12-A11	0.009	0.0016

*value for significance

Figure 14 34 paired t-tests for Map A



p>=0.05
p<0.05

Node to connected node transitions were also characterized as a percentage of the total number of transitions. Each of the 34 sets per participant was normalized by calculating the forward and backward transitions as percentages.

$$\text{Forward transition percentage} = \frac{\text{Forward transitions}}{\text{Total transitions}} = \text{FT\%}$$

$$\text{Backward transition percentage} = \frac{\text{Backward transitions}}{\text{Total transitions}} = \text{BT\%}$$

For each pair, a mean was calculated representing the average FT% across all participants (Figure 15). For example, the average FT% for the A12-A11 pair was equal to 60.0%. Therefore, 60.0% of the time a transition occurred, it was in the forward direction, and 40.0% of the time it was in the backward direction. Highlighted in Figure 15 are the three pairs in which the FT% was less than 40.0% (blue), and the six pairs in which the FT% was greater than 60.0%.

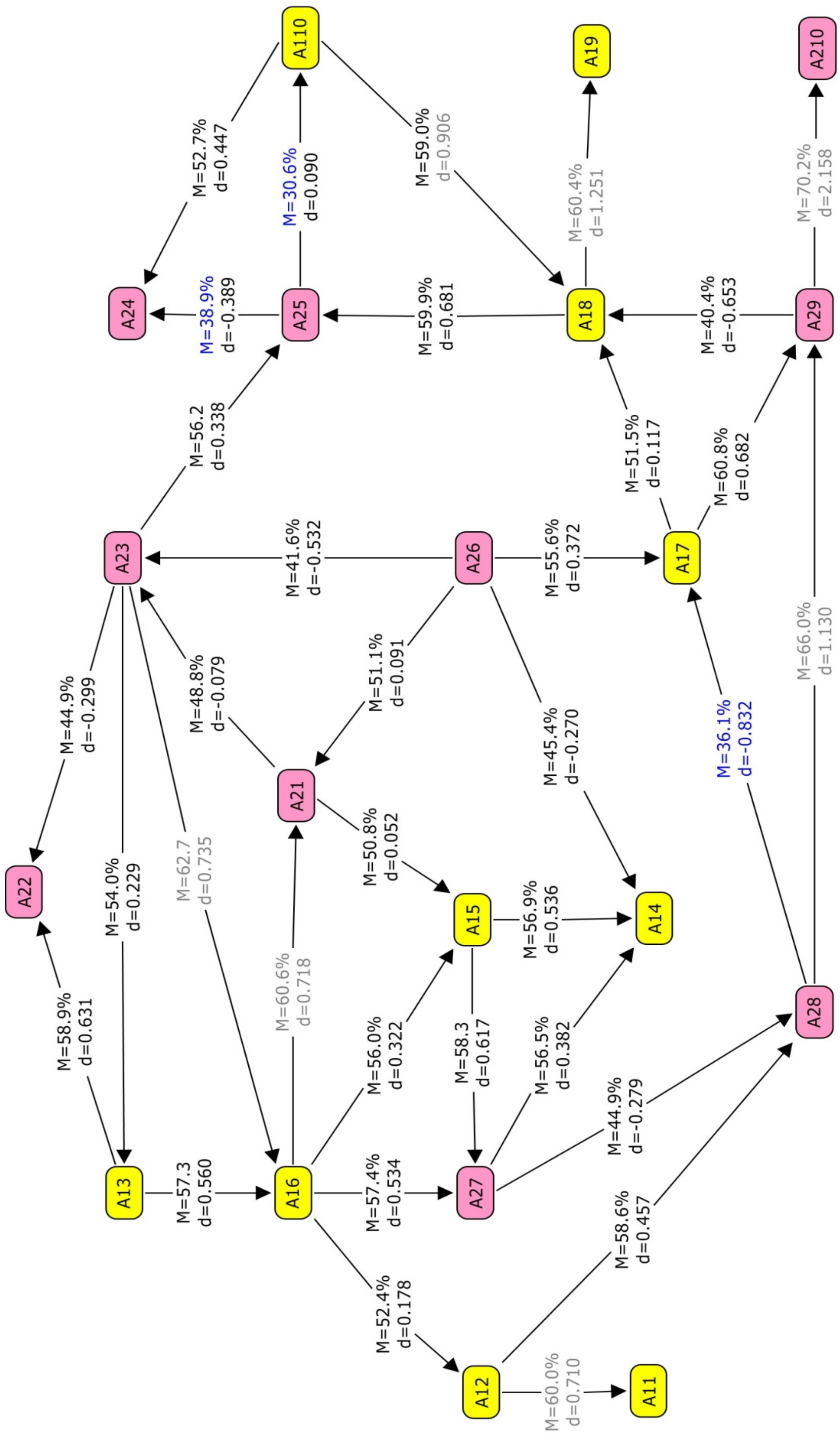
Using the FT% and BT% means and standard deviations, a standardized mean difference effect size (Cohen's *d*) was obtained for each of the 34 pairs. Effect size (*d*) was calculated by subtracting the mean BT% from the mean FT%, and then dividing by the pooled standard deviation. A large effect size was found for seven pairs, six of which also had an FT% greater than 60.0%.

Table 28 FT% and effect size

	Range	Pairs	Colour
FT%	0-40%	3	Blue
	40-60%	25	Black
	60-100%	6	Grey
Cohen's *d*	< -0.70	1	Blue
	-0.70 < d < 0.70	26	Black
	> 0.70	7	Grey

These results failed to confirm the hypothesis that participant eye gaze was directed by arrowheads while they studied Map A.

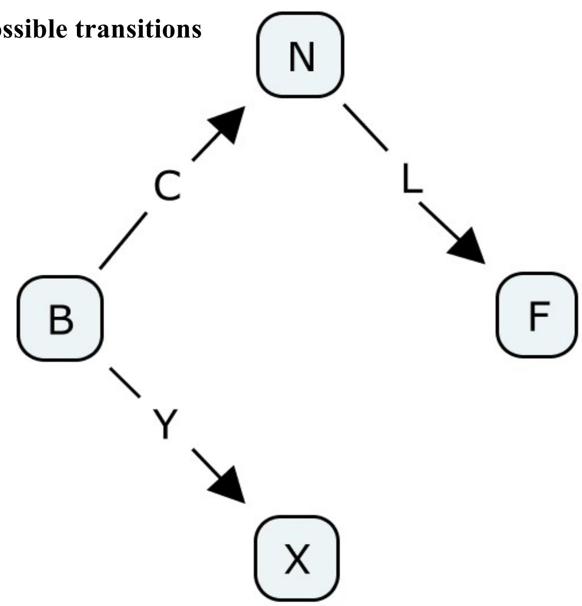
Figure 15 FT% and effect sizes for each pair



4.2.6 Multiple Transitions

First, a model for all possible transitions sequences in a concept map was built to group transitions into sequences. Imagine node "N" is the beginning node of a sequence of transitions and all other nodes and links are in relation to "N" (refer to Figure 16). The node "F" is a node connected by an arrow coming from "N" in the forward direction, node "B" is a node connected by an arrow coming from "N" in the backward direction, and node "X" is an unconnected node to "N". The link "L" is connected to "N" is the forward direction, whereas link "C" is connected to "N" in the backward direction. Link "Y" is an unconnected link to "N".

Figure 16 Model for all possible transitions



Each transition sequence began with "N", and ended with one of three terminal events: textboxes, "not an AOI", or a transition to a link or node that was unconnected to the current node or link. Transition sequences were coded as "forward" if they followed arrow direction, and "backward" if they did not.

The pre-determined transition sequences are listed in Table 29. There were two possible transition sequences that followed a proposition's archetype, coded as "complete forward" and "complete backward" transitions. "Incomplete" node-link-node transition sequences in the forward or backward directions were also tracked. There were six sequences that transitioned from "N" to another AOI, and then returned to "N" (coded as "immediate retrospections"). As well, when a sequence followed the proposition pattern (node-link-node), and returned back to "N", it was coded as "delayed immediate retrospection".

Table 29 Transition sequences

Transition sequences		Model
Complete	Forward	NLF
	Backwards	NCB
Incomplete	Forward	NL
	Backwards	NC
Immediate Retrospection	Forward Node	NFN
	Backwards Node	NBN
	Forward Link	NLN
	Backwards Link	NCN
	Unlinked Node	NXN
	Unlinked Link	NYN
Delayed immediate retrospection	Forwards	NLFN or NLFDN
	Backwards	NCBN or NCBCN

4.2.7 Research Question 4

Do eye gaze patterns support the understanding that learners view concept maps in terms of propositional units?

Each participant's transition string was analyzed for the pre-determined transition sequences. Initial visitations and return visitations for each node were also recorded. The sums of participant transition sequences are listed below in Table 30.

Table 30 Number of transition sequences by all participants

Transition sequences		Model	First	Return	Total
C.	Forward	NLF	47	491	538
	Backwards	NCB	35	387	422
Inc.	Forward	NL	43	285	328
	Backwards	NC	31	244	275
IR	Forward Node	NFN	65	633	698
	Backwards Node	NBN	126	668	794
	Forward Link	NLN	135	1247	1382
	Backwards Link	NCN	142	1164	1306
	Unlinked Node	NXN	141	640	781
	Unlinked Link	NYN	65	335	400
DIR	Forwards	NLFN or NLFDN	8	72	80
	Backwards	NCBN or NCBCN	3	45	48

Some of the pre-determined sequences were of the form considered to be a proposition (of the form NLF or NCB). Others involved the revisiting of the initial node (of the form N-AOI-N). In this analysis, it was found that the most common transition sequences were immediate retrospection, rather than those of a propositional form. These results do not support the conventional theory that learners primarily interpret concept maps in terms of propositional unit.

A strong relationship was found between the frequency of first visit and return visit pre-determined transition sequences ($r = 0.880$, $p < 0.01$).

CHAPTER V: DISCUSSION

5.1 Discussion of Results

5.1.1 Research Question 1

Did participants fixate longer on nodes or links during the argumentation task?

Investigation of participant fixation durations revealed that participants fixated longer on nodes than links. This was also true when the number of AOIs and screen area were taken into account.

Although it is difficult to infer specific cognitive processes from particular fixations, it is generally thought that there is a connection between where one is looking and one's thought process (Just & Carpenter, 1984; Grant & Spivey, 2003; She & Chen, 2009). Fixation durations often correlate positively with complexity of task. These tasks include solving difficult math and physics problems (Hegarty & Just, 1993; Hegarty et al., 1992) and reading ambiguous syntax or low-frequency words (Rayner et al., 2006; Frazier & Rayner, 1982). Therefore, greater fixation durations on nodes may be an indication that participants expended greater cognitive resources on nodes than links.

Several results found in the AOI Fixation Duration and Count section support the notion that fixation durations were related to participant cognitive processes. Fixation durations were longer on the nodes participants identified as argument related. As well, ANOVA results reveal that participants fixated longer and more often on the AOIs they remembered correctly on the fill-in-the-blank concept maps.

One possible explanation for this result is that participants were able to deduce the relationship between nodes, and therefore did not have to fixate as long on links. This is convergent with previous research that suggested not all learners require explicitly labeled lines to infer the connection between two concepts (Lambiotte and Dansereau, 1992). The concept maps presented ideas from the topic of space exploration, and participants did not require highly specialized background knowledge in order to understand these ideas. However, since all the participants were university students, they likely arrived with well-practiced inference-making skills.

As well, longer fixation durations on nodes could have resulted from the combination of the task and the presented materials. One aim of the task was to identify argument relevant nodes. Perhaps while participants fixated on a node, they were deciding its relevance to the argument, cumulatively leading to longer fixation durations on nodes than links.

Learners were also asked to synthesize an argument by studying the information presented in the concept maps. Possibly, the links imposed an organization of the concepts that was incompatible with their pre-existing understanding of how the concepts were related (Ausubel, 1968; Milam et al., 2000). Since links constrained how the information could be manipulated, participants spent less time visiting them. If the task had asked participants to memorize the relationships, or study the map for a comprehension examination, the difference between fixation duration on nodes and links may have been smaller.

5.1.2 Research Question 2

Did the lines that connect nodes guide eye gaze when a learner studied the concept map?

I conducted two analyses to address this question. First, single transitions between connected nodes (NCN) were compared to transitions between unconnected nodes (NUN) for each participant. Second, NCN and NUN transitions originating from the same node were compared. The result of both tests was that participants made NCN transitions statistically detectably more often than NUN transitions.

An alternative explanation for these findings was further investigated. In the maps presented, connected nodes were usually also closer in distance than unconnected nodes. One factor that may affect the direction of a subsequent saccade during visual search is peripheral stimuli (Duchowski, 2007, p. 224). Perhaps instead of lines guiding eye gaze, the connected nodes were positioned just outside the fovea, in the parafoveal and peripheral regions, and “caught the eye” of the participants. A brief analysis of distance was performed to demonstrate that participants made a NCN transition more often than a NUN transition, even when the end nodes were at similar distances from the node of origin. However, without designing stimulus materials that more tightly control distances between nodes, it is difficult to fully determine the role of distance as a variable influencing eye movement between nodes and rule out the possibility that it accounts for the preference for NCN transitions.

This result is consistent with previous research that proposes visual search is dependent on viewing strategy (Duchowski, 2007, p. 224). The viewing strategy chosen by participants would presumably have optimized identification of Argument 1 nodes in the map. As related concept map nodes are linked together, nodes associated with Argument 1 would also be connected to each other. Therefore, one viewing strategy may have been to locate one Argument 1 node, and then scan the connected nodes for possible candidates.

5.1.3 Research Question 3

Did arrowheads guide eye gaze as learners studied the concept map?

Participants were specifically instructed to follow arrow direction to read propositions (node-link-node units). The arrowheads encoded information about the relationship between two concepts. However, the results failed to support the hypothesis that arrowheads directed the eye gaze of participants working with concept maps.

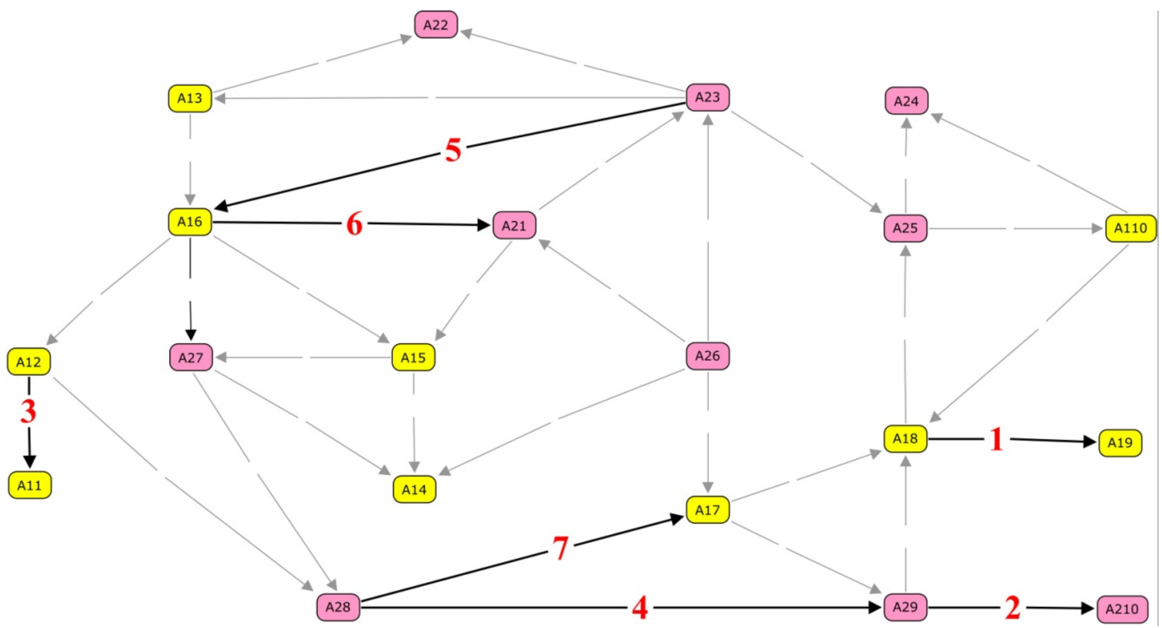
Each pair of connected nodes was analyzed separately, and therefore 34 separate analyses were carried out for Map A. For 76% of the pairs, paired samples t-tests failed to reject the null hypothesis that the direction of transition was by chance. As well, an average percentage of forward transitions, accompanied by effect size, were calculated for each pair. Out of the eight pairs in which the t-test had shown a statistically significant difference between the forward and backward transitions ($p < 0.05$), seven showed participants fixated in the forward direction greater than 60% of the time. As well, those seven pairs had an effect size greater than $d > 0.70$ and are identified in Figure 17. Some of these pairs will be further discussed below where the node with the outgoing arrow will be referred to as the origin node, and the node with the incoming arrow will be referred to as the terminal node.

For pairs 1, 2 and 3, the terminal nodes only have one connection, and this connection is to a more densely connected node. Essentially, if participant eye gaze followed the lines (as was confirmed from research question 2), then eye gaze would land in densely connected nodes earlier than less densely connected nodes. Therefore, the tendency to follow the arrowhead direction in these three cases may be because the participant is more likely to have arrived at the more densely connected node earlier.

Therefore, an examination of these three pairs does not support the hypothesis that arrowheads guide eye gaze.

Among the 34 pairs of nodes, pairs 4 and 5 exhibit the greatest distance between the origin and terminal nodes. Perhaps distance is a factor that influences whether arrowheads guide eye gaze. If the terminal node was outside the foveal region, participants were less likely to transition against the arrow direction. Further investigation is needed to determine if there is a relationship between arrowheads and distance. Also, the fewest number of participants made the pair 5 transition, therefore, perhaps the sample size was not large enough to draw conclusions.

Figure 17 Map A with identified 7 pairs



Although the results indicate arrowheads do not guide eye gaze, participants could still recognize and use them to understand the presented relationship. To fully extract the proposition, participants need four pieces of information: node A, node B, the link and the directionality. Despite the order in which these four pieces of information were perceived, the participants may have rearranged them to formulate the proposition. On the other hand, since lines guided eye gaze and also signified relationships, perhaps the inclusion of arrowheads is unnecessary and adds to the complexity of the concept map by burdening the working memory of the learner (Gurlitt & Renkl, 2008).

5.1.4 Research Question 4

Did eye gaze patterns support the understanding that learners view concept maps in terms of propositional units?

Multiple transitions were analyzed to assess how often participant eye gaze followed the sequence node-link-node when viewing the concept map (Novak & Gowin, 1984, p. 15). The results did not support the hypothesis that participants primarily make complete forward transition sequences (moving from one node to a connected node in the direction indicated by an arrowhead) while studying the concept maps. Rather, the most common transition sequences were immediate retrospections (transitioning from the origin node to another AOI, and then returning to the origin node). This pattern was found in both initial visits and subsequent return visits to a node. These results did not support the conventional theory that learners visually process concept maps in terms of propositional units.

While reading text, a backwards saccade is often induced by a comprehension failure (Kliegl, Olson, & Davidson, 1982; Blanchard, & Iran-Nejad, 1987; Frazier & Rayner, 1982). One plausible explanation to account for the number of immediate retrospections is that participants were unsuccessful at understanding how node "N" and the "AOI" were related, and would have to return to "N" to build a connection.

By immediately returning to the same node, participants were probably engaged in the process of integrating and ensuring complete understanding (Blanchard & Iran-Nejad, 1987; Hyona, 1995).

Hyona, Lorch and Kaakinen (2002) studied and categorized the fixation frequencies and durations of college student eye movements as they read. One category of fixations, termed “look backs”, went back across sentence boundaries. The researchers claimed that this process was a manifestation of global integration of information. Perhaps an immediate retrospection with an unlinked node is an indication of understanding the concept map as a whole. When participants made this transition sequence, they were assessing the importance of a node by comparing its content to other information in the map.

5.2 Significance

Eye-tracking data can provide valuable information about learning strategies, as fixation duration is an indication of processing and transitions can encode a learner’s viewing priorities and motivations. In this study, eye-tracking data were first validated and then used to study participant eye gaze patterns as they worked with concept maps.

Although learners fixated longer on nodes, learners did attend to both nodes and links. This justifies the inclusion of both nodes and links in concept maps.

When asked to study a concept map, learners may generate relationships between concepts based on their prior knowledge and expectations of how the nodes relate to the argument. This study provides caution to instructors who display information in concept maps. Despite presenting learners with relationship information encoded by links and the line embellishments (i.e. arrowheads), learners may still infer the connections between nodes when studying concept maps.

Although concept maps are constructed from propositions, the results demonstrated that learners do not navigate concept maps strictly in these terms. This result raises questions for current theories about why studying from concept maps helps learners understand structural knowledge. Therefore, perhaps the focus should switch from structuring the concept maps to optimize representation of explicit relationships, to facilitating self-generated relationships. It has been suggested that unembellished links prompt the learner to ask themselves questions about how two concepts are interrelated, acting as self-generation prompts (Gurlitt & Renkl, 2008).

Another significant piece of this research was that a novel method for modeling how learners understand concept maps was put forth and investigated. The key benefit of this approach is that it provides the researcher with temporal information about a learner's cognitive processes, without introducing bias from self-reports (through think-aloud protocols or decision analysis). In this method, a model was used to aggregate all possible transitions into transition sequences assembled from plausible eye gaze behavior. Then eye-tracking data were used to verify which pre-determined transition sequences were most commonly found in the learners' eye gaze data. This approach can be replicated and transformed to study other learning materials (such as math equations, chemistry synthesis reactions, or geographical maps).

5.3 Limitations and Future Research

As few studies have investigated how learners process concept maps by tracking eye movements, in this research it was difficult to predict eye gaze data characteristics, and therefore, impractical to avoid sparseness of the eye-tracking data. This limited the statistical tests with which the research questions could be answered. For example, a critical assumption of many other statistical tests is that the data are normally distributed. However, the transition counts between pairings for individuals were too sparse to meet this assumption (often participants made one, two or no transitions between pairs).

Another limitation of the study is that a measure to detect preconceived ideas about the presented concepts or the argument was not used. Learners seek information that is congruent with their prior knowledge (McKenzie, 2006; Nickerson, 1998), and constructing an argument is a task where bias can easily influence a person's information searching behavior. It is difficult to assess whether or not participants completed the task with expectations of how the nodes should relate to each other and the argument. This is similar to the Einstellung effect, where a learner is prevented from searching for a better solution because of an answer that has already occurred to them (Luchins & Luchins, 1954). Previous work has detected evidence of the Eistellung effect from the analysis of eye-tracking data (Bilalic, McLeod, & Gobet, 2008).

Although the current study does provide some evidence that participants made the transition from a node to a connecting node, a rigorous statistical test is still necessary to determine if distance is a more important factor in guiding node-to-node transitions than lines connecting nodes. Future research should attempt to establish the impact distance between nodes has on eye gaze patterns.

There may be some advantage in reducing the complexity in the way that concept maps are presented so that learners can more readily extract whole propositions. For example, animated concept maps (Nesbit & Adesope, 2010) can add one new proposition in each frame.

The results in Wiegmann et al. (1992) Experiment 3 found that students with high verbal ability performed better when they learned from concept maps with link embellishments (arrowheads, labels, and line fill), whereas low verbal ability students did not. Wiegmann et al. suggest that complex embellishments required more semantic processing. This experiment may also aid in further analysis of the current data. The relationship between verbal ability and eye gaze patterns could be investigated to determine whether high verbal ability participants used the line embellishment (arrows) to guide eye gaze and made a higher percentage of transitions in the forward direction. Therefore, perhaps high verbal ability students are able to more readily process relationship information encoded in a link and line, whereas low verbal ability students would benefit from a simplified concept map.

There is an inherent caveat when using eye-tracking equipment to conduct research. Although analysis of eye gaze data provides insight into a student's visual processes, it is limited when offering conclusions about a student's cognitive processes.

In order to couple visual and cognitive processes, the presented material and task would need to be highly structured, thereby making it easier for the researcher to make conjectures about the temporal motivations and goals of the participant from the eye-tracking data. For example, had I given participants concept maps with the various components of the argument (evidence, warrant, rebuttal) labeled, then the visual process of fixating on an "evidence" node could have been coupled with the cognitive process of thinking about how this piece of evidence relates to the argument. Providing greater structure to the concept maps would have reduced the individual variation in eye gaze patterns among participants.

However, in an open-ended task with unstructured materials (as in this study), individual differences can be highlighted, as participant eye gaze would have been more distinct. Without restrictions, participants are afforded more flexibility in how they visually process the concept maps. The trade-off in this case is that it is more difficult to make conjectures about cognitive processes with eye gaze data variation. As well, each individual's eye gaze data would need to be analyzed separately since each participant is fixating on different things at different times.

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APPENDICES

Appendix 1

Poster

Appendix 2

Research Study Information

Purpose and goals of this study:
The purpose of this study is to investigate how students process and retain information when asked to study concept maps. All activities in this study are intended to help you learn from concept maps. We want to discover new and better approaches to teaching and learning.

What you will be required to do:
If you agree to participate, you will fill out a Personal Information Form on the computer, read paragraphs about a topic and study concept maps on a computer monitor. After you have studied the concept maps, you will answer a few questions about what you learned.

Risks to you, third parties or society:
There is no risk to you by participating in this study. Participation is voluntary and you may decide not to be in this study, or to be in the study now and then change your mind later. You may refuse to answer any question you do not want to answer. We agree to share with you any new information learned during the study that might affect your decision to continue.

Benefits of study to the development of new knowledge:
You will receive $15 for your participation in this study. Information learned from this study will help educational researchers understand the cognitive processes that happen when a person studies a concept map. This in turn will aid future instruction.

Statement of confidentiality:
We will maintain confidentiality of your name and the contributions you have made to the extent allowed by the law. All names will be removed and replaced with identification numbers. All documents and data will be kept under lock and key and the computer used for analysis will be password protected.

We will not contact you at a future time for other studies.

Appendix 3

Informed Consent By Participant

The University and those conducting this research study subscribe to the ethical conduct of research and to the protection at all times of the interests, comfort, and safety of participants. This research is being conducted with the permission of the Simon Fraser Research Ethics Board. The chief concern of the Board is for the health, safety and psychological well-being of research participants.

Should you wish to obtain information about your rights as a participant in research or about the responsibilities of researchers, or if you have any questions, concerns or complaints about the manner in which you were treated in this study, please contact the Director, Office of Research Ethics by email at hweinber@sfu.ca or phone at 778-782-6593.

Your signature on this form will signify that you have received a document which describes the procedures, whether there are possible risks, and benefits of this research study, that you have received an adequate opportunity to consider the information in the documents describing the study, and that you voluntarily agree to participate in the study.

Title: Investigating argumentation process with eye tracking equipment
Investigator Name: Kiran Bisra
Investigator Department: Education

Having been asked to participate in the research study named above, I certify that I have read the procedures specified in the Study Information Document describing the study. I understand the procedures to be used in this study and the personal risks to me in taking part in the study as described below:

I understand the risks and contributions of my participation in this study and agree to participate:

Participant Last Name:	Participant First Name:
Participant Signature (for adults):	
Date (use format MM/DD/YYYY)	

Appendix 4

Demography

Age: ☐

Gender: ☐ Male ☐ Female

Highest Level of education: ☐ High school ☐ Bachelor ☐ Master ☐ PhD

Current program of study: ☐ Bachelor ☐ Master ☐ PhD ☐ Post doc

Faculty:
- ☐ Applied Sc.
- ☐ Arts and Social Science
- ☐ Communication
- ☐ Education
- ☐ Environment
- ☐ Health Science
- ☐ Sciences
- ☐ Business Administration
- ☐ Other

Years studied in English (including Kindergarten): ☐

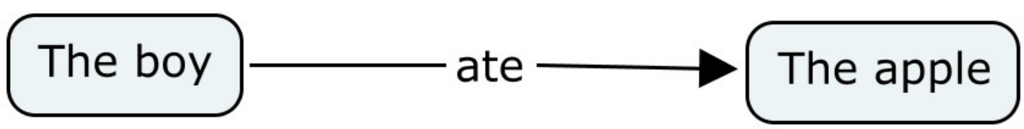
Appendix 5

Concept Map Instructions

Concept maps visually organize information. They are most commonly used in education and are taught to students to help them understand ideas and the relationships between those ideas.

Concept maps have two elements: nodes and lines. Nodes are circles that describe a concept. Nodes are connected by lines which show how the concepts are related to each other. Often, lines are labeled or have arrowheads to specify the relationship further. The concept maps we will be using today are arranged to make meaningful sentences. In other words, each node-line-node combination forms a complete thought.

For example, the nodes “the boy” and “the apple” can be related by an arrow labeled “ate”, which forms the sentence = “the boy ate the apple”



Appendix 6

Argumentation Instructions

A. Purpose of building a good argument

The purpose of building an argument is not always to win a debate. At times, it can be useful to learn about a topic by examining different points of views. By building support for both sides of an issue, you can explore and further understand the topic. Also, by preparing for both sides of an argument, you will be better prepared to counter an adversary's claims.

B. There are 3 parts of an argument:

1. Claim – the position that you are going to argue
2. Support – reasons in the form of evidence, facts, and examples
3. Rebuttal – reasons that contradict support presented on the other side

Tuition should be free because debt discourages students from attending post secondary institutions. Also, some countries pay for their citizens' post secondary education. For example, Finland and Sweden offer free tuition for their students.

Tuition should not be free because students will take their studies more seriously if they are paying for it themselves. Although some countries such as Finland and Sweden may offer their students a free education, most countries do not. Canada and the United States are just two examples of the countries which do not.

C. Arguments can be represented in concept maps

Your first task:

For the concept map given to you, please select all the nodes that you feel are relevant to the argument and write out an argument for both sides in the space below. Please present all pieces of support and rebuttal found in the concept map.

Argument: Should we fund space exploration or cancer research?

Appendix 7

Practice Task Sample Argument

Should we fund space exploration or cancer research?

Space exploration should be funded instead of cancer research because it saves lives, and this means that people will live longer. An example of the type of technology made possible by space exploration is the kidney dialysis machine.

Cancer research should be funded instead of space exploration because it helps the economy by creating jobs all over the world. Two examples of organizations that employ people are the American Cancer Society and the BC Cancer Society. As well, cancer research can improve quality of life for many people.

Please Note: There is also extraneous information in this concept map that is irrelevant to the argument. For example, the fact that space exploration was driven by the Cold War and that the American Cancer Society was found in 1913 are both "outside" the argument. As well, there are many reasons why space exploration should be funded instead of cancer research, or vice versa, but those reasons are not given in the concept map. **In your essays, please refer only to the information in the maps.**

Appendix 8

Map Task

Your last task:

You will be shown three concept maps that all pertain to the same argument. For the concept map given to you, please select all the nodes that you feel are relevant to the argument and write out an argument for both sides in the space below. Please present all pieces of support and rebuttal found in the concept map.

Advice:

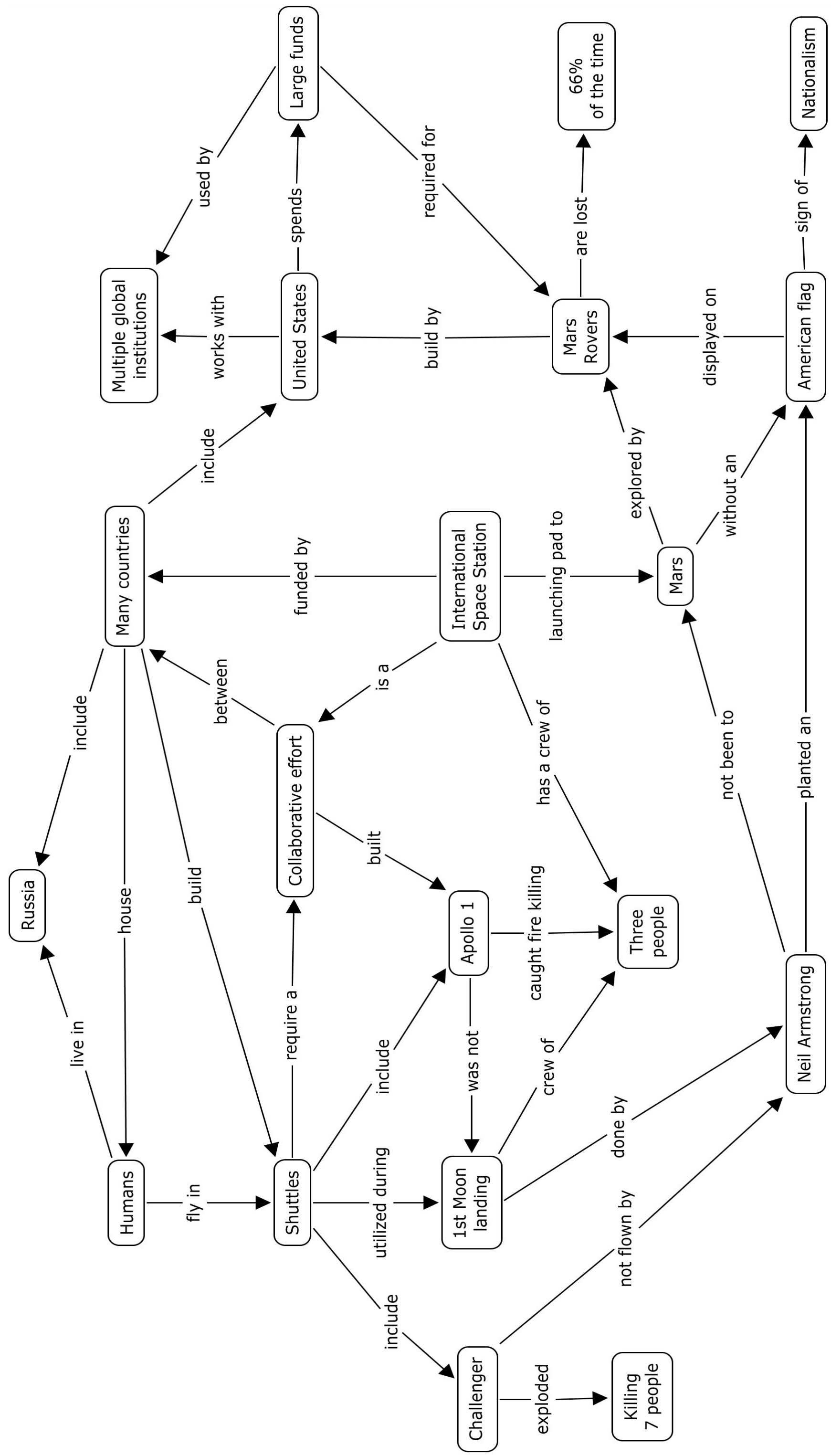
- On average, people take five minutes to study the map, but you can take as much as you need.
- Read the map at face value. Sometimes there are nodes that you feel should fit, but don't. Do not waste too much time trying to make nodes fit.
- Approximately half of the nodes on screen are related to the argument.

The argument:

Should we support human space exploration or robotic space exploration?

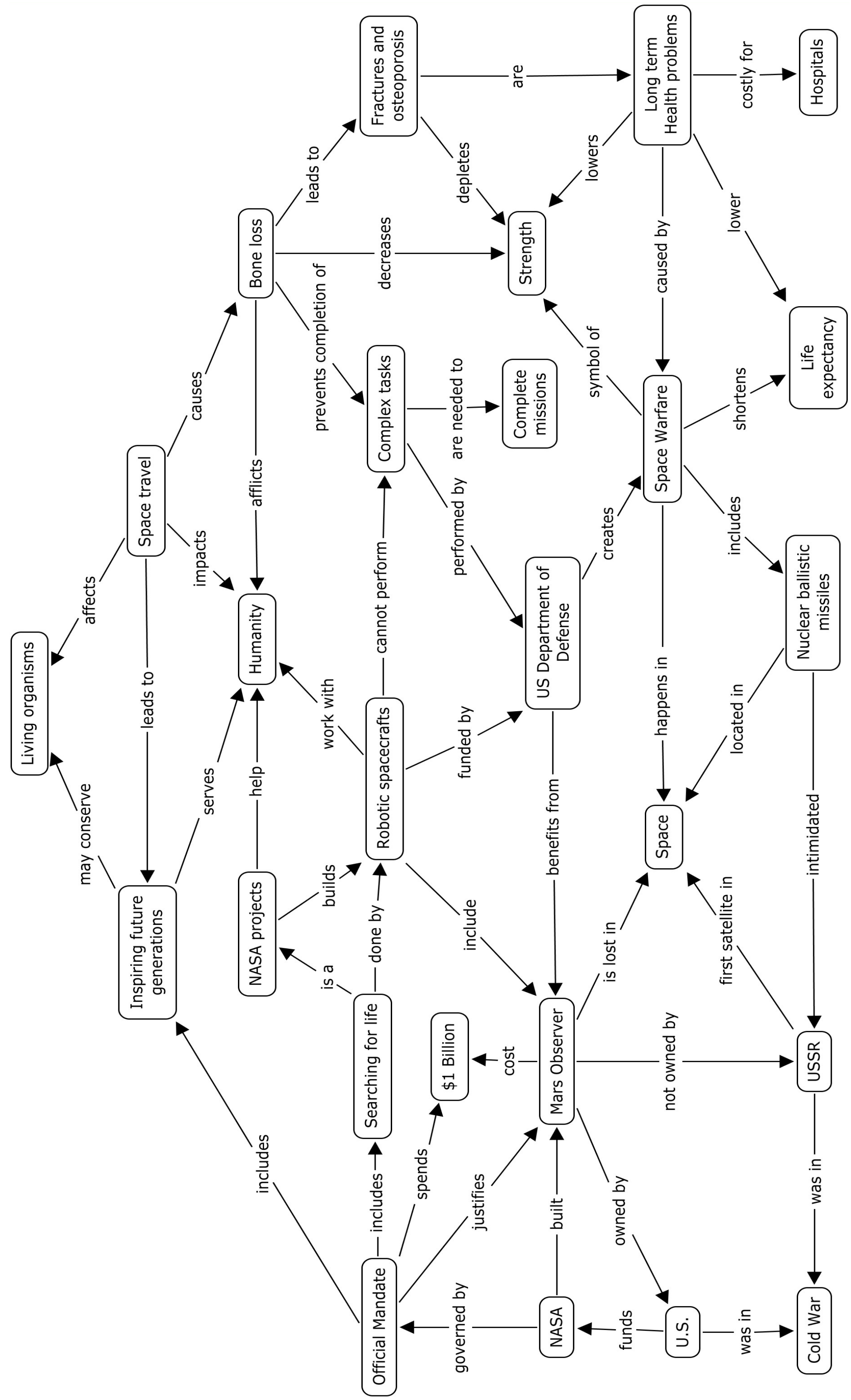
Appendix 9

Map A



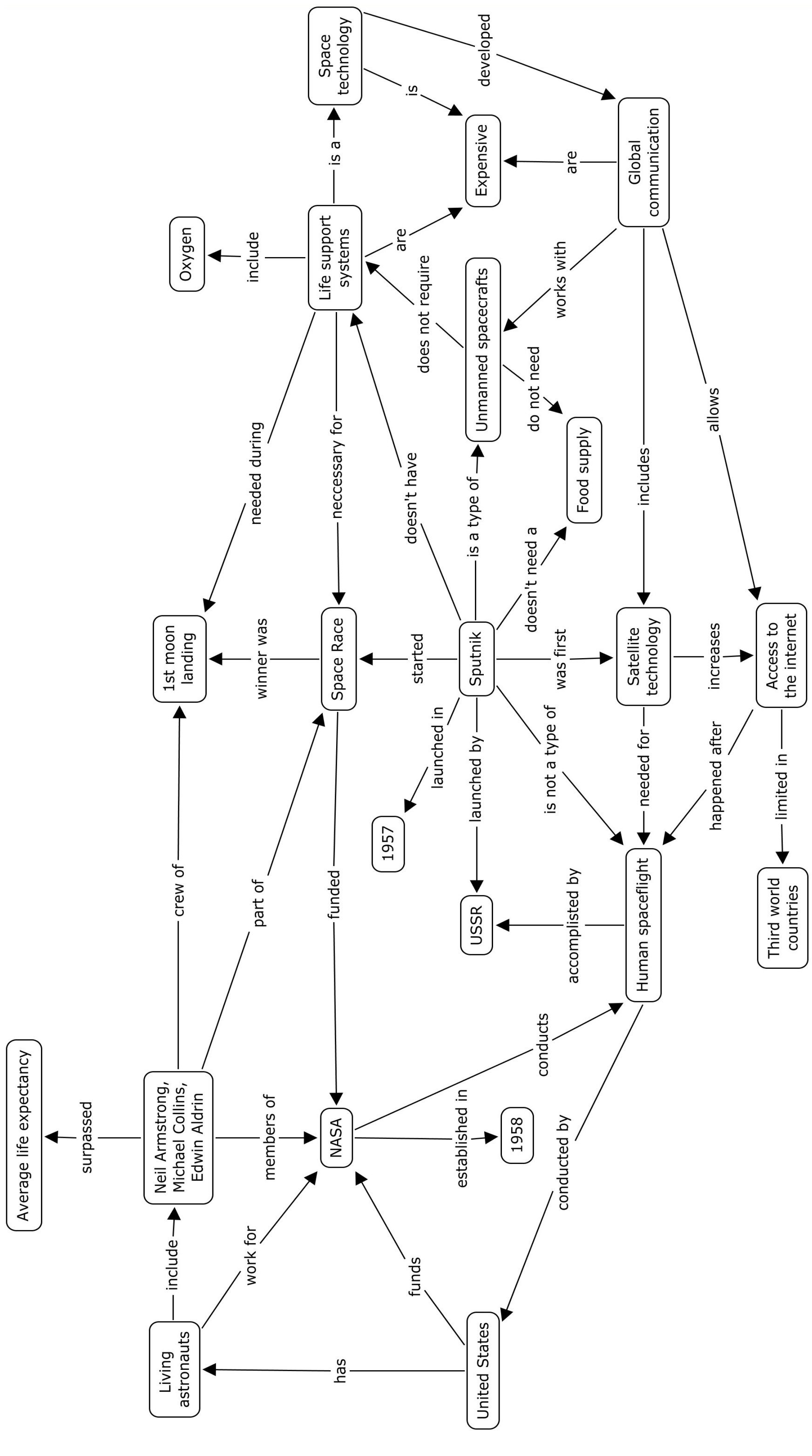
Appendix 10

Map B



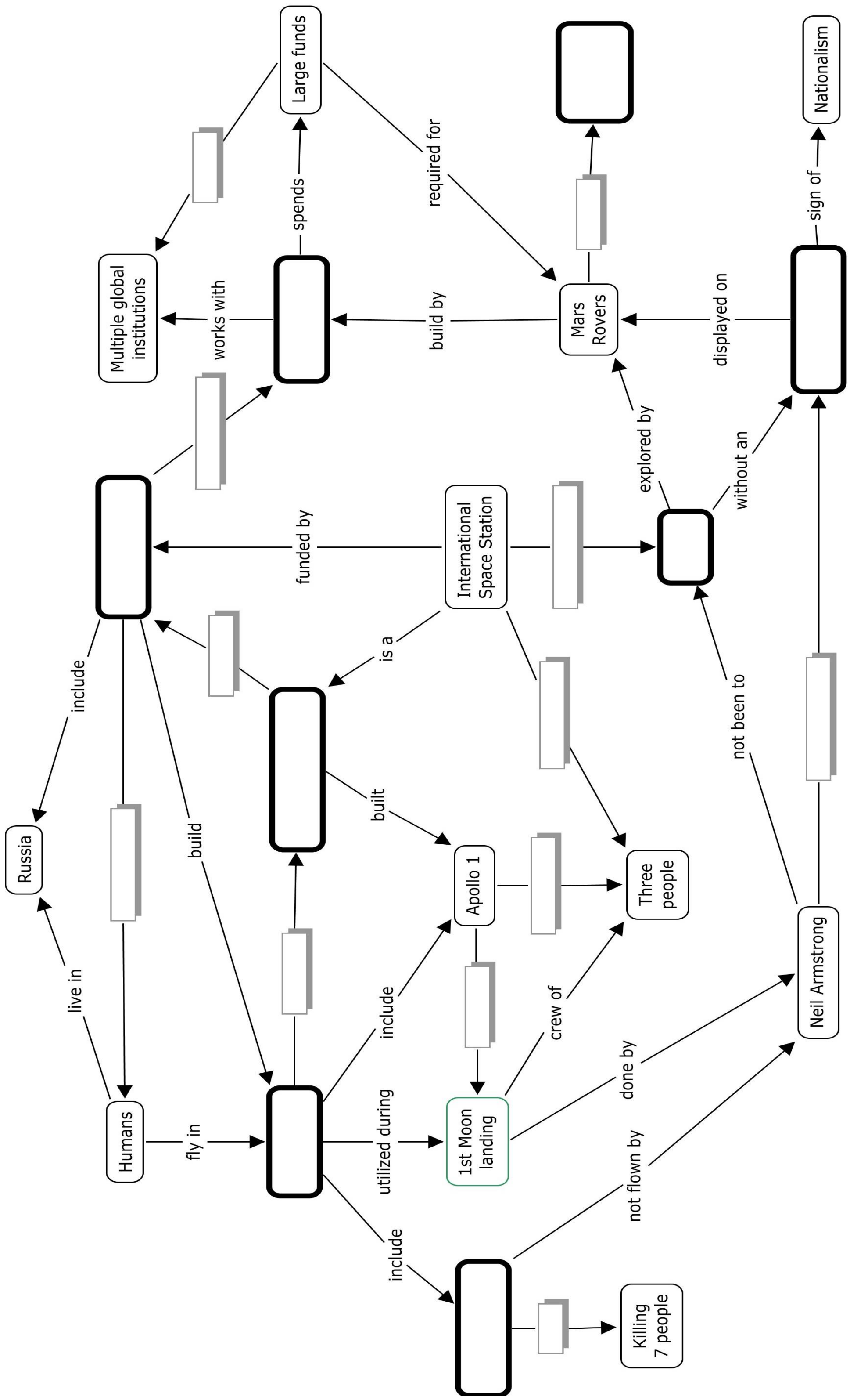
Appendix 11

Map C



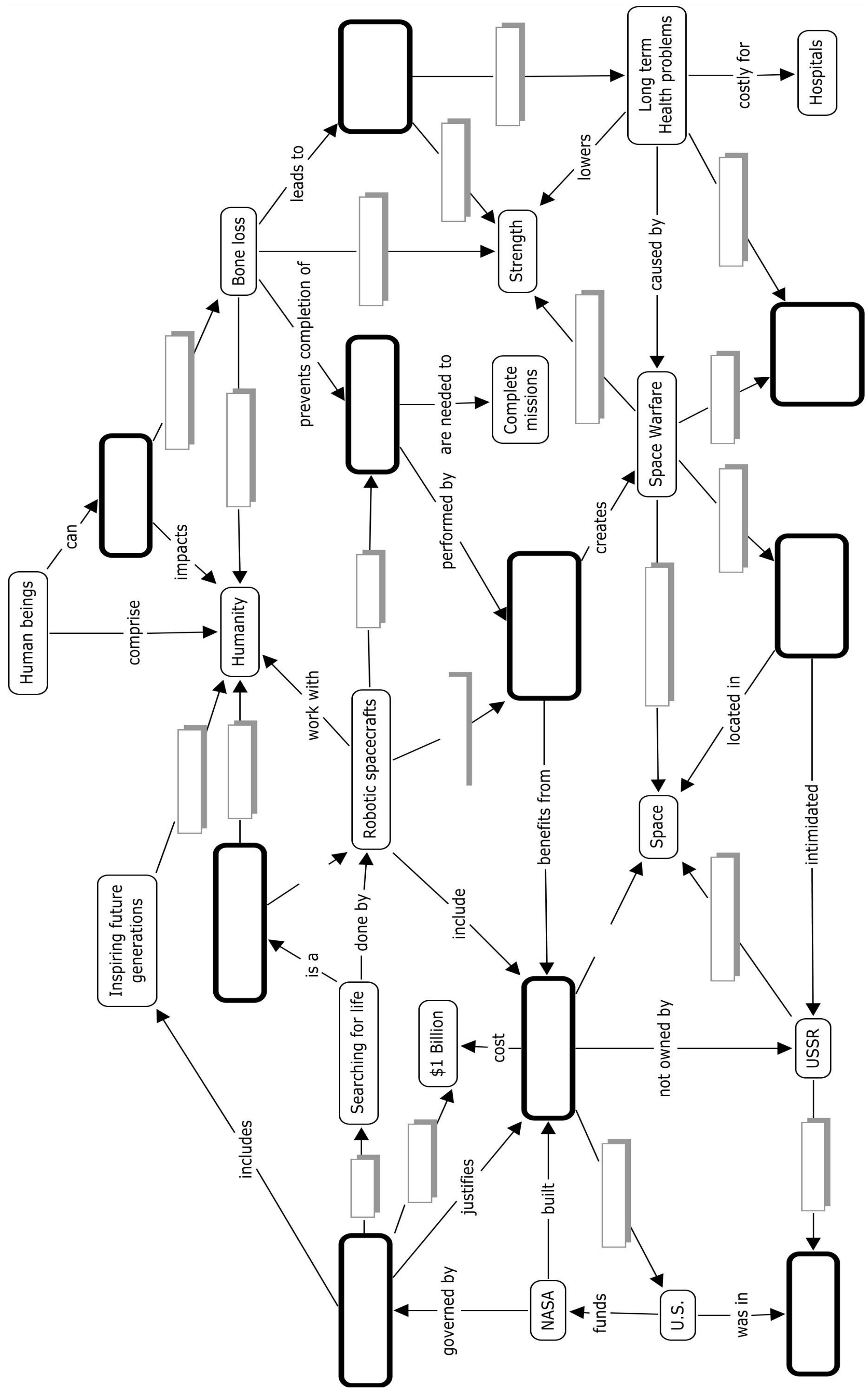
Appendix 12

Map A – Fill-in-the-blank map



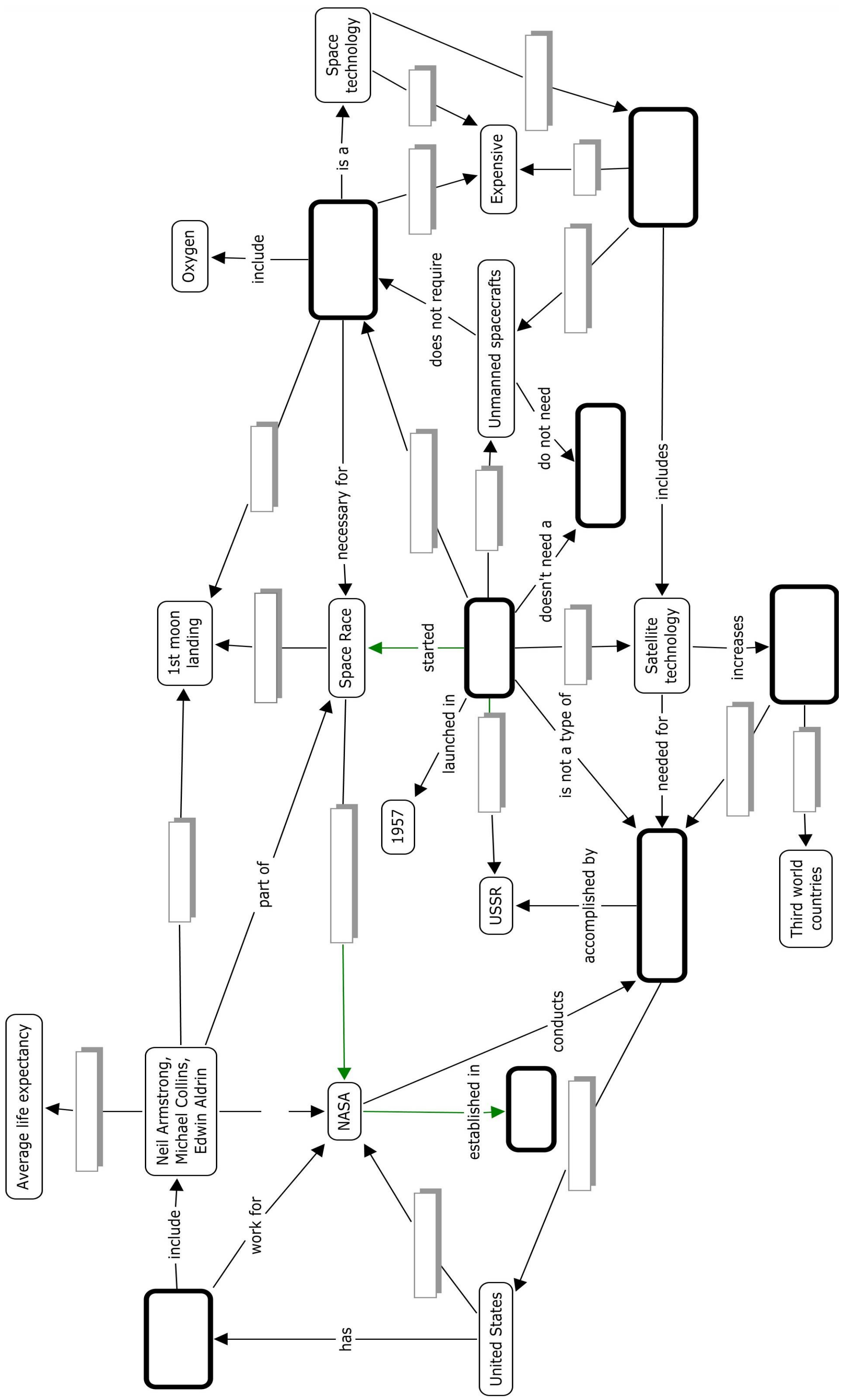
Appendix 13

Map B – Fill-in-the-blank map



Appendix 14

Map C – Fill-in-the-blank map



Appendix 15

Need for Cognition

1	2	3	4	5	6	7
not at all true of me						very true of me

1. I would prefer complex to simple problems.	1 2 3 4 5 6 7
2. I like to have the responsibility of handling a situation that requires a lot of thinking.	1 2 3 4 5 6 7
3. Thinking is not my idea of fun.	1 2 3 4 5 6 7
4. I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.	1 2 3 4 5 6 7
5. I try to anticipate and avoid situations where there is likely chance I will have to think in depth about something.	1 2 3 4 5 6 7
6. I find satisfaction in deliberating hard and for long hours.	1 2 3 4 5 6 7
7. I only think as hard as I have to.	1 2 3 4 5 6 7
8. I prefer to think about small, daily projects to long-term ones.	1 2 3 4 5 6 7
9. I like tasks that require little thought once I've learned them.	1 2 3 4 5 6 7
10. The idea of relying on thought to make my way to the top appeals to me.	1 2 3 4 5 6 7
11. I really enjoy a task that involves coming up with new solutions to problems.	1 2 3 4 5 6 7
12. Learning new ways to think doesn't excite me very much.	1 2 3 4 5 6 7
13. I prefer my life to be filled with puzzles that I must solve.	1 2 3 4 5 6 7
14. The notion of thinking abstractly is appealing to me.	1 2 3 4 5 6 7
15. I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.	1 2 3 4 5 6 7
16. I feel relief rather than satisfaction after completing a task that required a lot of mental effort.	1 2 3 4 5 6 7
17. It's enough for me that something gets the job done; I don't care how or why it works.	1 2 3 4 5 6 7
18. I usually end up deliberating about issues even when they do not affect me personally.	1 2 3 4 5 6 7

Appendix 16

Vocabulary I

Part 1 (4 minutes)

1. airtight — 1-firm 2-light 3-hermetically sealed 4-plane sick . . . . ( )
2. peddle — 1-tattle 2-cheat 3-misrepresent 4-sell. . ( )
3. raider — 1-frontiersman 2-plunderer 3-murderer 4-cynic . . . . ( )
4. energetically — 1-inspiringly 2-skillfully 3-delightfully 4-vigorously . . . . ( )
5. implicate — 1-involve 2-remove 3-retaliate 4-exaggerate . . . . ( )
6. gloaming — 1-autumn 2-midnight 3-twilight 4-daybreak . . . . ( )
7. legibleness — 1-crookedness 2-amity 3-plainness 4-carelessness . . . . ( )
8. laceration — 1-cut 2-oration 3-tumor 4-flogging . . . ( )
9. jollification — 1-capitulation 2-merrymaking 3-emancipation 4-teasing . . . . ( )
10. willowy — 1-lithe 2-windy 3-quiet 4-fickle . . . . ( )
11. feline — 1-guileless 2-fabulous 3-equine 4-catlike . . . . ( )
12. dispiritedly — 1-neglectfully 2-conspicuously 3-dishonorably 4-dejectedly . . . . ( )
13. intricacy — 1-delicacy 2-complexity 3-invisibility 4-hostility . . . . ( )
14. excerpt — 1-accept 2-extract 3-curtail 4-deprive . ( )
15. arrogance — 1-contrariness 2-insubordination 3-haughtiness 4-vivacity . . . . ( )
16. gallivant — 1-serenade 2-gad about 3-plunder 4-espouse . . . . ( )
17. sheik — 1-priest 2-casque 3-shepherd 4-chief . . ( )
18. exorbitance — 1-excessiveness 2-dissidence 3-unanimity 4-gaiety . . . . ( )

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Part 2 (4 minutes)

19. chef 1-cheese 2-style 3-head cook 4-candle . . ( )

20. milestone 1-marker 2-plant 3-soft music 4-grindstone . . . . ( )

21. chowder 1-dog 2-chemical 3-pigment 4-stew . . . . ( )

22. emancipator 1-theorist 2-liberator 3-prophet 4-spy . ( )

23. consultative 1-monitory 2-conservative 3-advisory 4-narrative . . . . ( )

24. emergence 1-laziness 2-identity 3-contrast 4-coming forth . . . . ( )

25. sheepfold 1-blanket 2-warm coat 3-sheeppen 4-crooked stick . . . . ( )

26. ignoramus 1-monster 2-gossip 3-dandy 4-dunce . . . ( )

27. calamitous 1-clamorous 2-discontented 3-disastrous 4-uncouth . . . . ( )

28. furlough 1-leave of absence 2-garden 3-foot soldier 4-timberland . . . . ( )

29. incubate 1-inform 2-anticipate 3-burn 4-brood . . ( )

30. incessantness 1-hopelessness 2-continuousness 3-inclination 4-rashness . . . . ( )

31. blithesome 1-morbid 2-cheery 3-blessed 4-venturesome . . . . ( )

32. devitalize 1-eat 2-deaden 3-soften 4-wave . . . . . ( )

33. exonerate 1-betray 2-transgress 3-exult 4-vindicate . . . . ( )

34. decadence 1-decline 2-decision 3-color 4-joy . . . ( )

35. ungainly 1-cheap 2-stupid 3-clumsy 4-hazardous . . ( )

36. pestilential 1-malignant 2-preparing 3-boisterous 4-yearly . . . . ( )

DO NOT GO BACK TO PART 1 AND DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO.

STOP