Cartography M.Sc.

Master thesis

A STUDY IN NODE-LINK CONCEPT MAP VISUALIZATION ENHANCEMENT

Jonathan King

2022

UNIVERSITY OF TWENTE.
ITC

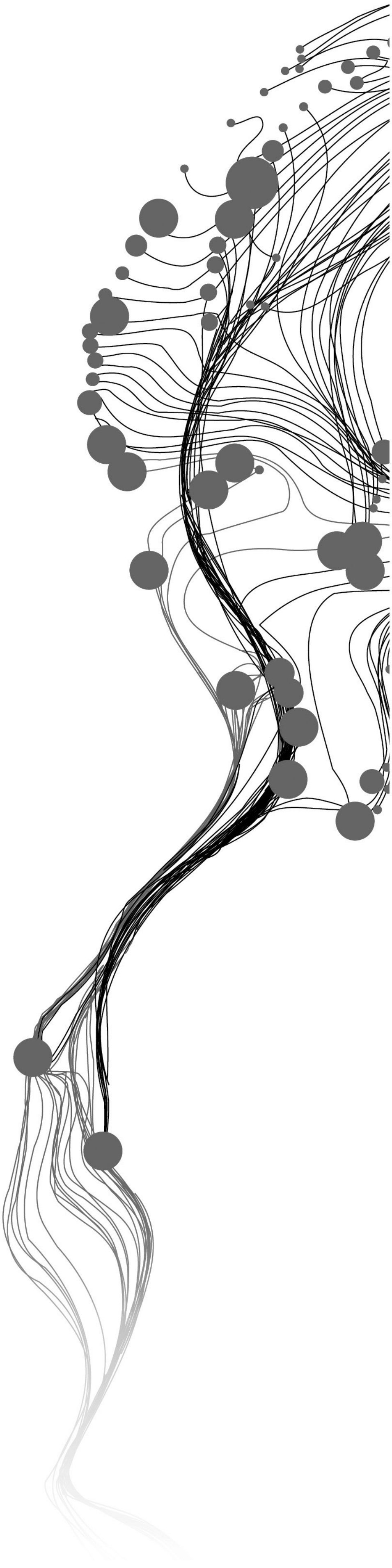
Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

"A STUDY IN NODE-LINK CONCEPT MAP VISUALIZATION ENHANCEMENT"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Enschede, 18 November 2022 Jonathan King



A STUDY IN NODE-LINK CONCEPT MAP VISUALIZATION ENHANCEMENT

JONATHAN KING
Enschede, The Netherlands,
November 2022, 2002

Thesis submitted to the Faculty of Geo-information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Cartography

SUPERVISORS:
Dr. ir. R.L.G. Lemmens
Dr. ir. P.W.M. Augustijn

THESIS ASSESSMENT BOARD:
Priv.-Doz. Dr. Franz-Benjamin Mocnik (chair)
Dr. E. Bogucka

ABSTRACT

Node-link concept maps have the potential to be a powerful learning tool. While concept maps' capacity to facilitate learning is widely recognized, research on enhancing their designs to encourage learning is still rare (Krieglstein et al., 2022; Schroeder et al., 2018). In this study, a conceptual framework for good concept map design is developed that integrates ideas yielded from past relevant academic research about the topic and the researcher's own ideas. The framework posits that the learning utility of a concept map depends on its semiology's lucid representation of conceptual relationships contained in its semantics and its navigability, and the framework identifies design principles relevant to these two factors. Guided by this framework, efforts are made to improve the learning utility of two existing node-link concept maps by enhancing their designs. The design enhancement process roughly followed usability engineering protocol for good user-centered design. This included user needs assessment, rapid prototyping of new design forms, and user testing of a selection of the new design forms. User testing involved both a questionnaire and an in-person user study. The user test questionnaire found the prototyped design forms to have good learning utility in some regards: Semiology of all prototyped new design forms were found to likely enable more accurate retrieval of knowledge about conceptual relationships than that of the existing concept maps undergoing enhancement. This finding reveals that design principles relevant to lucid conceptual relationship representation in the researcher's conceptual framework and the researcher's approach to implementing them were likely good. However, the navigability of all but one of the tested new design forms was found to be similar or less optimal than that of the existing concept maps whose design was being enhanced. This finding reveals that design principles relevant to the navigability of concept map semiology in the researcher's conceptual framework and the researcher's approach to implementing them could likely be improved upon. The selection of tested design forms included two sets of two forms. Both forms belonging to a set represented some of the semantics of one of the two existing concept maps undergoing enhancement. The two forms within each set were compared with each other. Within each set was one form that represented conceptual relationships in a way that might be considered innovative for concept map design: In one of the forms with innovative representation, nested polygons were used to represent hierarchical collections of conceptual relationships. In the other, the visual variable of color hue was associatively integrated into the design of links to show variation in the identity of the relationships the links represent, and a legend was used to identify the conceptual relationships signified by the various color hues. The design forms with these innovations were compared with other design forms representing the same semantics but in more traditional ways. The forms with innovative representation were found to have comparable learning utility with regards to lucid communication of knowledge about conceptual relationships as the forms with more traditional representation. This finding suggests invites further research regarding the learning utility of the innovative design forms. The in-person user study found that, when presented with the opportunity to use both of the compared forms in each set simultaneously while engaged in a learning task, they tend to use both forms. However, the comparative degrees to which each of the compared forms is used and the ways in which it is used varies from person to person. The in-person user study additionally identified spaces on each of the tested design forms where the arrangement of marks may be less than ideal

for learning.

Keywords

concept map, navigation, conceptual relationships

ACKNOWLWEDGEMENTS

First of all, I would like to communicate my heartfelt thank you to my amazing thesis supervisors Dr. Rob Lemmens and Dr. Ellen-Wien Augustijn for their wonderful guidance as I worked on this project. I am beyond grateful to have had the opportunity to work with two such talented, passionate people on such an interesting project. Throughout the time I worked on this project, I was I unsure had the ability to complete it. I'm so glad that I had such patient and supportive supervisors. I leave this project feeling far more capable than I was when I started and hope I have the opportunity to do similar work in the future. I had never heard of the word "concept map" before working on this project. I'm very glad that I had the opportunity to spend several months becoming an expert in the topic of the concept mapping and work on improving the visualization of such a high profile concept map focused on one of my favorite subject areas.

I thank everyone who participated in my questionnaires and user studies. I hope the experience wasn't too tedious and a bit of fun.

I'm so glad I had the opportunity to study in the wonderful Cartography MSc program. I thank Juliane Cron for all of the great help she gave me when I applying the program and for her indefatigable work coordinating the studies of me and all other students in my intake. She took care of us all like a mother! I thank Dr. Barend Köbben for coordinating such a great thesis semester for me and other students studying at ITC for being so understanding and beyond generous in offering me extensions as I worked to finish my thesis. I additionally thank all other faculty and staff involved in the Cartography M.Sc. program for their amazing teaching and support. Studying in this program allowed me to pursue in depth a topic that has fascinated me for a long time. I am grateful to have had the opportunity to do this.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1
Introduction

1.1 CONTEXT OF RESEARCH

Node-link diagrams can visualize knowledge structures thanks to their semiology (Ahnert et al., 2020; Kruja et al., 2001). This semiology includes points called nodes, which are connected by lines called links. Nodes may represent concepts and lines may represent relationships shared by concepts represented by nodes they connect. Arrows often append the linking lines, indicating directional relationships between concepts.

Nowadays such diagrams are frequently used as learning tools (Cañas et al., 2014; Schroeder et al., 2018). Commonly called concept maps, node-link diagrams designed as learning tools can communicate to a learner what concepts compose a body of knowledge and how the concepts interrelate with each other (Novak & Cañas, 2006).

While concept maps' capacity to facilitate learning is widely recognized, research on enhancing their designs to encourage learning is still rare (Krieglstein et al., 2022; Schroeder et al., 2018). People creating concept maps lack significant guidance. This research study seeks to identify principles for good concept map design, integrating the researcher's own ideas with ideas from other scholarship.

The study posits that the relative utility of a concept map as a learning tool depends on how well it communicates knowledge about conceptual relationships. Thus, the research presented in the study focuses on optimizing the design of concept map semiology representing knowledge about conceptual relationships to ensure accurate retrieval of this knowledge by a learner. The research project recognizes that retrieval of this knowledge by someone using the concept map to learn requires her navigation throughout the concept map's semiology between and among nodes representing concepts. The optimization of concept map design to enable learner navigation through the map is thus another research focus of the study.

Principles of good concept map design identified in the study are used to guide the improvement of two existing node-link concept maps whose subject matter focus is geo-information science and earth observation. These concept maps visualize knowledge presented in two sections of the online publication *The Living Textbook* (LTB), which is managed by the University of Twente, Faculty of Geo-Information Science and Earth Observation (UT-ITC). Large and interactive, these concept maps are exemplify an increasingly common form of concept map (Hanewald & Ifenthaler, 2014; Novak, 2004; Plotnick, 1997). The design enhancement process roughly followed usability engineering protocol to enable good user-centered design described in Nielsen (1992) and Nielsen (1993), including needs analysis and requirements gathering, prototyping of new design forms, and user testing of the new design forms.

1.2 RESEARCH IDENTIFICATION

1.2.1 Research objectives

Three research objectives guide this study:

RO1. Identify principles for good node-link concept map design that facilitate learning.

RO2. Improve the visualization of node-link concept maps existing in UT-ITC's digital publication *The Living Textbook* (LTB) in alignment with identified principles of good concept map design.

RO3. Assess the learning utility of prototyped design forms for LTB concept maps.

1.2.2 Research questions and methods

To meet the aforementioned objectives, the following research questions are addressed:

RO1.

(A) How do concept maps facilitate learning?

(B) How can the design of concept maps be enhanced to facilitate learning?

RO2.

(C) How can the designs of existing LTB concept maps be enhanced to facilitate learning?

RO3.

(D) How can the learning utility of the prototyped new LTB concept map design forms created while answering question C be optimally evaluated?

(D) What learning utility do the prototyped new LTB concept map design forms created by answering question (C) possess?

1.2.3 General caveats

The research project does not seek to identify all principles of good concept map design that facilitate learning. Instead, a selection of principles that likely hold a particularly strong importance for people involved in concept map creation to consider is presented. Helpful principles not identified in the study likely also exist, and people creating concept maps may benefit from consideration of these other principles alongside those identified in the study when doing their work.

The new design forms for existing LTB concept maps generated and evaluated during the project were created with consideration of the use case, target user groups, and existing semantics and semiotic structures of these maps. The study does not suggest the new design forms presented are appropriate for all concept maps. However, the design principles considered and processes involved in the creation of these design forms are offered as protocols with potential utility for all situations involving concept map creation.

1.2.4 Thesis structure

Introduction
This paper's first chapter describes the context of the thesis research, the objectives and research questions guiding the research project, general caveats about the research project, and structure of the thesis.

Introduction to concept maps
This chapter describes the origin and historical development of node-link diagrams as learning tools and identifies the definition of concept map adopted in the study. It additionally summarizes contemporary scholarly thought regarding the learning utility of concept maps, describes how the learning utility of concept maps is being enhanced by contemporary technological developments, and offers thoughts regarding whether concept maps should be classified as knowledge or information visualizations.

Principles of good concept map design
This chapter identifies principles of good concept map design. Ideas from other scholars are integrated with the researcher's own ideas. When the principles are presented, they are grouped into two broad categories. One group of principles includes those relevant to lucid representation of conceptual relationships; the other includes those relevant to navigability. The chapter concludes by presenting a conceptual framework regarding good concept map design that visually summarizes all ideas presented in the chapter and is used to guide a concept map design enhancement process described in proceeding chapters.

Introducing *The Living Textbook* concept maps
This chapter introduces concept maps whose designs are enhanced during the course of this research study. It describes the maps' existing user interface and experience designs. It additionally presents important ways by which the maps differ in their use cases, target user groups, and semantic and semiotic structures. It concludes with an outline of stages of the design enhancement process.

Design enhancement process: Stage 1
This chapter describes the needs assessment stage of the design enhancement process, which involved two sets of actions. In the first, the researcher himself assessed the concept maps' compliance with principles of good concept map design identified in the third chapter of the thesis and offered ideas for ways the maps could be improved upon in areas where compliance was lacking. In the second, the researcher used questionnaires to gather from other people information helpful for guiding the concept map design enhancement process. People participating in the questionnaires were asked to interact with the LTB concept maps undergoing design enhancement.

Design enhancement process: Stage 2: Describing the visualization prototyping process
This chapter describes the prototyping stage of the design enhancement process. The reasons for a focus on visualizations resulting from search and node-click interactions are identified. Software programs used in the visualization prototyping process are identified, and prototyped visualizations are presented. Among prototyped visualizations, two associated with each of the two concept maps being worked on that likely have have good learning utility are selected for user testing. The selected visualizations are described, and the reasons behind

the design choices the researcher made when creating them are identified.

Design enhancement process: Stage 3
Methods and results of learning utility tests for each of the two visualizations for each of the two LTB concept maps described in the previous chapter are presented. The test methods included a questionnaire and an in-person user study.

Closing discussions
The thesis closes with summary of the research project, discussion of results, and suggestions for further, related research.

Chapter 2
Introduction to concept maps

2.1 DEFINING CONCEPT MAPS

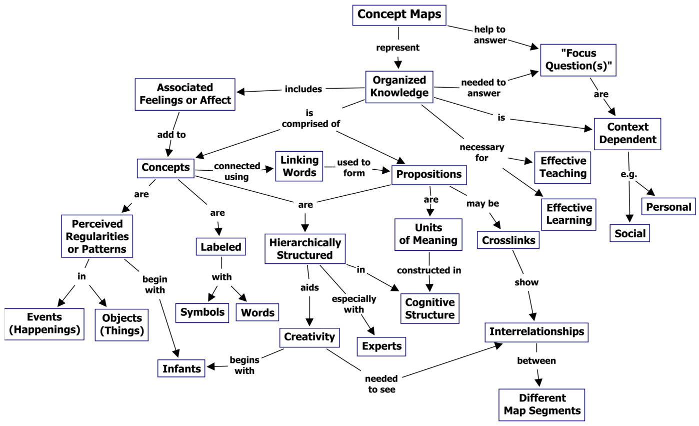
The creation of node-link diagrams visualizing structures of knowledge has been a common practice within communities of philosophers and logicians for nearly a millennium (Ahnert et al., 2020; Drucker, 2011; Kruja et al., 2001). However, these diagrams' widespread use in educational settings as learning tools is a much more recent phenomenon. It traces its origins primarily to the work of educational psychologist Joseph Novak and his colleagues in the 1970s. While studying how children learn science, these researchers interviewed children after providing them with audio-tutorial lessons. Novak's team experienced difficulty identifying specific changes in the children's understanding of science concepts during the examination of transcripts of the interviews. They found constructing node-link diagrams they called concept maps helpful in tracking the evolution of children's conceptual knowledge. Graduate students working on the research project additionally found that creating concept maps of their own knowledge of subject material they were studying helped them in their academic performance. The value of concept maps as learning tools became evident (Nesbit & Adesope, 2006; Novak & Cañas, 2006; Schroeder et al., 2018).

Following this research project, Novak has, throughout his career, continued to explore the power of concept maps to facilitate learning and has published widely about the topic. His work has inspired investigations by many other researchers. Over time, educators of various disciplines worldwide have found concept maps helpful to their work (Nair & Narayanasamy, 2017; Novak & Cañas, 2006, 2010; Wang et al., 2018).

Novak considers the ideal form of concept map to have a hierarchical network structure (*Figure 2.1*). He thinks the top of the map should house nodes representing general concepts, downward from which extend links connected to nodes representing more specific concepts. Novak additionally recommends that concept maps include horizontal cross-links representing conceptual relationship semantics unrelated to generality and specificity (Novak & Cañas, 2006).

The knowledge map is another type of diagram with a node-link structure whose value as a learning tool has been researched in recent years, by American psychologist Donald F. Danserau and his colleagues. In knowledge maps, all links represent relationships belonging to a fixed set of relationship type categories, which are identified in *Table 2.2*. By the exclusion of links representing conceptual relationships that don't belong to these type categories, the knowledge map differs in definition from the Novakian concept map: When researching the learning utility of node-link diagrams, Novak and his colleagues do not place restrictions on the types of conceptual relationships that links can represent (Nesbit & Adesope, 2006; O'Donnell et al., 2002). Knowledge maps can additionally be distinguished from Novakian concept maps by the fact that research regarding knowledge maps has focused on learner interaction with diagrams, in whose construction the learners are not involved. For example, in experiments conducted by Danserau and colleagues described in Wiegmann et al. (1992), the

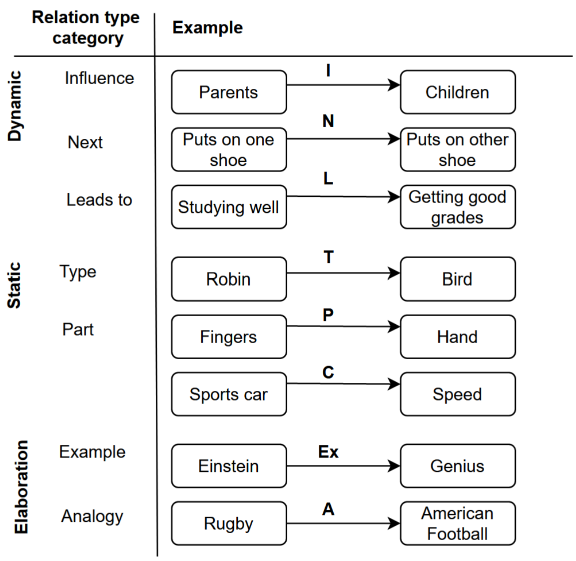
Figure 2.1: *Concept map with a hierarchical network structure*



Note: Based on (Canas Novak, 2008, p. 27). From “Evaluating a concept mapping training programme by 10 and 13 year-old students,” by A. Habok, 2012, *International Electronic Journal of Elementary Education, 4*(3), 460. CC BY 4.0.

learning utility of different forms of concept map design is compared. Student experiment participants were asked to interact with node-link diagrams constructed by the researchers running the experiments. The experiment participants played no role in the construction of the diagrams. By contrast, Novak and his colleagues have primarily explored how a student’s being involved in the construction of node-link diagrams impacts her learning (Nesbit & Adesope, 2006). Despite these differences, some scholars, including Nesbit and Adesope (2006) and Schroeder et al. (2018) consider the knowledge map a form of concept map.

Figure 2.2: *Knowledge map link relationship categories*

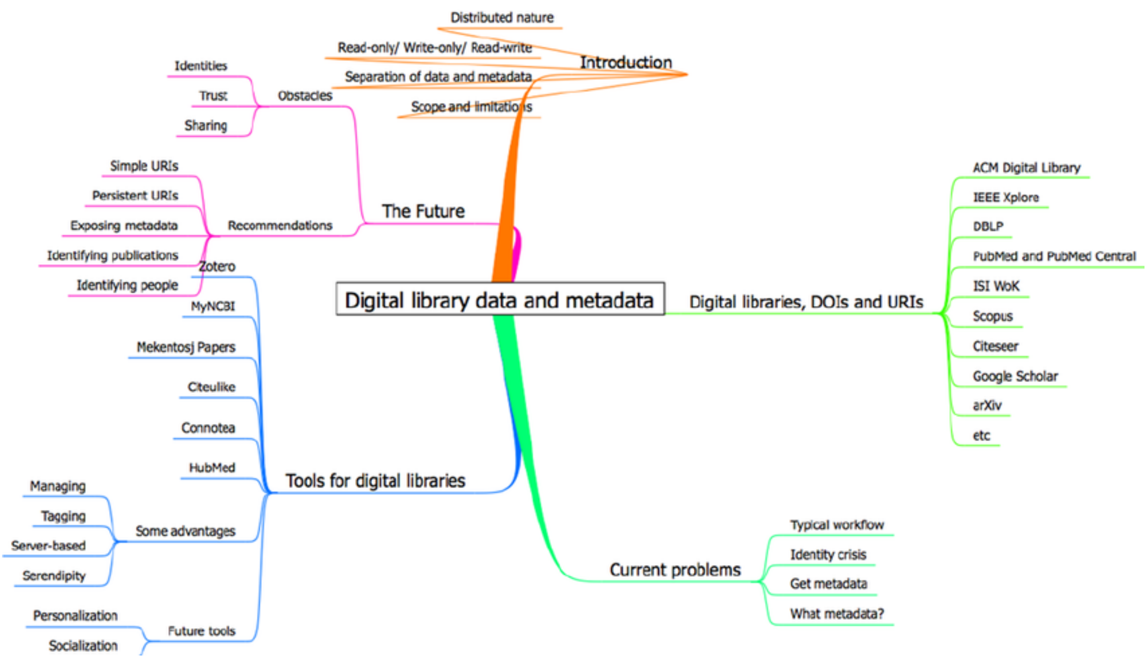


Note: Based on O’Donnell et al. (2002) p. 73.

Schroeder et al. (2018) defines a concept map as "any node-link diagram in which each node represents a concept and each link identifies the relationship between the two concepts it connects" (p. 431), additionally identifying the typical setting where concept maps are used as educational. This research project adopts this definition.

According to this definition, mind maps *(Figure 2.3)* are a form of concept map. Some scholars define these two types of diagrams differently (Nesbit & Adesope, 2006; Schroeder et al., 2018). For example, Eppler, Martin, J. (2006) distinguishes mind maps from concept maps by their lack of a network structure: They typically have a radial tree structure with one root node and several branches and lack links connecting concepts associated with different branches of the tree. However, because nodes and links compose their core structure, Nesbit and Adesope (2006), Schroeder et al. (2018), and this research project consider mind maps a form of concept map.

Figure 2.3: *Mind map about digital libraries*



Note: From “Defrosting the Digital Library: Bibliographic Tools for the Next Generation Web,” by D. Hull et al., *PLoS Computational Biology, 4*(10), (https://doi.org/10.1371/journal.pcbi.1000204.g001). CC BY 4.0.

2.2 HOW CONCEPT MAPS FACILITATE LEARNING

Significant empirical evidence supports the effectiveness of concept maps as learning tools. Schroeder et al. (2018) meta-analyzed 63 studies that experimentally compared learning with concept maps to learning with other forms of knowledge transmission whose value as learning tools is known. Learning of multiple varieties with concept maps was found to be more effective, with moderate to large effect sizes as indicated by Hedge’s *g* values,[1] than learning with lectures, discussions, prose texts, lists, or outlines. These findings corroborate those of a previous similar meta-analysis carried out by Nesbit and Adesope (2006).

[1] A measure of effect size, a hedges *g* value indicates the advantage of a treatment, adjusted for small sizes, expressed in standard deviations (Schroeder et al., 2018).

According to Schroeder et al. (2018), much current theorizing among scholars who study concept maps attributes these diagrams' strong effectiveness as learning tools to two factors. First, concept maps can easily facilitate meaningful learning. Second, a lower extraneous cognitive load may be associated with learning with them.

The idea of meaningful learning originated in the Assimilation Learning Theory of American psychologist David Ausubel, who thought the most important element in learning is what the learner already knows. He considered meaningful learning an ideal form of learning involving the semantic integration of newly acquired knowledge into one's existing cognitive structures. Meaningful learning has come to be defined as one end of a continuum. On the other end lies rote learning, which occurs when one's mind encodes newly learned information semantically isolated from knowledge gained in the past (Ausubel, 1968, 2000; Novak & Cañas, 2006). The node-link structure of concept maps can help someone retrieving knowledge from the map learn meaningfully: She may see easily how concepts unknown to her relate to her existing knowledge (Nesbit & Adesope, 2006; Novak & Cañas, 2006; Schroeder et al., 2018).

Extraneous cognitive load can be defined as the mental burden caused by learning material whose design and format are less than optimal for knowledge transmission (Krieglstein et al., 2022; Sweller, 2010). A concept map may transmit knowledge with simpler and more lucid representational semiology and grammatical structure than other instructional forms, such as prose text. Everything is communicated in concept-relationship-concept semantic triples represented exclusively or primarily with points, lines, and short text labels. Additionally, conceptual relational superstructures comprising more than two concepts and more than one relationship may be presented more saliently in concept maps than in other instructional forms (Amadieu et al., 2009; Nesbit & Adesope, 2006; O'Donnell et al., 2002; Schroeder et al., 2018).

2.3 CONCEPT MAPS AND INFORMATION TECHNOLOGY

During the early years of the tool's development, concept maps were exclusively created through often ponderous and time-consuming hand-drawn methods. Eventually, the arrival and increasing use of personal computers in educational settings alleviated some of the tedium associated with learning with concept maps. Software programs for digital concept map creation, such as Inspiration, were developed. Learning with concept maps became easier and involved new forms of creativity: Concepts could be represented with clip art and digital photographs, for example. The popularity of concept maps as learning tools saw growth thanks to the availability of this software. The Internet has additionally fostered increase and innovation in concept map creation: Applications were developed enabling the sharing and collaborative construction of concept maps, whose content is often undergoing continuous growth and evolution, among large numbers of Internet users interested in the same body of knowledge (Hanewald & Ifenthaler, 2014; Novak, 2004; Plotnick, 1997). One of the most commonly used of these applications is CmapTools, which was developed by Joseph Novak and his colleagues at the Florida Institute of Human and Machine Cognition (IHMC) (Novak, 2004; Shakhnov et al., 2013; Wong, 2010). Others examples include LucidChart, Cacoo, Webspiration, and CM-ED (Arruarte et al., 2009; Colosimo & Fitzgibbons, 2012; Li, 2015; Price & Wright, 2012; Tünkler, 2021).

2.4 KNOWLEDGE OR INFORMATION VISUALIZATION?

Deciding whether to classify a concept map as a knowledge or information visualization is not necessarily straightforward: Different scholars define these two visualization form categories differently (Burkhard, 2004; Cañas et al., 2005; Dansereau, 2005; Keller & Tergan, 2005).

This research project takes guidance from the ideas of Cañas et al. (2005) about the topic. Drawing upon theorizing presented in Ausubel et al. (1978) and Novak (1977), Cañas et al. (2005) consider knowledge to be human understanding of concepts and relationships shared among concepts resulting from meaningful learning of relevant information. According to this definition, information becomes knowledge when the human mind assigns it meaning by associating it with what it already knows. The definition of knowledge visualization adopted by Cañas et al. (2005) comes from (Burkhard, 2004): "visual representation to improve the transfer of knowledge between at least two persons" (p. 520). Concept maps, which are visual representations created for learning purposes, can therefore be considered knowledge visualizations at their core. The creator of a concept map visually represents some of her own knowledge to allow others to acquire this knowledge. Cañas et al. (2005) qualify this notion with the idea that some concept maps, particularly a large number of Internet concept maps, can be considered a hybrid of knowledge visualization and information visualization. For example, CmapTools allows for the creation of concept maps connected to Internet search engines. Information from Internet repositories relevant to a particular concept and its context within the concept map housing it is retrieved when this concept is selected by a concept map user. Such concept maps may also be considered knowledge domain visualizations, a term often used to identify information visualizations with a node-link structure (Hook & Börner, 2005; Zhou et al., 2009).

Chapter 3
Principles of good concept map design

3.1 ENSURING ACCURACY OF RETRIEVAL OF KNOWLEDGE ABOUT CONCEPTUAL RELATIONSHIPS

As described previously, a person seeking to learn about a subject may benefit from retrieving knowledge from a concept map with content about this subject for two primary reasons:

1. A concept map can facilitate meaningful learning. (A description of what this form of learning entails can be found in chapter 2.2.)

2. A low extraneous cognitive load may be associated with learning with a concept map.

A concept map can benefit a learner in these ways thanks to how its semiology can enable understanding of relationships shared between and among concepts composing a body of knowledge. This study posits that the compilation of semantics about conceptual relationships in a concept map comprises two components:

1. Individual relationships connecting two concepts

2. Conceptual relational superstructures comprising multiple concept-relationship-concept triples, which may exist in a concept map at multiple levels of conceptual hierarchy

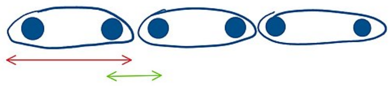
The learning utility of a concept map thus likely depends on how the map's semiology representing these semantics enables an accurate understanding of them.

3.1.1 Use of container polygons to represent conceptual relational superstructures

Any representational component of a two-dimensional graphic must come in the form of one of the three elementary figures of planar geometry: points, lines, and areas (Bertin, 1983; Card, 2007; Munzner, 2015). The core representational semiology of a network diagram, such as a concept map, is usually composed of points and lines: Objects or ideas are represented with points as nodes, and connections between pairs of nodes are represented with lines as links (Card, 2007; Munzner, 2015).

As previously explained, a concept map's learning utility likely lies not only in its visual communication of pairwise conceptual relationships: It may also come from its conveyance of conceptual relational superstructures comprising more than one concept-relationship-concept triple. In a network diagram, an area mark can signify a group of node-link-node triples representing a conceptual relational superstructure. Nodes and links belonging to this group can be placed within the boundaries of a container polygon (Card, 2007; Munzner, 2015). This representational possibility is thanks to the human perceptual tendency to assign different identities to spaces on different sides of a bounding contour line in a

Figure 3.1: *Law of common region*



Note: From *Law of Common Region* [Digital vector graphic] by BE12M, Wikimedia Commons, 2019 (https://commons.wikimedia.org/wiki/File:LawofcommonRegion.jpg). CC BY-SA 4.0.

graphic (*figure 3.1*). Referring to this tendency as the law of common region, Palmer (1992) considers it comparable to Gestalt laws of perceptual organization.

Commonly used concept map creation software, including CmapTools, LucidChart, Cacoo, Webspiration, and CM-ED present the option of representing conceptual relational superstructures with container polygons. The size of a node can be expanded and placed in the background of the map's content. Nodes and links representing concepts and relationships belonging to the superstructure represented by the polygon can be placed in the map's foreground within the polygon's boundaries. Unfortunately, a paucity of research regarding learning with concept maps with container polygons in their representational semiology means concept map creators using these and other tools likely lack significant guidance regarding how to integrate this container polygons into their map designs. This research study seeks to investigate how to effectively do this. It posits that representing conceptual relational superstructures with container polygons can help facilitate learning with a concept map for several reasons.

First of all, the placement of a collection of concept map nodes and links representing a conceptual relational superstructure inside the boundaries of a container polygon is a viable alternative to representing the superstructure with the spatial positions of nodes and links. As identified by the Gestalt law of proximity, the spatial positioning of marks in a graphic influences human perception of how the marks relate to each other: Marks separated by short distances are likely to be perceived as more related to each other than marks separated by longer distances (Ware, 2021). Representing conceptual relational superstructures by positioning relevant node-link-node triples in clustered spatial positions is a common practice in concept map design. The effectiveness of this practice for enhancing some aspects of learning received empirical validation in Amadieu et al. (2009), Wiegmann et al. (1992), and Krieglstein et al. (2022). However, this representational form may not always be possible. There may be a need to represent other semantics using the same set of spatial positions where the cluster of nodes and links representing the conceptual relational superstructure would be placed. Container polygons can prove helpful in such cases. *Figure 3.1* shows that, in a graphic with container polygons, the position of marks relative to the boundaries of container polygons can serve as stronger indicators of relationships shared among the marks than the length of distance in space separating the marks from each other. Consideration of human perception of relationships among points representing cities in a political geographic map can further elucidate the concept (Palmer, 1992). For example, the map of the Eastern Netherlands shown in *Figure 3.2* arguably makes the city of Deventer's relationship with the city of Enschede appear stronger than Deventer's relationship with the city of Zutphen. Though a smaller distance in space separates the points representing Deventer and Zutphen, the points representing Deventer and Enschede are both located within the boundaries of the polygon representing the province of Overijssel and therefore appear to be more closely related to each other.

Figure 3.2: *Eastern Netherlands*

Note: From *Map of the Eastern Netherlands* [Map] by Globe-trotter, Wikimedia Commons, 2013 (https://commons.wikimedia.org/wiki/File:Eastern-netherlands-map.png). CC BY-SA 3.0.

Secondly, a concept map's semantics may contain multiple conceptual relational superstructures with varied identities. Representation of these multiple superstructures with multiple container polygons allows for particularly lucid communication of this identity variation. The identity of a superstructure represented by a polygon in comparison to other superstructures represented by other polygons can be communicated with written and visual communication. Respectively, a text label can be printed within the map's polygon boundaries or visual variables can be effectively integrated into the visual designs of polygons.

Thirdly, some of a concept map's nodes and links may represent concepts and relationships belonging to more than one conceptual relational superstructure. Such complex conceptual relational semantics can likely be represented by placing these nodes and links within the boundaries of multiple container polygons whose spatial extents reflect the topological relationships of covered by, contains, covers, overlaps.

Finally, in a concept map, a concept may share a relationship with a conceptual relational superstructure even if the concept doesn't belong to that superstructure. Such a relationship can be efficiently represented in a concept map, in which conceptual relational superstructures are represented with container polygons: A link could connect the node representing the concept to a container polygon representing the conceptual relational superstructure.

3.1.2 Ensuring legibility

Legibility can be defined as the capability of being discerned or read ('Legible', n.d.). To ensure the semantics associated with any concept map mark representing conceptual relationships are lucid, the mark must be legible. This study posits that two factors govern the legibility of marks composing a concept map's design:

1. The size of all marks must be sufficiently large. For a concept map whose substrate is an interactive interface, at least some of the available interactive functions (e.g., zoom

control) must allow for all marks in the map to achieve discernible or readable sizes even if marks are too small during some interactions.

2. A learner interacting with the map must be able to visually discriminate all of its marks from each other. For example, marks should not topologically overlap with each other to an extent that they would be mistaken for one another.

3.1.3 Effective use of visual variables

The term visual variable has come to be defined as a dimension of a graphical object that identifies the object in relation to other objects in the same visualization where it appears (Garlandini & Fabrikant, 2009; Mackinlay, 1986; Roth, 2017). Optimally integrating visual variables into the design of a concept map's semiology representing conceptual relationships likely makes the semantics associated with this symbolic representation lucid and the map itself an effective learning tool.

Scholars debate about the best way to classify graphic dimensions as visual variables and for what types of representation each variable is appropriate. However, a general consensus exists in several similar variations of expansion and revision of the systematization of the idea described in *The Semiology of Graphics*, a seminal work of French cartographer Jaques Bertin (*figure 3.4*) (Garlandini & Fabrikant, 2009; Roth, 2017). Developing his ideas primarily from his background in print cartographic design, Bertin (1967; and translated to English in 1983) identified x-y position, shape, size, color value, color hue, orientation, and texture as variables that can be manipulated to encode information in any form of visualization.

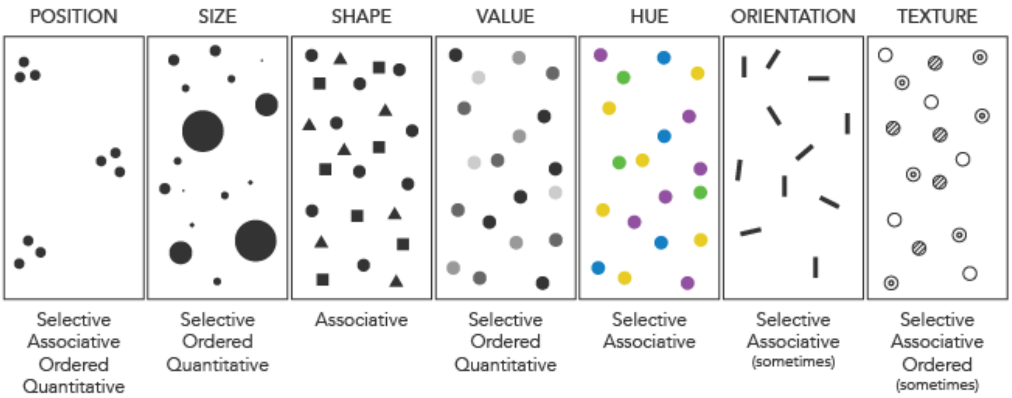
Bertin (1967, 1983) additionally identified four approaches by which the human eye visually perceives variation in identity across groups of marks of a particular type when the varied application of a visual variable in the design of a mark is used to indicate its group membership:

1. Associative: Perceiving all groups of a mark type on the same level.
2. Selective: Perceiving all groups of a mark type on the same level, with the exception of one group that is perceived on a different level.
3. Ordered: Perceiving all groups of a mark type on different levels from each other. However, the level difference from group to group can't be quantified.
4. Quantitative: Perceiving all groups of a particular mark type on different levels from each other. In this case, the level difference from group to group can be quantified.

Each visual variable was thought by Bertin to be perceived adeptly by a specific set of perceptive approaches. Principles of perceptual psychology predict that the forms of information retrieved and processed into knowledge by the human eye-brain system vary from perceptual approach to perceptual approach. Each variable is thus appropriate for encoding a specific set of information forms to enable human understanding (Roth, 2017).

Since the publication of *The Semiology of Graphics*, several scholars, primarily working in the field of cartography, have suggested alterations to Bertin's systematized ideas about visual variables. Notably, Morrison (1974) suggested consideration of arrangement and color saturation as visual variables; The advent of digital cartographic methods led MacEachren (1995) to recommend the additional inclusion of resolution, transparency, and crispness (the sharpness of a mark's boundary). From MacEachren (1995) also came the important clarification that while visual variables have been defined separately, combinations of visual

Figure 3.3: *Bertin's visual variables*



Note: From *Bertin's Visual Variables* [Digital vector graphic] Axis Maps, 2022 (https://www.axismaps.com/guide/visual-variables). CC BY-NC-SA 4.0.

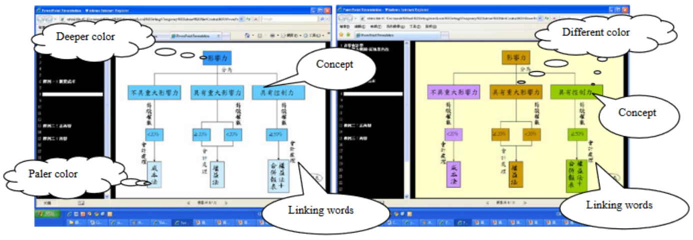
variables can be integrated into the design of a graphical object to ensure effective representation. Both Morrison (1974) and MacEachren (1995) expanded upon Bertin's ideas about the suitability of a visual variable for representing specific forms of information. They argued that most visual variables can encode any form of information but only at specific levels of appropriateness (Roth, 2017).

Some scholarly thought about visual variables in visualization fields other than cartographic design has also emerged. For example, Carpendale (2003) offered ideas for how Bertin's system could be adjusted to guide producers of computational visualizations to account for ways such visualizations differ from print geographic maps. An important topic addressed relevant to concept map design is the representational possibilities associated with the variable of spatial position in non-cartographic visualizations. In such visualizations, a mark's position is not constrained to represent geographic location and may be used for forms of associative, selective, ordered, and quantitative representation.

Researchers investigating concept map design enhancement have considered the visual variable of position both theoretically and empirically. For example, as described previously, Novak and Cañas (2006) theorized that the vertical positions of a map's nodes could effectively represent ordered levels of conceptual generality. In Krieglstein et al. (2022), the use of position in associative representation was empirically evaluated: In an experiment, the impact on learning of two concept maps with groups of nodes and links representing conceptual relational superstructures located close to each other is compared with that of two other concept maps. Each of the two maps in the latter set had the same nodes and links as one of the two maps in the former. However, the spatial positions of nodes and links in the second map less consistently indicated their associated semantics' membership in a conceptual relational superstructure.

The visual variable of color has also been considered in at least one study of concept map design enhancement. Chiou et al. (2012) experimentally assessed the learning utility of concept maps shown in *figure 3.4*. The colors of nodes of the map on the right side of the figure vary in value according to levels of conceptual generality present in the nodes' associated semantics. Variation in colors of the right-side map's nodes accords with conceptual categorical membership. In the study, these maps were compared with each other, as well as with prose text and a map whose nodes were all the same color.

Figure 3.4: *Colored concept maps whose learning utility was evaluated in Chiou et al. (2012)*



Note: From "Effect of Novak Colorful Concept Map with Digital Teaching Materials on Student Academic Achievement," by C. Chiou et al., *Procedia - Social and Behavioral Sciences, 64*(9), (Effect of Novak Colorful Concept Map with Digital Teaching Materials on Student Academic Achievement). CC-BY-NC-ND.

This research study suggests that someone creating a concept map should ideally consider all visual variables appropriate for application to the design of marks in the map representing conceptual relationships. Her doing this, alongside her consideration of the content, use case, and target user group of the concept map would likely result in a map whose design enhances learning. This study presents *table 3.1* as a tool to assist the concept map creation process. It identifies all components of a concept map's semiology potentially involved in the representation of conceptual relationships. It further identifies all visual variables likely suitable for the design of each of these components, given contemporary scholarly thought regarding the appropriate use cases for visual variables.

Table 3.1: *Visual variables appropriate for concept map semiology representing conceptual relationships*

Conceptual relationship type	Visual semiology representational component	Relevant visual variable
Relationships connecting two concepts	Link Lines	Associative Selective Ordered Color hue Texture Size (width) Color value Color saturation Resolution Transparency
Conceptual relational superstructure	Nodes belonging to superstructure	Associative Selective Ordered Shape Color hue Texture Position Size Color value Color saturation Resolution Transparency
	Container polygons	Associative Selective Quantitative Ordered Shape Color hue Texture Position Size Color value Color saturation Crispness Resolution Transparency

3.2 ENABLING NAVIGATION

Navigation in the context of media use can be defined as the media user's browsing between and among semantically related pieces of content (Garzotto, 2009). As described previously, a concept map's utility for learning comes from the way its representational semiology communicates knowledge about conceptual relationships. To retrieve this knowledge from a concept map's semiology, a learner must engage in navigation throughout this semiology: Browsing between pairs of semantically related nodes and among collections of node-link-node triples and container polygons representing conceptual relational superstructures is a necessity. Thus, to serve as a learning tool, a concept map must have a design that enables navigation.

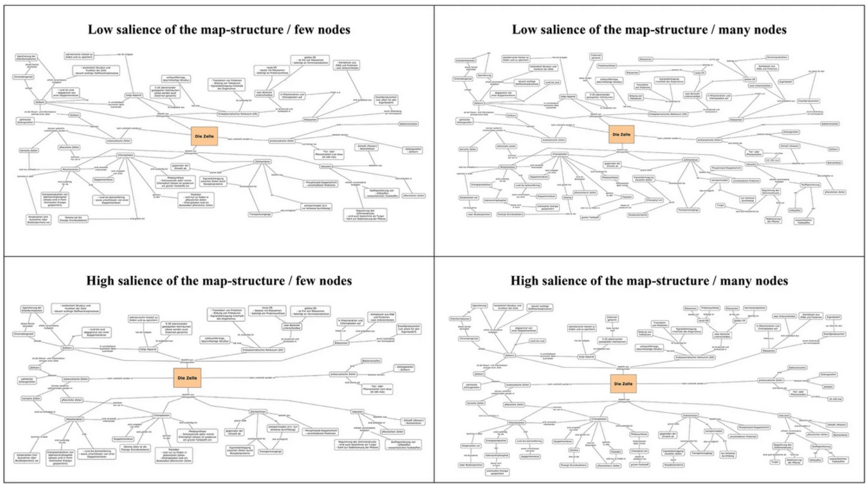
3.2.1 The likely relevance of map size and conceptual relational superstructure representation

Disorientation in the context of media navigation can be defined as a media user's subjective experience of being unable to effectively navigate a media substrate (Conklin, 1987; Head et al., 2000; Woods, 1984). Specifically addressing hypertext media, Ahuja and Webster (2001) describes the phenomenon as "the feeling experienced by users who do not know where they are within hypertext documents or how to move to desired locations" (p. 16). A concept map should thus be designed in a way such that a person using it to learn experiences low levels of disorientation. Additionally, an assessment of the learning-related disorientation associated with a concept map can perhaps help in the evaluation of the navigability, and, by extension, learning utility of the map.

In past research regarding concept map design and learning, disorientation has been addressed. Blankenship and Danserau (2000) associate disorientation with the phenomenon of map-shock, which has come to be defined as overwhelm potentially experienced by someone making efforts to learn with a concept map comprising a particularly large number of nodes and links (Adesope & Nesbit, 2013; Danserau et al., 1994; Moore et al., 2013). Someone interacting with a concept map and experiencing map-shock may not know "where to start or how to penetrate the topography of the map" (Blankenship and Danserau, 2000, p. 295). Map-shock may also contribute to extraneous cognitive load, and extraneous cognitive load and disorientation are likely correlated (Krieglstein et al., 2022; Wong, 2010). The learning-related disorientation, navigability, and learning utility associated with a concept map are thus perhaps related to the map's size. A large concept map could perhaps be made less likely to cause learning-related disorientation, more navigable, and more useful for learning if the number of nodes and links composing it is reduced via appropriate generalization decisions. Another potential similar remedy is the decomposition of a large map into multiple maps with smaller sizes. These smaller maps could be located close to each other in space to ensure that a learner has access to the same aggregate content found in the large map when interacting with one of the small maps. Wiegmann et al. (1992) labels such a practice as map stacking. In the case of concept maps found on interactive interfaces, an alternative practice to map stacking that would produce a similar result is the reduction in number of visible nodes and links during some interactions. When a node is clicked, for example, the content of the map shown on the interface could be reduced. It could come to only show nodes and links with associated semantics belonging to the same conceptual superstructures, to which the semantics of the clicked node belong. Unfortunately, reliance on map stacking or interaction decomposition to reduce map shock comes with a potential drawback: Learning-related disorientation may increase if the number of nodes and links in the stacked map or concept map semiology resulting from interaction is too small. When trying to understand relationships shared among nodes and links found on different small maps, the learner may come to feel disoriented when transitioning from one small map to another. The optimal sizes of small maps into which large concept maps should be decomposed during map stacking or interaction likely depends on the large map's typical use case and semiological structure.

In addition to theoretical scholarship addressing a potential inverse relationship between concept map size and learning-related disorientation, at least one study has empirically investigated the topic. In an experiment, Krieglstein et al. (2022) compared disorientation experienced by groups of people engaged in learning tasks using concept maps shown in the left column of *figure 3.6* with that experienced by groups of people interacting in the same way with maps located in corresponding vertical positions in the right column. Disorientation was measured using modified items of the perceived disorientation scale from Ahuja and Webster (2001). The maps in the left column have fewer nodes and links than those in the right column. In contradiction with previously described theorizing, the study found no statistically significant inverse relationship between map size and learning-related disorientation. In this same study, learning-related disorientation associated with maps in the top row of *figure 3.5* was compared with that associated with maps located in corresponding horizontal positions in the bottom row. Conceptual relational superstructures are more saliently represented in the bottom row maps than in the top row maps, thanks to the clustered spatial positioning of node-link-node triples representing concept-relationship-concept triples composing such superstructures. Experiment participant groups interacting with the bottom row maps were assessed to have experienced statistically significant lower levels of disorientation than those interacting with the top row maps. The results of this study show that learning-related disorientation, and, by extension, navigability, and learning utility associated with a concept map may depend more on how saliently the map represents conceptual relational superstructures than on the number of nodes and links the map comprises.

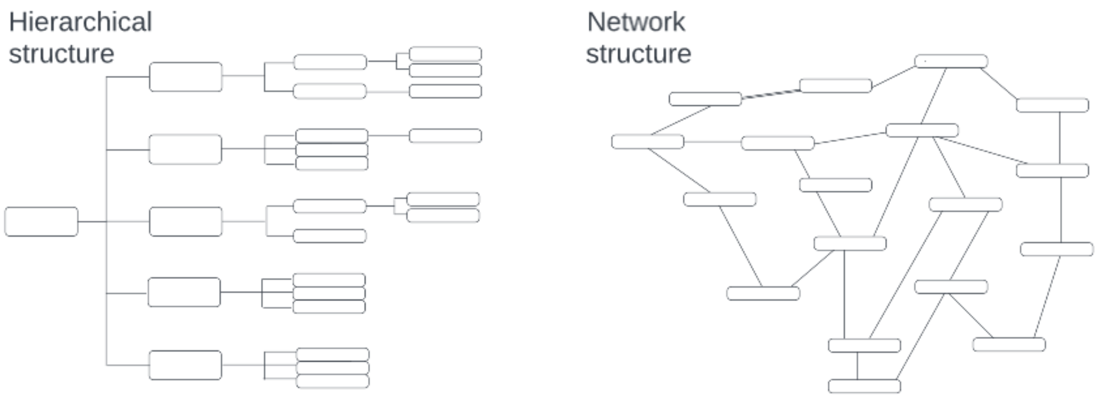
Figure 3.5: *Semantically-similar concept maps with varied sizes and representation of conceptual relational superstructure*



Note: From "How the design and complexity of concept maps influence cognitive learning processes," by F. Krieglstein et al., 2022, *Educational technology research and development*, 70, 105. CC BY-NC-SA 4.0.

Amadieu et al. (2009) also empirically investigated the relationship between concept map design and learning-related disorientation. The learning-related disorientation associated with a map with a hierarchical structure similar to that shown on the left side of *figure 3.6* was compared with that of a map with a network structure similar to that shown on the right side of the figure. In this study, as was the case in the study described in Krieglstein et al. (2022), disorientation was measured using modified items of the perceived disorientation scale from Ahuja and Webster (2001). The hierarchical-structure map represents conceptual relational superstructures more saliently than the network-structure map in two ways: Firstly, the map's horizontal tree structure clearly communicates hierarchical conceptual relationships. Secondly, the vertical clustering of nodes in spaces on the right side of the map makes lucid conceptual categorical relationships. During an experiment, a group of participants made efforts to retrieve knowledge from the hierarchical structure map, and another group interacted in the same way with the network structure map. A factor assessed during the experiment was the knowledge of the concept maps' subject area focus held by participants before the experiment. Based on this assessment, data gathered from each participant during the experiment was assigned a high-prior knowledge (HPK) or low-prior knowledge (LPK) classification during analysis of results of the experiment. The level of learning-related disorientation assessed to have been experienced by HPK participants who interacted with the hierarchical structure map did not differ with statistical significance from that assessed to have been experienced by HPK participants who interacted with the network structure map. However, learning-related disorientation experienced by LPK participants who interacted with the hierarchical structure map was assessed to have been lower to a statistically significant degree than that of LPK participants who interacted with the network structure map. The findings of this study further indicate that learning-related disorientation associated with a concept map can perhaps be mitigated by its salient representation of conceptual relational superstructures. Additionally, a concept map's lucid representation of both hierarchical and categorical conceptual relational superstructures can perhaps perhaps prove particularly helpful to the learning experience of people with little prior knowledge of the map's subject material. In concept maps used primarily by such people, semiology representing these forms of conceptual relationships should have particular visual prominence. Effective use of selective visual variables or principles of visual hierarchy could prove helpful, for example.

Figure 3.6: *Concept maps similar to those featured in an experiment described in Amadieu et al. (2009)*



Note: Based on Amadieu et al. (2009), p. 379.

Past research studies revealing the mitigation of concept map learning-related disorientation made possible by lucid conceptual relational superstructure representation have investigated representational forms only involving the spatial positioning of nodes and links. This study posits that other methods of effective conceptual relational superstructure representation in a concept map may help people feel less disorientated, and by extension, effectively navigate and learn while interacting with the map. In particular, it suggests that a concept map's use of container polygons to represent conceptual relational superstructures can enhance the subjective navigation experience of someone using the map to learn. Parallels can perhaps be drawn between this idea and ideas regarding the best way to design maps that help people effectively navigate cities. According to both academic researchers and industrial practitioners working in the field of wayfinding cartography, people using maps to to navigate urban environments can benefit from such maps' lucid representation of geographic features belonging to five categories (Gibson, 2009; Jeffrey, 2017; Lynch, 1960; Passini, 1992; Schwartz, 2018; Steinfeld, 2018; Vaez et al., 2016). These include:

1. Paths: These are the channels where locomotion during navigation occurs. Examples include streets, walkways, transit lines, canals, and railroads.

2. Nodes: Paths lead to and through nodes. They are path intersections, or points or places of interest located along paths or at path intersections.

3. Districts: These are two-dimensional, medium-to-large city sections. In addition to their geographic locations, spaces belonging to a district have similar attributes that lend them a collective identity and distinguish their identities from city spaces located outside the district's boundaries.

4. Edges: These are linear elements not used in locomotion. Examples include walls, railroad cuts, shores, and district boundaries.

5. Landmarks: These are points of interest disjoint from paths. Serving as visual anchors, they can help with orientation.

These feature categories were first described by American urban planner and designer Kevin Lynch in his seminal work *The Image of the City* (1960). Lynch and other scholars theorize that the human mind stores geographic information in images similar in structure and content to those of conventional actual-reality geographic maps. Often referred to as mental or cognitive maps, such mental images are thought to aid human spatial orientation and wayfinding during navigation (Golledge, 1999; Lynch, 1984; Lynch, 1960; Montello, 2001; Tolman, 1948; Vaez et al., 2016). Lynch (1960) posited that human mental maps of urban spaces comprise the previously identified geographic feature categories as elementary components. An actual- reality city map whose semiology represents features belonging to these categories may help people navigate the urban environment depicted on the map: It presents geographic information in a manner similar to the way the human mind likely stores such information. On such a map, a network of points representing nodes and lines representing paths overlays polygons representing districts. A concept map whose node-link network overlays container polygons thus conspicuously resembles a Lynchian city map. Additionally, this semiology comprising point-line networks overlaying polygons in both of these types of maps represents similar things. Networks of nodes and paths in a city are comparable to knowledge structures identified by a concept map's node-link network semiology. They both comprise entities and relationships connecting these entities. Furthermore, analogies can perhaps be drawn between the collective identity of paths and nodes found in a city district and that of concept-relationship-concept triples represented by a node-link network found within the boundaries of a container polygon in a concept map. A concept map with container polygons in its semiology may perhaps help people using the map to learn effectively navigate its content similarly to the way a Lynchian city map can aid a person's orientation and wayfinding during actual reality navigation.

3.2.2 Navigable link lines

When retrieving knowledge about a relationship shared by a concept with another concept, someone using a concept map to learn must be able to navigate from an origin node representing the former concept to a destination node representing the latter concept. Navigation occurs along the link representing the relationship connecting the concepts. The learner's accomplishment of this navigation task may be hindered if the link is too long: During navigation, she may lose track of which link she is navigating. Thus, concept maps should ideally not include especially long links. A learner may additionally more easily keep track of which link she is navigating if its semiology allows for her to easily visually discriminate it from other links links representing other relationship types. Thus, the integration of visual variables into the design of a map's links can enhance navigation. If a legend is used to identify the relationship types represented by a concept map's links whose varied identities are signified by varied application of visual variables to their designs, the legend should be optimally integrated into the design of the map to ensure its existence does not exacerbate disorientation.

A learner's navigation along a link connecting an origin and destination node may also be hindered if the link crosses paths with one or more links. During navigation, she may mistakenly transition to an intersecting link. She then may come to think, perhaps incorrectly, that the concept represented by one of the nodes appending this intersecting link shares with the concept represented by the origin node the relationship represented by the original link or the intersecting link. In a concept map's semiology, links thus ideally shouldn't cross. However, a complete absence of link crossings may not be possible in a concept map: The spatial positioning of nodes necessary for effective conceptual relational superstructure representation may require some link crossings. According to human perceptual psychology researchers, the more acute the angle at which links cross in node-link diagrams, the more likely the crossing will cause visual confusion (Blake & Holopogan, 1985; Triesman & Gormican, 1988; Ware et al., 2002). Therefore, if a concept map's semiology must include link crossings, links should perhaps ideally cross at or close to 90-degree angles.

Navigation along a directed link in a concept map is possible in only one direction, and the navigation-related roles of each of the two nodes appending the link are not interchangeable: Only one node can serve as the origin node and one node as the destination node. A concept map's semiology must coherently communicate which node serves which role, and in which direction along the link navigation must occur. This coherence depends on at least the following two factors:

1. The link arrow indicating the direction of navigation must be legible.

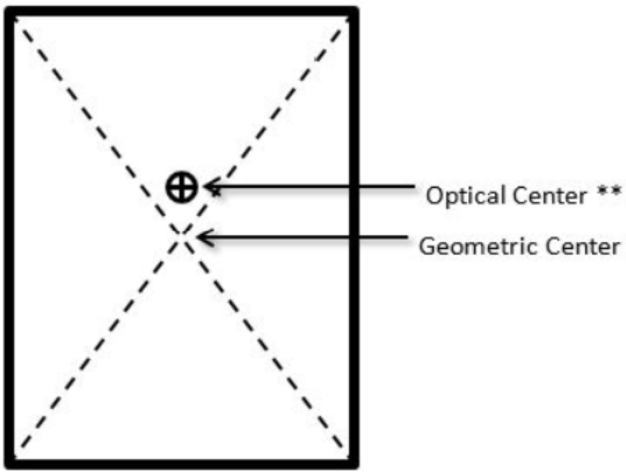
2. The direction assigned to the relationship by the link's arrow and label voice (active or passive) should make intuitive sense given the identity of the relationship.

In a concept map, the collective semantics associated with a series of consecutive node-link-node triples may be of particularly strong importance to someone using the concept map to learn. Her easy navigation along all links, one after the other, composing this series is necessary for her to gain an understanding of these collective semantics. For any two links in the series, ensuring that the angle whose vertex is the node connecting the links is close to 180 degrees would likely help facilitate this ease of navigation: The learner would not be hindered by a need to substantially change direction when transitioning from link to link. A link series with such connection angles would comply with the Gestalt principle of continuity. According to this principle, humans are more likely to perceive a series of consecutive individual linear elements as one whole entity if the elements connect smoothly (Ware, 2021). According to the results of an experiment described in Ware et al. (2002), a lack continuity among a series of consecutive links in a node-link diagram may be of greater hindrance to navigation across the series than the presence of link crossings in the series. Thus, during the concept map creation process, continuity should perhaps be prioritized over link crossing minimization when a series of consecutive links whose collective semantics is of strong importance for learning is designed. Ideally, curved lines should be used in lieu of straight lines in the designs of links in such a series. This would further visually emphasize the relatedness of all components of the series, thanks to their closer compliance with the Gestalt law of spatial proximity.

3.2.3 Use of the visual center of the map's substrate as navigation launchpad

When a human views content on a two-dimensional substrate, her gaze tends to focus first slightly above the geometric center of the substrate *(figure 3.7)*. Commonly referred to as the visual or optical center of the substrate, this location can serve as a balancing point or center of gravity for substrate's content (Buckley et al., 2022; Harrington et al., 2004; Schölgens et al., 2016). The visual center of a concept map's substrate should therefore perhaps serve as the location of content that someone using a concept map to learn should ideally view first before navigating to other parts of the map. For an interactive map with clickable nodes, the arrangement of the map's semiology should perhaps be adjusted when a node is clicked to allow for the placement of the clicked node at the visual center of the substrate housing the map.

Figure 3.7: *Difference between the optical and geometric centers of a substrate*

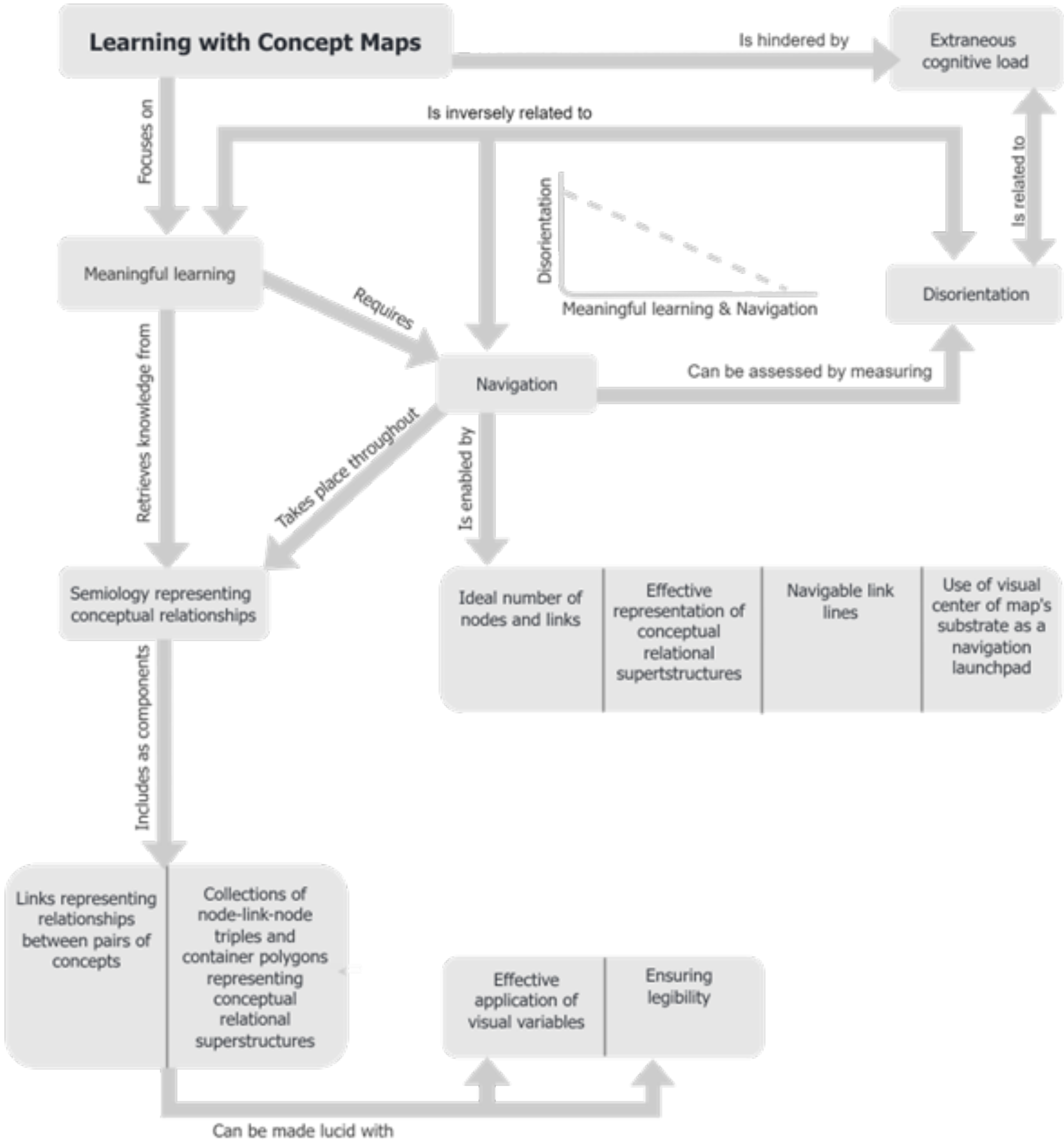


Note: From *Figure 26: Map Centers* [Digital vector graphic] by U. Ingram, Introduction to Cartography, (https://alg.manifoldapp.org/read/introduction-to-cartography/section/b9662d0a-4926-4947-922d-a67a2cae0eec). CC BY 4.0.

3.3 CONCEPTUAL FRAMEWORK

Figure 3.8 visually summarizes the information presented in this chapter and serves as a conceptual framework for a research case study involving concept map design enhancement described in the following chapters of this paper.

Figure 3.8: *Conceptual framework for enhancing concept map design*

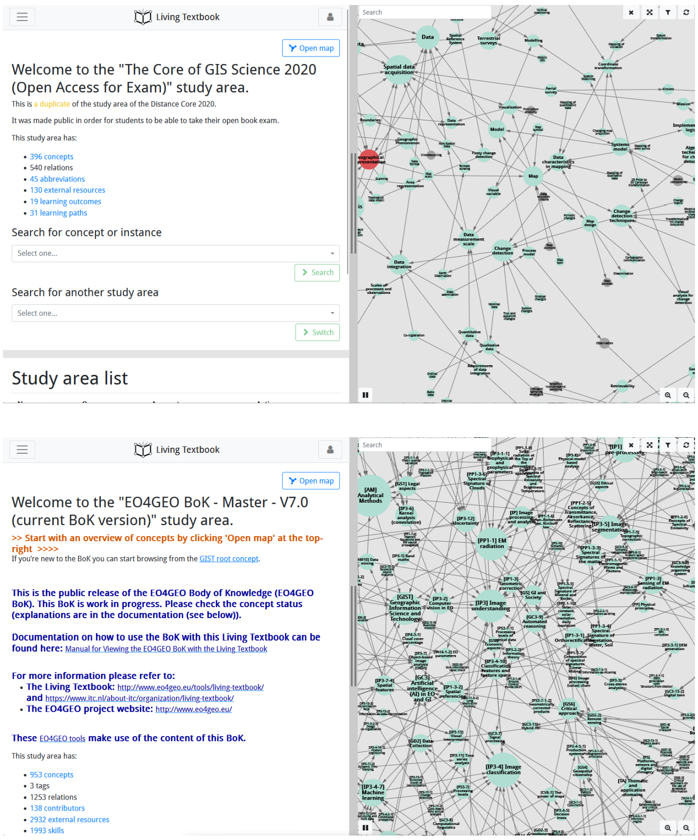


Chapter 4

A case study of concept map design enhancement involving two large, interactive maps

During this study, efforts were made to enhance the design of two large, interactive concept maps associated with *The Living Textbook* (LTB), an Internet publication managed by the University of Twente, Faculty of Geo-Information Science and Earth Observation (UT-ITC). The design enhancement process was guided by principles of good concept map design identified in chapter 3. It also roughly followed some usability engineering protocols to enable good user-centered design described in Nielsen (1992) and Nielsen (1993), including user needs assessment, prototyping of new design forms, and user testing of the new design forms.

Figure 4.1: *The Core and BoK Concept Maps upon first access*



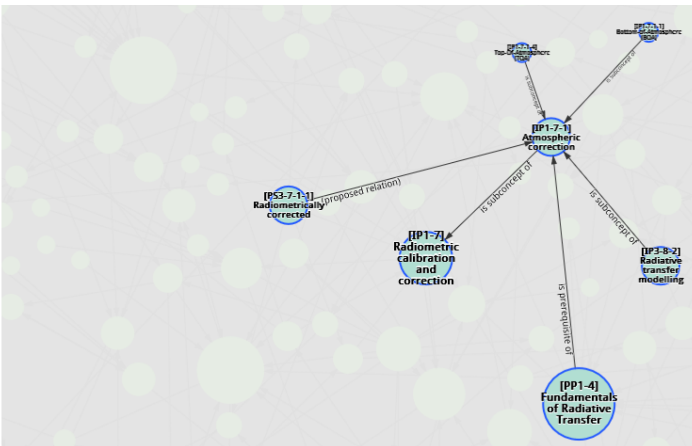
4.1 INTRODUCING LTB CONCEPT MAPS

Both concept maps examined in this study visualize relationships shared among hundreds of concepts in the geo-information science and earth observation knowledge domains. They have similar user interface and experience designs. They can both be accessed from LTB web pages with white backgrounds, on which content welcoming users to the maps is printed. Located in the upper right hand corner of these web pages is a button, on which the text "Open map" map is printed. When a user of either of these web pages clicks this button, part of the page's associated concept map comes to occupy the right side of the user's browser window. The left side of the window remains occupied by the white welcoming page (*figure 4.1*).

The maps both have medium grey backgrounds. All relationships in their semantics are directed and represented with arrow-appended links. The links are black and straight lines, all with the same width. In one map all nodes connecting these links are colored medium teal. In the other, nearly all nodes also have this color, but a few are dark grey and red. In both maps, the size of each node is determined by the number of links connected to it. When each map is opened on the web page housing it *(Figure 4.1)*, a large number nodes and links comprising its semiology are visible. The default zoom is a medium level. Zooming out makes all nodes and links visible. While node labels are visible when the map is first opened, link labels are not.

Hovering the cursor over a node in either of the maps changes this map's semiology in four ways *(Figure 4.2)*. First of all, labels of all links connected to the hovered-over node become visible. Secondly, all links not connected to the hovered-over node become invisible. Thirdly, all nodes with the exception of the hovered-over node and nodes with which this node is connected by one link become invisible and see a reduction in color value. Fourthly, the hovered-over node and all nodes connected to it by one link become bounded by a thick light-blue border.

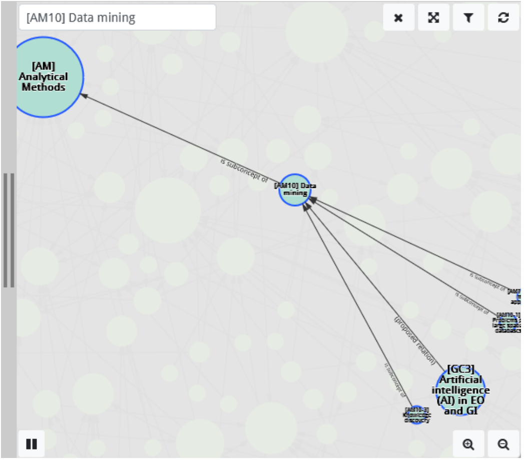
Figure 4.2: *The BoK map semiology following cursor hover-over interaction*



Note: When the node labelled "Atmospheric correction" was hovered over by the cursor, the BoK map's semiology changed in ways described in the above paragraph

Both maps have a search function *(Figure 4.3)*. Entering the name of a concept represented by one of the map's nodes changes the map's content in the same ways that hovering over a node with a cursor does. This action also changes the content of the map in a few other ways: The part of the map housing the node associated with the searched name and nodes connected to this node comes to be located near the geometric center of the window. The zoom level of the map also increases to a high level if it is not already at this level.

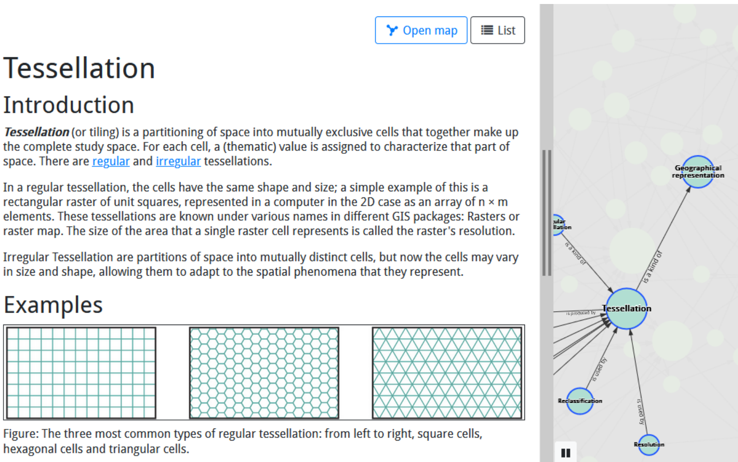
Figure 4.3: *The BoK map semiology following search interaction*



Note: After "Data Mining" is entered into the search field, the node representing this concept is brought close to the geometric center of the window housing the map, and the map's zoom level increases.

Clicking a node in either of these maps changes its semiology in the same ways that hovering over a node with the cursor or using the search function do. The white web page located to the left of the map in the browser window housing it also changes: Content welcoming users to the map is replaced with content about the concept represented by the clicked-on node *(Figure 4.4)*.

Figure 4.4: *The Core map semiology following clicking node interaction*



Note: Clicking the node labelled "Tessellation" causes the white web page located to the left of the map to become populated with content about the topic of "Tessellation."

4.2 IMPORTANT DIFFERENCES BETWEEN THE TWO MAPS

While the two maps have similar subject area foci and user interface and experience designs, their use cases differ. Thanks to these differences, the semantic and semiotic structures of the maps also differ.

One map is housed in LTB's The Core of GIScience 2020 (The Core) section. This LTB section is a digital textbook associated with an eponymous print textbook. ITC teachers develop and manage The Core to help ITC students in their studies. By contrast, the group of people involved in the development, management, and use of the other map investigated in the study is larger and more diverse. The map is associated with LTB's EO4GEO Body of Knowledge (BoK) section. EO4GEO is a Sector Skills Alliance of the European Union's Erasmus+ program focused on education and training in the space/geospatial sectors. LTB's BoK section serves as an information-sharing space for this program, and the BoK's concept map is its visualization platform. The concept map is developed and managed by a network of experts who work in the Geo-Information Science and Earth Observation domains, both at the University of Twente and other organizations. Target users of the concept map are educators and researchers at both ITC and other organizations. These target users both produce and consume the concept map's content. The concept map is built in such a way that additional web applications can reuse all or part of its content. For example, the EO4GEO Occupational Profile tool, a web application allowing users to browse, create, edit, and share occupational profiles in the field of earth observation and geo-information science, makes use of content from the BoK concept map. This map can to a certain extent be considered both a concept map and knowledge domain visualization. It is used not only as a learning tool. People also use it to explore large amounts information from multiple sources. Content that appears in the white window on the left side of the map when a node is clicked on serves a more informative purpose than an instructional one. People who interact with the map are generally more interested in learning about relationships shared among large numbers of concepts than relationships shared between pairs of concepts, according to the researcher's interactions with such people during conversation and via questionnaire. The conceptual relationship focus of the BoK map's semantics is on hierarchical and categorical conceptual relational superstructures. To accurately visualize these semantics, the map has similar architectonics in its semiology. The vast majority of links carry the label "is a subconcept of." Nearly all nodes are connected via one or a series of such links to at least one of 13 parent nodes representing general conceptual categories in the earth observation and geo-information science knowledge domains. Examples of such conceptual categories include "geocomputation," "image processing and analysis," and "cartography and visualization." A smaller number of links represent other relationships, carrying labels such as "is a property of," "is based on," "is caused by," "is defined by," and "is measured by."

In contrast to the BoK concept map, The Core concept map serves strictly as a learning tool. The typical user is a student seeking to learn about geo-information science and earth observation subject material, about which she has none or relatively little prior knowledge. The white window descriptive content that appears when a node is clicked has an instructional focus. Educational prose text is often accompanied by explanatory information graphics, as shown in *Figure 4.4*. Students who currently use the map have communicated that when doing so, they seek to learn both about relationships shared among groups of concepts, as well as relationships shared between pairs of concepts. The map's semantics have a stronger focus on individual relationships connecting two concepts than those of the EO4GEO BoK concept map. The map does feature some conceptual relational superstructures in its semantics as well as semiology representing these semantics: A number of nodes are connected to other nodes with links labelled "is a kind of" or series of links carrying such a label. However, conceptual hierarchies generally have fewer levels and node-link-node triples than those than in the BoK concept map, the percentage of links carrying this label is relatively small, and series of links carrying the label are relatively short. A large number of nodes are not connected to "is a kind of" links. Thus, in contrast to the BoK map's semantics, some concepts in the Core's semantics completely lack membership in hierarchical conceptual relational superstructures. Labels other than "is a kind of" applied to the map's links include "is part of," "is based on," "is measured by," "is represented by," "is a property of," "is used by," and "is modelled by." A majority of links carry these other labels.

4.3 DESIGN ENHANCEMENT PROCESS

The design enhancement process involved roughly three stages of work.

Stage 1 involved two steps. First The researcher assessed the map designs' compliance with principles of good concept map design identified in chapter 2 and offered ideas for ways they could be improved upon in areas where compliance is lacking. Second, user needs assessment questionnaires were used to gather helpful information and ideas from other people.

Stage 2: Guided by ideas and information generated in stage 1, visualizations conveying design enhancements suitable for typical use cases for each map were prototyped.

Stage 3: The prototyped visualizations were evaluated.

Chapter 5
Design enhancement process: Stage 1

5.1 RESEARCHER COMPLIANCE EVALUATION

The two LTB node-link concept maps under investigation have many strengths. However, the researcher finds they arguably lack compliance with a number of principles of good concept map design, with regards to both lucid conceptual relationship representation and navigability. *Figure 5.1* and *Figure 5.2* offer commentary on these concept maps' compliance with good concept map design identified in chapter 3 of this paper, as well as suggestions for improvement where compliance is lacking.

Figure 5.1: *Researcher's evaluation of LTB maps' compliance with principles of good concept map design regarding conceptual superstructure representation lucidity*

Principles of good concept map design		LTB Compliance evaluation
Conceptual relationship representation lucidity	Use of container polygons	Container polygons are at the moment not optimally integrated in to the representational semiology of either concept map. The integration of container polygons into the representational semiology of the BoK concept map might enhance the design of this map to an especially strong degree, thanks to the strong conceptual relational superstructure focus of its semantics.
	Effective use of visual variables	The design of many components of the maps' semiology involved in representation of conceptual relationships arguably do not make effective use of visual variables. For example, all pairwise conceptual relationships are represented with the same arrow symbol. Associative visual variables could be used to allow for better visual discrimination among links carrying different labels. For example, the colours of links could vary according to the different relationship types they represent. Additionally, selective and ordinal variables could be integrated into the design of links to indicate varying levels of importance existing relationship types represented by the links. Links representing more important relationship types could be made wider or be assigned a lower colour value, for example. Visual variables could also perhaps be better integrated into the design of marks representing conceptual relational superstructures. Links representing more important relationship types could be made wider or assigned a lower colour value, for example. Visual variables could also perhaps be better integrated into the design of marks representing conceptual relational superstructures. In particular, the use of the visual variable position in associative representation could prove helpful. Node-link-node triples belonging to the same conceptual relational superstructures could be placed closer to each other in space. Colour could also be used in associative representation. The colours of nodes and container polygons could vary according to their membership in conceptual relational superstructures.
	Legibility	The legibility of marks representing conceptual relationships in both concept maps is arguably poor in some ways. For example, as mentioned previously, labels of links only become visible when nodes they connect are hovered over with a cursor, clicked on, or searched for. The concept maps' semiology visible when these actions aren't taken arguably lacks utility, as it doesn't make lucid the specific identities of conceptual relationships represented by its links.. Additionally, many link lines overlap each other., making visual discrimination among these marks difficult.. Ensuring that link arrows don't overlap each other could help ensure that knowledge about conceptual relationships represented by the links carrying the arrows can be accurately retrieved by someone using the concept maps to learn.

Figure 5.2: *Researcher's evaluation of LTB maps' compliance with principles of good concept map design regarding navigability*

Principles of good concept map design		LTB Compliance evaluation
Navigability	Individual link navigability	The navigability of link lines in both maps is arguably poor due to a number of reasons. First of all, overlapping link arrows render difficult identification the origin and destination roles of nodes in some node-link-node triples. Ensuring that sufficient space separates all arrows connected a node would help fix this problem. Secondly , a large number of links cross paths with each other, and most crossing angles are acute. Ideally, no links in the maps should cross each others' paths. If crossings are necessary, they should occur as close to 90-degree angles as possible. Thirdly, some links are unnecessarily long. Shortening long links would both improve their navigability as well as better make lucid the relatedness of their associated nodes because they would be located closer to each other in space. Finally, the use of the passive voice in link labels assigns a direction to the relationships represented by some links that perhaps makes the origin and destination roles of the nodes connected to them less intuitive to understand than perhaps would be the case if the active voice were used. For example, in the BoK concept map, the directions of relationships represented by links labeled "is a prerequisite of" might be more intuitively understood if these links carried the label "requires" and had arrows pointing in directions opposite of those, in which they currently point.
	Link series navigability	The collective semantics associated with series of consecutive links in both maps are arguably poorly represented. Series of consecutive link lines are not easily navigable or perceivable as whole entities. Very few pairs of links connected to the same node form angles at or close to 180 degrees, which may make transitioning between links when navigating a link series difficult. The lack of these forms of connections and the use of straight lines in lieu of curved lines also makes it difficult to perceive all components of link series as one whole entity.
	Conceptual relational superstructure representation	The lack of good representation of conceptual relational superstructures present in the maps' semantics may cause disorientation in people making efforts to retrieve knowledge from the maps. Map shock has already been identified as a problem associated with LTB concept maps in research described in Walsh (2017). People interacting with the version of the map visible when cursor hover-over, node-clicking, or search interaction functions are not used may be prone to overwhelm due to the large number of visible nodes and links. While the previously described interaction functions can alleviate map shock by reducing the map's size, they may not necessarily be solutions to disorientation: The content of the map is reduced to only show the interacted-with node and links connected to it, as well as nodes connected to those links. The learner may seek to understand how the interacted-with node relates to other nearby nodes whose labels are not visible, interact with those nodes, and then become disoriented when trying to find the original node
	Location of most important node	Whenever a node is clicked on or its associated concept is searched for, it very helpfully comes to occupy a position near the visual center of the interface window housing the map. Ensuring that the interacted-with node is placed even closer to this window's visaual center could perhaps better enable the map's navigability by allowing the interacted-with node to more effectively serve as a navigation launch pad.

5.2 QUESTIONNAIRES

Prior to prototyping enhanced design forms, two questionnaires, one regarding each of the two LTB concept maps, were used to gather information from other people potentially helpful in guiding the concept map design enhancement process. The researcher distributed and analyzed data gathered from the questionnaires in an effort to answer the following four questions regarding LTB's The Core and BoK node-link concept maps.

Questionnaire questions:

qq1 Are people able to accurately retrieve knowledge about conceptual relationships communicated by the maps' semiology when interacting with the maps?

qq2 Are people able to effectively navigate the maps when making efforts to retrieve knowledge about conceptual relationships from them?

qq3 Do people who make efforts to retrieve knowledge about conceptual relationships from the maps' semiology agree with the researcher's design enhancement recommendations identified in chapter 5.1?

qq4 Do people making efforts to retrieve knowledge about conceptual relationships from the maps' semiology have ideas for ways the maps' designs could be enhanced that are not identified in chapter 5.1?

5.2.1 Distribution and participation instance numbers

The questionnaires were distributed to people who currently use LTB's The Core and BoK concept maps, as well as other people. Additional potential participants were recruited from the researcher's Cartography Master of Science cohort, social media channels, and Amazon.com's Mechanical Turk (MTurk) crowdsourcing marketplace. The total number of participation instances for the questionnaire regarding the The Core concept map was 187 and that for the questionnaire regarding the BoK concept map was 122. MTurk workers contributed the vast majority of participation instances for both questionnaires, including 132 for that regarding The Core concept map and 98 for that regarding the BoK concept map. When the questionnaires were distributed on MTurk, participation was restricted to MTurk workers with a Master's qualification. Such a qualification is granted by MTurk to those of its workers who have demonstrated superior performance while completing thousands of tasks of multiple varieties on MTurk. This restriction was put in place in an effort to ensure MTurk workers participating in the questionnaires would take this work seriously and the data they provided would be suitable for analysis. Write-in responses associated with a substantial number of participation instances contributed by MTurk workers (28 for The Core questionnaire, 29 for the BoK questionnaire) led the researcher to disqualify the instances. Data associated with disqualified instances was not considered during questionnaire results analysis. Content of write-in responses that merited disqualification included curse words, plagiarized text, and exact duplicate text of responses of other participation instances.

5.2.2 Questionnaire section descriptions and results

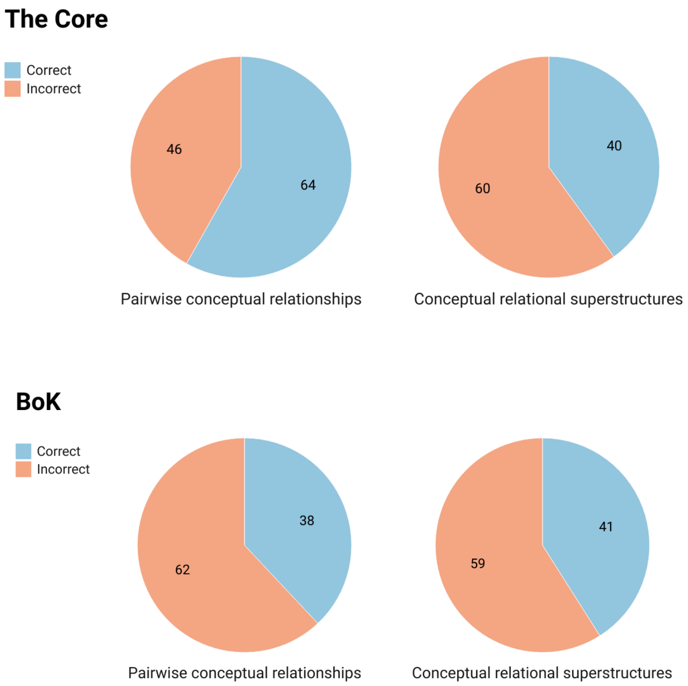
Each of the two questionnaires comprised four sections whose questions addressed different topics:

Section 1: Educational and professional background
Responses to questions in this section helped the researcher to limit data considered during questionnaire results analysis to that provided by people belonging to a demographic similar to that of the concept maps' target users, ensuring compliance with user-centered design protocol. Only participation instances contributed by people who self-identified themselves as holding a master's degree or being enrolled in master's degree program in their responses to this questionnaire section's questions were analyzed.

Section 2: Conceptual relationship knowledge retrieval assessment
Data gathered from questionnaire participants completing section 2 of the questionnaires were used to answer qq1. Participants of each questionnaire were requested to open the website housing the questionnaire's associated concept map and enter the name of a concept represented by one of the map's nodes in the map's search field. Following this request were questions about conceptual relationships represented by links visible upon this search interaction. Questionnaire participants' answers to these questions were used to assess retrieval of knowledge about pairwise conceptual relationships. After answering these questions, questionnaire participants were asked to click one of the nodes with a visible label following the search interaction that wasn't the searched-for node. They were then presented with questions about conceptual relationships represented by series of two node-link-node triples comprised both of nodes and links that became visible upon the click interaction, as well as those that were visible upon the search interaction that became visible upon the click interaction. Questionnaire participants' responses to these questions were used to assess retrieval of knowledge about conceptual relational superstructures represented by series of two node-link-node triples. As mentioned previously, students using The Core concept map to learn typically have low or relatively low knowledge of the concepts represented by nodes with which they interact, prior to interacting with them. People completing section 2 of the questionnaire regarding The Core concept map were asked to assess whether their knowledge of the searched-for concept prior to participating in the questionnaire was not-at-all strong, somewhat strong, moderately strong, very strong, or expert level. During analysis of data gathered from questionnaire participants answering questions in section 2 of the questionnaire regarding The Core concept map, data contributed by people who identified their knowledge of the searched-for concept as being not-at-all strong, somewhat strong, or moderately strong prior to participating in the questionnaire were exclusively considered. Thanks to this filtering, data analyzed exclusively came from people with levels of knowledge of the concept represented by the searched-for node similar to that held by the concept map's target users of the concepts represented nodes with which they interact. Charts in *figure 5.3* communicate, for each the two questionnaires, information derived from data contributed people completing the questionnaires' second sections. The graphs show that relatively low percentages of participants in both questionnaires who made efforts to retrieve from each questionnaire's associated concept map knowledge about both pairwise conceptual relationships and conceptual relational superstructures were able to do so accurately. Definitive conclusions about the quality of these concept maps' representation of these types of conceptual relationships can't be drawn from the information presented in these graphs: The information was derived from a small data sample, and the data was contributed by people engaged in a small set of interactions with small sections of the concept maps. However, the graphs' information can likely nevertheless be accepted as a suggestion that people making efforts to retrieve knowledge about conceptual relationships from the maps' existing semi-

ologies experience some difficulty doing so accurately.

Figure 5.3: *Number of correct and incorrect responses to questions about conceptual relationships*



.

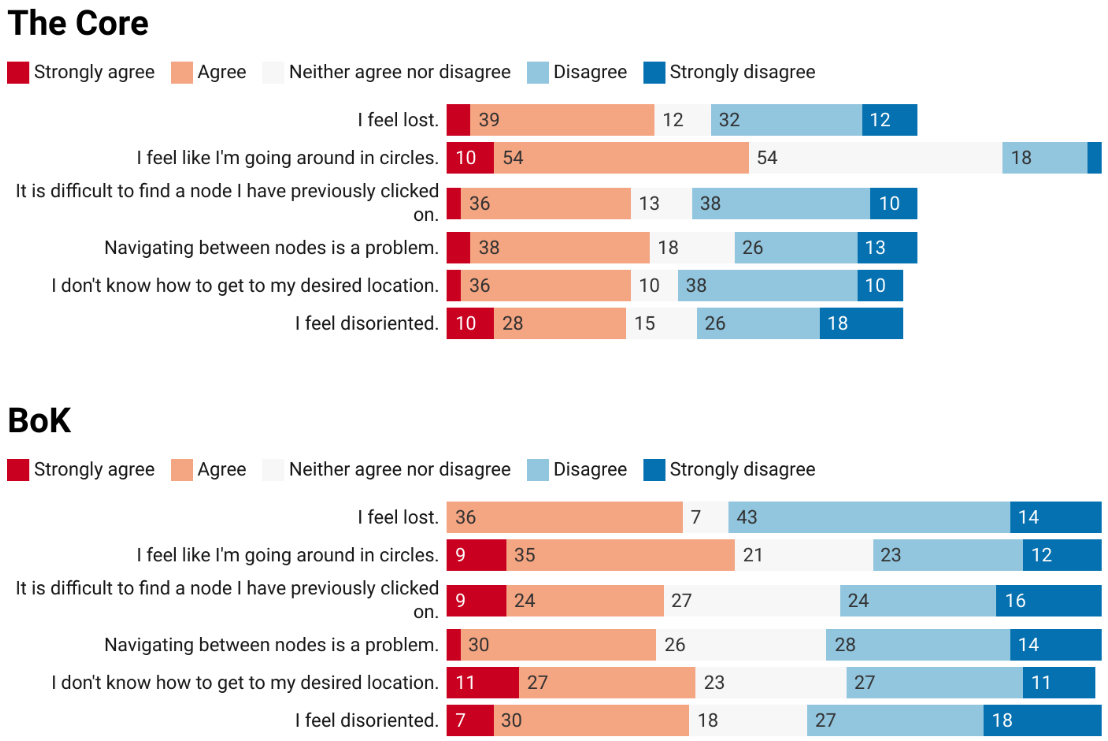
Section 3: Concept map navigability assessment

Data provided by questionnaire participants completing the third sections of the questionnaires were used in answering qq2. After making efforts to retrieve knowledge from the concept maps while completing section 2 of the questionnaires, questionnaire participants were asked to specify their level of agreement with each of the following five possible conclusions to statement "When using the node-link concept map to learn information...":

- I feel lost.
- I feel like I'm going around in circles.
- It's difficult to find a node I've previously clicked on.
- Navigating between nodes is a problem
- I don't know how to get to my desired location.
- I feel disoriented.

A participant's expressing agreement with these items may indicate she experienced disorientation and difficulty navigating the concept map associated with questionnaire she completed when engaged in a learning task while interacting with the map. This method of assessing a concept map's learning-related disorientation is a slightly modified version of that used by Krieglstein et al. (2022) and Amadieu et al. (2009), whose research is described in chapter in chapter 3.2.1 of this paper. The stacked bar graphs found in *figure 5.4* communicate information derived from data associated with the third sections of both questionnaires. Some disorientation can be ascribed to data contributed by a relatively high percentage of questionnaire participants who completed the task the found in this questionnaire section. This information may indicate that disorientation plagued a substantial percentage of questionnaire participants during their interactions with the LTB concept maps being examined in this study while completing section 2 of the questionnaires. People may have difficulty navigating these concept maps when using the maps' search, node-click, and cursor hover-over interactive functions to retrieve from the maps knowledge about conceptual relationships.

Figure 5.4: *Questionnaire respondents' levels of agreement with five possible responses to the statements "When using the node-link concept map to learn information..."*

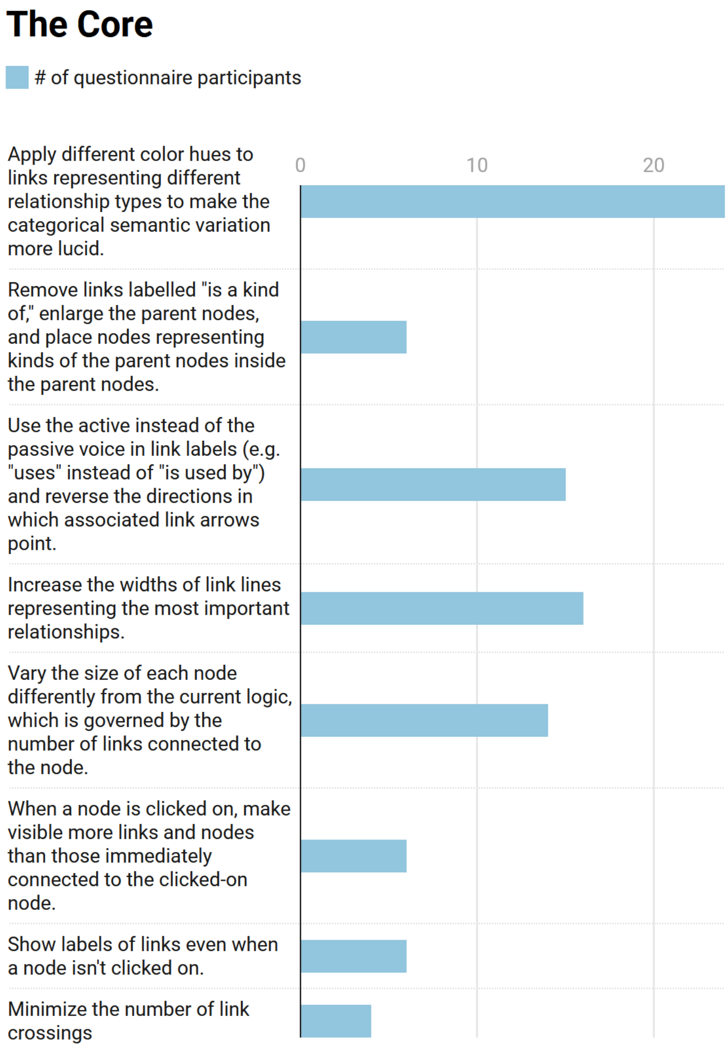


Note: Each number represents the number of participants selecting its associated agreement level.

Section 4: Solicitation of suggestions from questionnaire participants

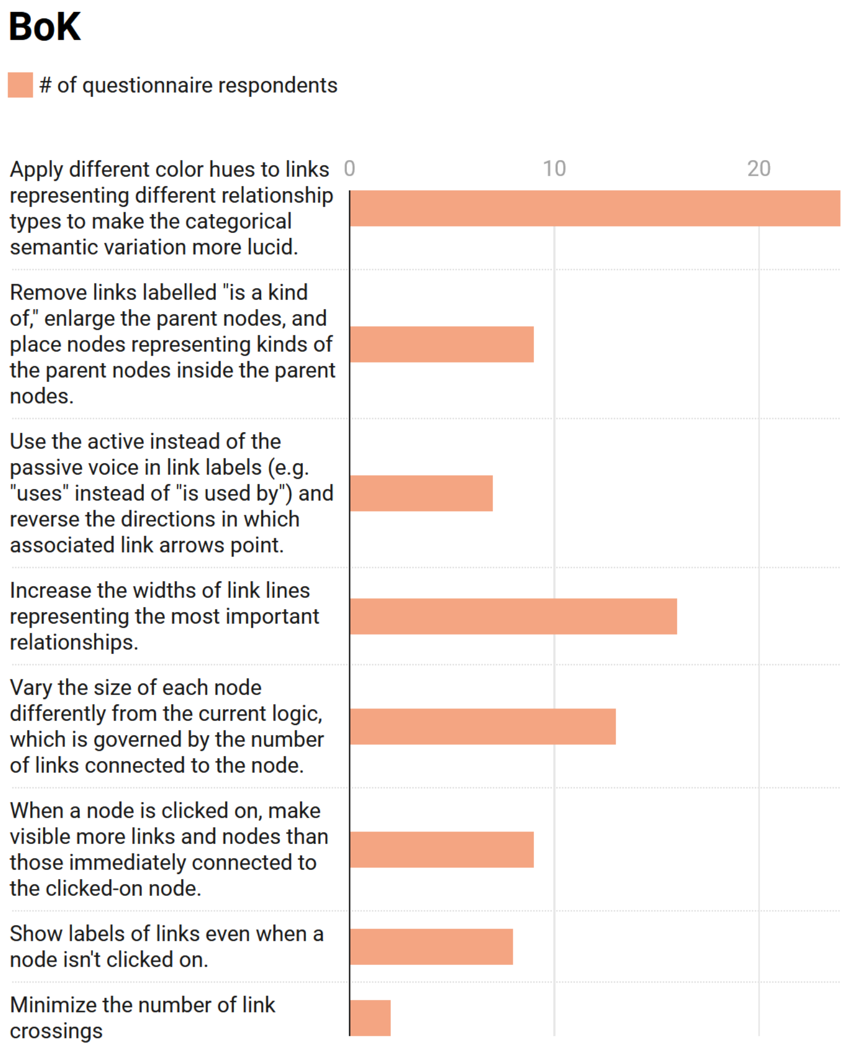
Data gathered from questionnaire participants completing this section were used in answering qq3 and qq4. Questionnaire participants were asked to answer the question "Do you have any suggestions for ways [Name of Concept Map] could be improved upon to be more navigable for people learning the information the map communicates?" Answering this question involved clicking checkboxes, next to which were printed some of the ideas for design enhancement developed by the researcher, which are identified in section 5.1 of this paper. *Figure 5.4* and *Figure 5.5* show information derived from data gathered from questionnaire participants who answered this question. At the time that the questionnaire was created, the researcher was only considering users' navigation experiences with regards to concept map design enhancement. Users' accurate retrieval of knowledge about conceptual relationships was not yet being considered. This is the reason why the question addresses navigability, but not retrieval of knowledge about conceptual relationships. Additionally, the researcher was only considering the design enhancements identified in *Figure 5.4* and *Figure 5.5* at the time that the questionnaire was created. This is the reason why this question did not ask questionnaire participants whether they think a number of the design enhancements identified in section 5.1 of this paper should be implemented. Of interest are many aspects of graphs presented in *Figure 5.4* and *Figure 5.5*. Perhaps most notable is the similarity in the size of the bars shown next to each design recommendation in *Figure 5.4* with those with that of the bars show in *Figure 5.5*: In general, similar numbers of people participating in both questionnaires clicked the checkboxes next to each listed design recommendation. This information may suggest that people interacting with both concept maps would like to see their designs improved upon in generally similar ways. The general consistency in bar sizes between the two graphs can perhaps also to some extent indicate that people participating in the questionnaires took seriously the task answering the the questionnaires' questions and did not randomly select answers to questions. This likely information can be inferred from the fact participation instances for both questionnaires generally came from different people. An additional interesting aspect of the two graphs is perhaps the notable difference in sizes between the second bar from the top in both of them. A relatively substantially larger number of people who participated in The Core questionnaire than in the the BoK questionnaire thought that using the active instead of the passive voice in link labels and reversing the directions of link arrows relationships would help improve the navigability of the map. This difference can likely be attributed to the fact that links in this map represent a wider variety of conceptual relationships and the representation distribution among links is more equal. (As mentioned previously, the vast majority of links in the BoK map represent the same "is a subconcept of" relationship.) People navigating The Core concept map are likely more easily hindered by links whose arrow direction and label voice don't make intuitive sense given the identity of the relationship because they must make efforts to try to understand the relationship represented by each new link they begin to navigate. By contrast, when beginning to navigate a link, people using the the BoK map likely expect that it carries an "is a subconcept of" label. Only when they discover that the link does not carry this label, a likely rare occurrence, will they need to make efforts to understand the label. A third interesting aspect of both graphs is the small sizes of the three bars at the bottom of both of them. As described previously, while completing section 2 of the questionnaire, a relatively high percentage of questionnaire participants may have experienced disorientation upon clicking between two nodes in order to understand the conceptual relationships represented by series of node-link-node triples, to which the nodes belong. Given this fact, the relatively small number of participants expressing a desire for labels of links to be visible when a node isn't clicked on and for more links and nodes than those immediately connected to the clicked-on node to be visible when a node is clicked on is perhaps surprising. The small number of participants in both questionnaires who thought that the number of link line crossings in the concept map should be minimized is also perhaps surprising. The relative lack of interest in this design enhancement is likely thanks to the fact that link crossings don't actually impact how users of these concept maps understand conceptual relationships: As described previously, link labels are only visible when a node is clicked-on or hovered-over, or a concept is searched for. During such interactions, link crossings are absent from the concept maps because the only visible links are those connected to the node that is the focus of the interaction, and, thanks to the computer programming behind the concept maps, these links never cross each other's paths.

Figure 5.5: *The Core questionnaire participants' agreement with the researcher's ideas for design enhancement*



When answering this question, questionnaire participants were also invited to offer their own ideas for design enhancements. *Figure 5.7* shows the ideas offered.

Figure 5.6: *The BoK questionnaire participants' agreement with the researcher's ideas for design enhancement*



In this section of the questionnaire, questionnaire participants were additionally presented with the questions "What aspect(s) of this node-link concept map's design enable navigation" and "What aspect(s) of this node-link concept map's design hinder navigation?" Some answers to these questions can be found in *figure 5.8* and in *figure 5.8*. According to information communicated in *figure 5.8*, people interacting with both maps find their search, click, and node hover-over interactions helpful for navigation. However, according to *figure 5.9*, some people find the lack of labels applied to nodes that aren't connected by one link to the interacted-with node during these interactions a hindrance to navigation. *figure 5.9* additionally notably communicates that people interacting with each of the two maps find their navigation hindered by the poor legibility of the maps' node and link label text. Mentioned causes of this poor legibility include the small size of the text, the blurred appearance of the text, and links' overlapping with the text.

Figure 5.7: *Additional design enhancements suggested by users*

The Core
Be able to recenter a node and the items around it for better viewing, without triggering all other unrelated nodes
I was thinking color would help, but on second thought it wouldn't
Make them visible and lighter shades so you can easily tell they are in the background but still part of the larger whole data set.
Start with a more central concept that is larger.
Balloon a node when scrolled over.
Drop down mini window showing history of clicked on links
Fix whatever issue I experienced written above
It might be cool to use color to emphasize not the type of relationship, but to reiterate the direction and build in some redundancy. I.e. left arrows one color, right arrows another color. I find I have to focus too hard to see which direction the arrow is pointing. Or make arrows more prominent.

BoK
Add layers to the nodes when navigating so it doesn't look like a drawer full of loose marbles.
too much overlap (occlusion) of nodes, links, labels
Do use active instead of passive voice but do not reverse directions of associated links

Figure 5.8: *Questionnaire participants' answers to the question "What aspects of this node-link concept map enable navigation?"*

The Core
The detailed definitions of what terms mean when click on them.
The search bar.
The search tool is very useful.
I think the information on the right side is so helpful for learning.
But for navigation, I like the highlighting/brushing when you click on a node, and it's easy to click away from a node.
I like that you can drag the circles around, but the fact that they move and "bounce" makes it harder to remember where they were previously

BoK
Search bar, arrows between nodes
The links are all fairly cleanly laid out and the nodes are spaced at reasonable distances from each other
The search bar and the ability to click on each node to focus on it
Being able to use the search box quickly to find a node, zooming in and out
Shows different branches of things in an okay way
Being able to trace the relationships by the directions of the arrows and the notations on them
The ability to click on relationship definitions
Click on it and can rotate to know the concepts and links linked
The navigation feature is amazing. Clicking on any circle will highlight all the nodes. Clicking on empty area will highlight everything.
Clicking on each node will drill down into the different subconcepts and links, and then clicking out of it will bring you back to the main node-links
I am able to click on a node and see all the topics related to it.

Figure 5.9: *Questionnaire participants' answers to the question "What aspects of this node-link concept map hinder navigation?"*

The Core
The color of the nodes.
The font seems blurry, which makes it harder to read.
I don't like how the arrows get covered by the text. I also was confused at first about how one concept leads to another, i.e. because there is no text specifically on the link between vector and geographical representation, I later just assumed that the adjacent text "is a kind of" applied to that line.
I don't like that all of the non-connected nodes have no titles - it would be helpful to see the titles even when the nodes aren't selected.
The cluttered appearance of terms and related subjects on the map.

BoK
The unrelated nodes disappear once you click on a node, so you lose the ability to see connections that the other nodes have.
It refocuses whenever you move your cursor around, which is very disorienting.
Trying to move the map around was frustrating. I couldn't get it to work.
Bit too much going on.
Remote radar concept.
The smaller size of some type, requiring zooming in, sometimes to the extent where it's difficult to see other relations.
My own lack of knowledge about concepts and time limitations of this posted task, rather than the map itself
The text or small and cannot understand
Whenever you have selected a particular circle. And you want to jump to another, it is not possible sometimes.
Some of the text is very small. Some of the nodes are small and hard to click on.

Chapter 6
Design enhancement process: Stage 2

Efforts were made to enhance existing visualizations in LTB's The Core and BoK concept maps, so that they would better facilitate learning. Information yielded by the researcher's compliance assessment and user needs assessment questionnaires guided the enhancement process.

6.1 A FOCUS ON VISUALIZATIONS RESULTING FROM INTERACTIONS

As mentioned previously, two primary visualizations can be found in LTB's The Core and BoK concept maps. These two visualizations include the large ones comprising hundreds of nodes and links that are visible when each map is first opened and smaller ones resulting from the node-hover, node-click, and search interactions. The design enhancement process focused on the smaller visualizations, specifically addressing those resulting from the node-click and search interactions. These smaller visualizations at the moment arguably have more learning utility than the larger ones: As previously described, the learning utility of a concept map likely comes from its lucid communication of knowledge about conceptual relationships contained in its semantics and its navigability. The large visualizations visible when each of these concept maps is first opened has semiology communicating knowledge about conceptual relationships: Links representing conceptual relationships connect nodes. However, this semiology communicates this knowledge insufficiently: The links lack labels identifying the specific relationships represented by them. Additionally, users often have difficulty navigating the visualization: As previously described, users often experience map shock when viewing the large visualizations due their large numbers of nodes and links. By contrast, the smaller visualizations associated with search, node-click, and node-hover interactions have more learning utility. Knowledge about conceptual relationships can be sufficiently retrieved from them, thanks perhaps primarily to the fact that the links have visible labels. The learning utility of the visualizations is further enabled by the fact that their semiology is navigable, primarily thanks to the small number of nodes and links it comprises. However, as shown by the results of the user needs assessment questionnaires, the learning utility associated with these visualizations is not ideal: The level of accuracy with which people retrieve knowledge about conceptual relationships during these interactions may not be particularly high, and many people may experience at least some disorientation while interacting with multiple nodes at consecutive moments in time. The researcher came to think that focusing the design enhancement work on the visualizations that already had some learning utility made more sense than working on those with little-to-no learning utility. Focusing design enhancement work on the small visualizations in lieu of the large visualizations additionally made sense given the limited amount of time available to work on visualizations. If the newly developed small visualizations demonstrated themselves to have learning utility, aspects of their designs could be replicated in the large visualizations where it makes sense.

Thirdly, people completing user needs assessment questionnaires made efforts to retrieve knowledge about conceptual relationships and navigate visualizations resulting from search and node-click interactions. Thus, information yielded from data provided by questionnaire participants that is being used to guide the concept map design enhancement process primarily regards the small visualizations. Specifically addressed were visualizations resulting from the node-click and search interactions because both of these interactions result in the same zoom level.

Visualizations created during the design enhancement process include more labelled nodes and links than the interacted-with node, links connected to this node, and nodes connected to these links. Although a small number of questionnaire participation instances expressed agreement with the researcher's recommendations for this design enhancement (see *Figure 5.5* and*Figure 5.6*), the researcher came to think that people using these concept maps to learn could benefit from viewing these larger-sized visualizations while interacting with LTB maps for several reasons. First of all, wrong answers to questions about conceptual relational superstructures in section 2 of the user needs assessment questionnaires were provided by a substantial number of participation instances in which these questions were answered. Additionally, agreement with statements about disorientation presented in section 3 of the questionnaires were provided by substantial percentages of participation instances in which these questions were answered: People associated with these participation instances may have experienced disorientation when clicking between nodes to understand how concepts represented by nodes connected by more than one link relate with each other. Higher percentages of correctly answered questions to questionnaire section 2 questions about conceptual relational superstructures and lower levels of agreement with section 3 questions about disorientation may have been present among questionnaire participation instances if more labelled nodes and links in the concept maps had been visible during search and click interactions, in which questionnaire participants engaged. Secondly, the percentage of space in the window housing the concept map typically occupied by labelled links and nodes at the times of search and node-click interactions is usually small. The existence of a significant percentage of space not occupied by such nodes and links at the times of these interactions makes feasible the visualization of more labelled nodes and links than the interacted-with node, links connected to this node, and nodes connected to these links.

6.2 VISUALIZATION PROTOTYPING

A variety of enhanced visualizations of The Core and BoK concept map content resulting from search and node-click interactions were prototyped. *Figure 6.1* shows some of the prototyped visualizations for The Core concept map and *figure 6.2* shows some prototyped visualizations for the BoK concept map.

Figure 6.1: *Examples of visualization forms for The Core concept map prototyped by the researcher*

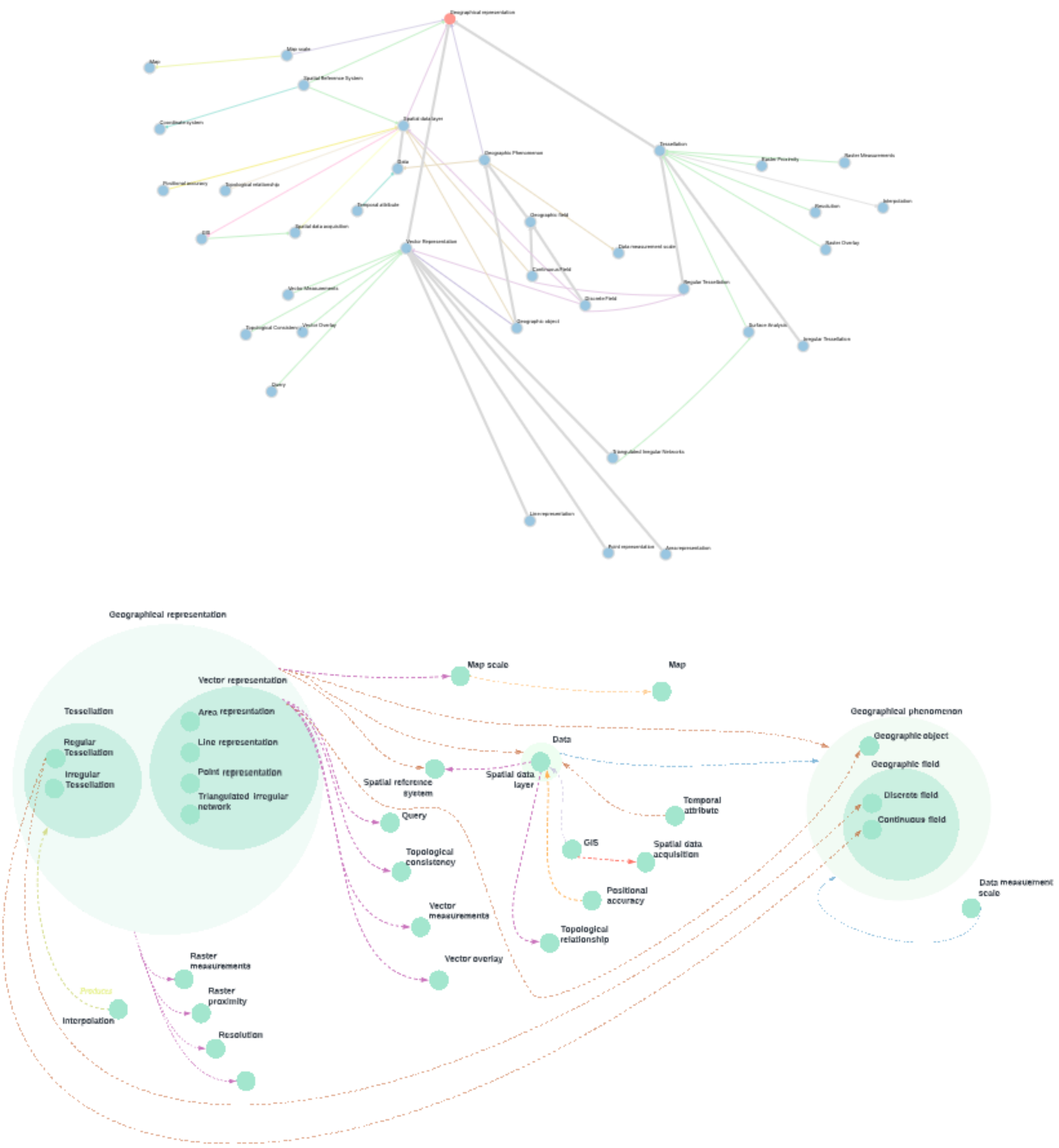
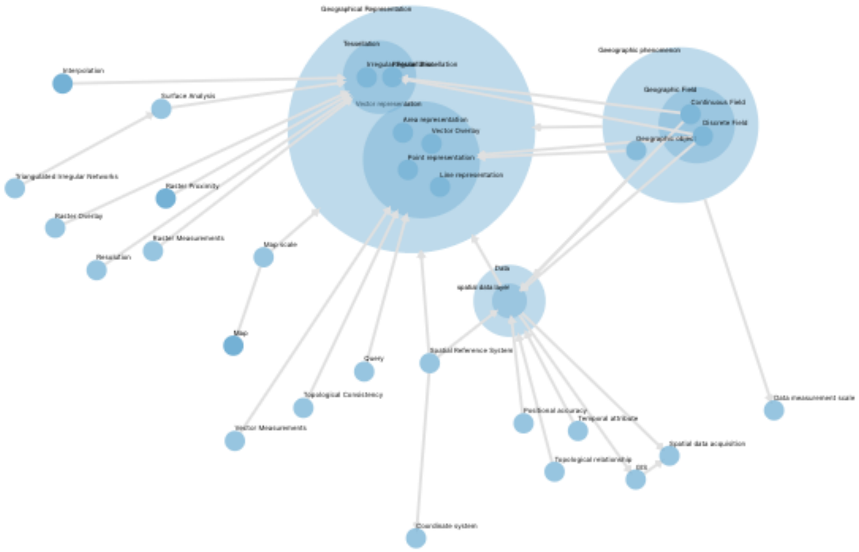
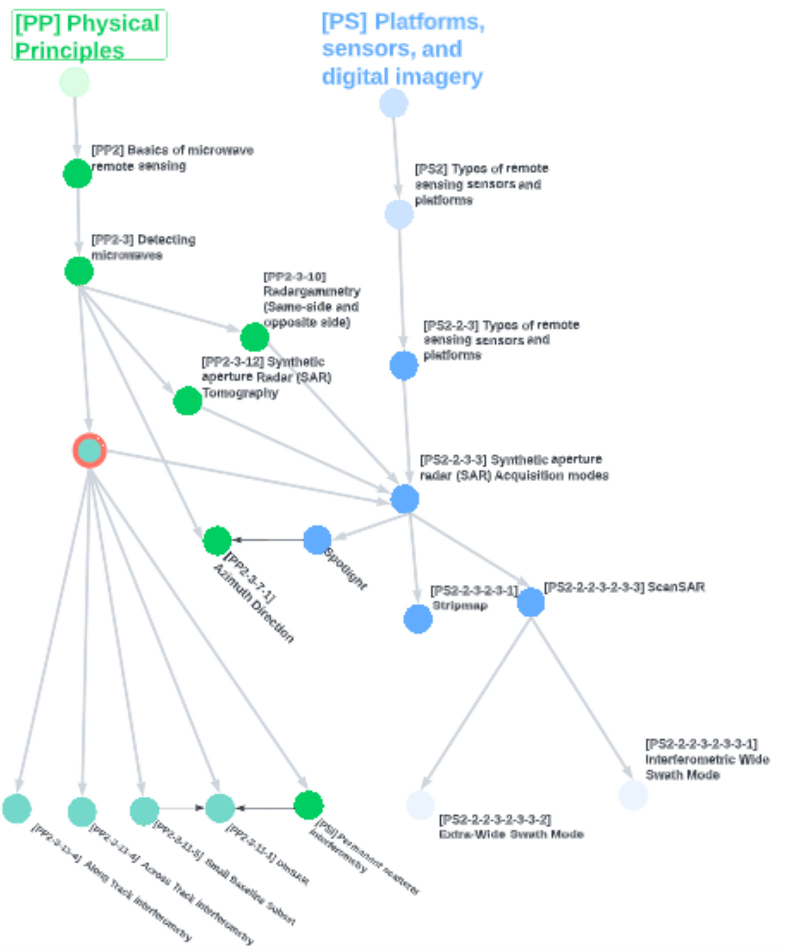


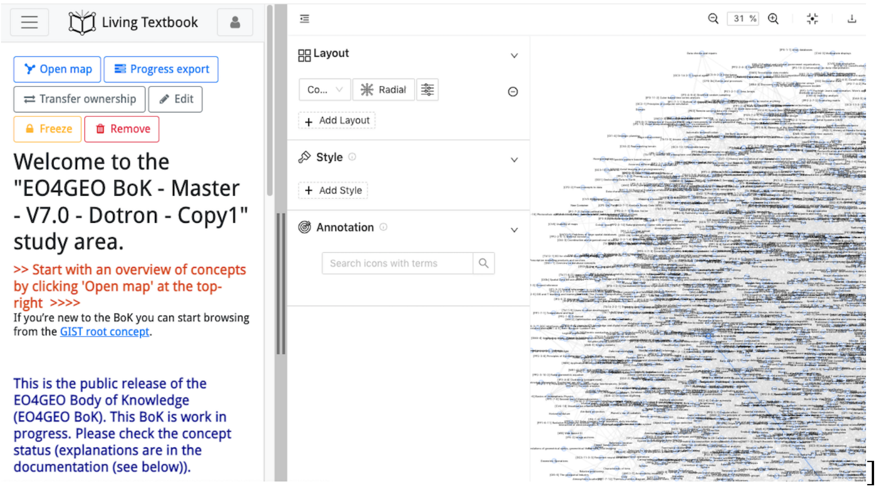
Figure 6.2: *Examples of design enhancement forms prototyped for The BoK concept map by the researcher*





In alignment with recommendations from the researcher's thesis advisor, visualization prototyping initially took place in a UT-ITC-managed D6.js test bed interface called Dotron. This Dotron test bed interface (*figure 6.3*) contains the same content that the LTB's BoK and The Core sections do, including both a right-side window containing concept map nodes and links and a left-side window with associated explanatory text. The versions of the concept

Figure 6.3: Dotron interface



maps found on Dotron have the same interactive functions as as the publicly accessible versions of the concept map. The Dotron interface offers the researcher the ability to style and adjust the layout of the nodes and links in the concept maps, as well create and style container polygons.

The researcher initially used the Dotron interface when new design forms were prototyped. While this interface initially proved very helpful, the researcher encountered a number of problems with the interface and therefore decided to use the Internet diagramming software LucidChart for visualization prototyping in lieu of Dotron. Problems with Dotron included the fact that adjustments to visualizations often wouldn't save and the illegibility of some components of concept maps found on the interface: Labels of links are difficult to read, and link arrows are difficult to see. Additionally problematic was the researcher's inability to implement some desired design enhancements while prototyping visualizations due to a lack of tools enabling this work. For example, the directions of link arrows and the voices of link labels can't be changed. Additionally, semiology visible upon interaction is the same as that of the existing LTB concept maps (labelled nodes, labelled links visible upon interaction, and labelled nodes connected to these links), and it's not possible to adjust this semiology. Finally, while the interface does allow for nodes and links to be placed within boundaries of container polygons, it does not permit topological overlap of these polygons. Such topological overlap of container polygons is necessary for effective representation of some conceptual relationships contained in the BoK concept map. Using LucidChart in lieu of Dotron for enhanced visualization prototyping made sense thanks to the researcher's familiarity with the software and its established reputation as a good software tool for concept map creation.

6.3 THE RESULT OF PROTOTYPING: VISUALIZATIONS TO COMPARE WITH USER TESTING

At the end of the rapid prototyping process, the researcher selected two visualizations with potentially optimal learning utility to further examine with user testing. *Figure 6.4* and *figure 6.5* show design forms for the BoK concept map. They visualize semiology resulting from hypothetical user interaction with the node representing the concept Principles of InSAR. *Figure 6.6* and *figure 6.7* show design forms selected for The Core concept map. They visualize semiology resulting from hypothetical user interaction with the node representing the concept Tessellation. For all visualizations, the color of the background is similar to that of existing LTB concept maps and the actual size of the substrate is 148.5 x 210 mm, which approximates the size of the LTB website window, in which concept map semiology is visible when the researcher interacts with it on his computer. All nodes have the same size, which approximates the size of the smallest nodes in the existing LTB concept maps.

Figure 6.4: *BoK visualization 1: Semiology resulting from interaction with node representing the concept "Principles of InSAR"*

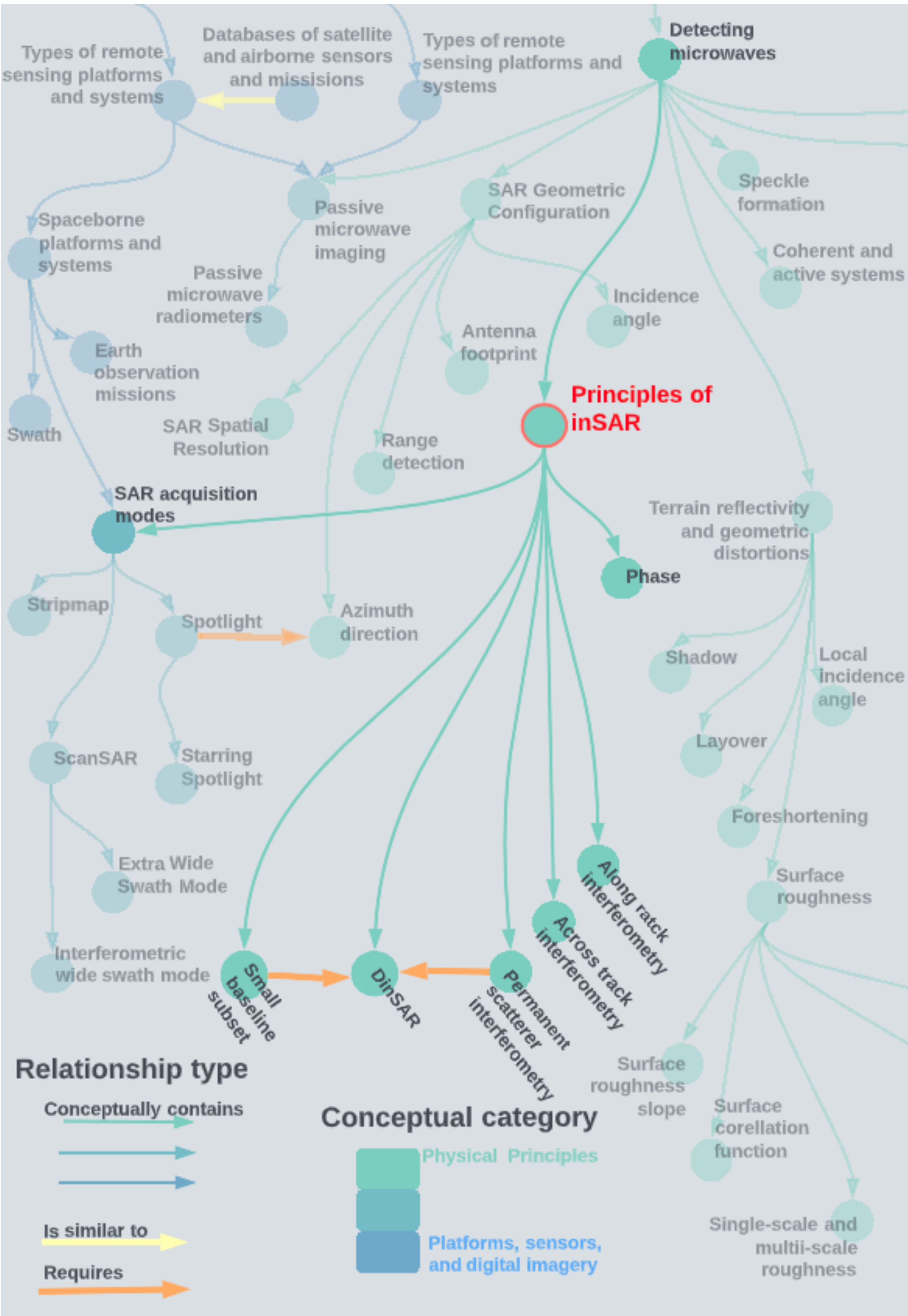


Figure 6.5: *BoK visualization 2: Semiology resulting from interaction with node representing the concept "Principles of InSAR"*

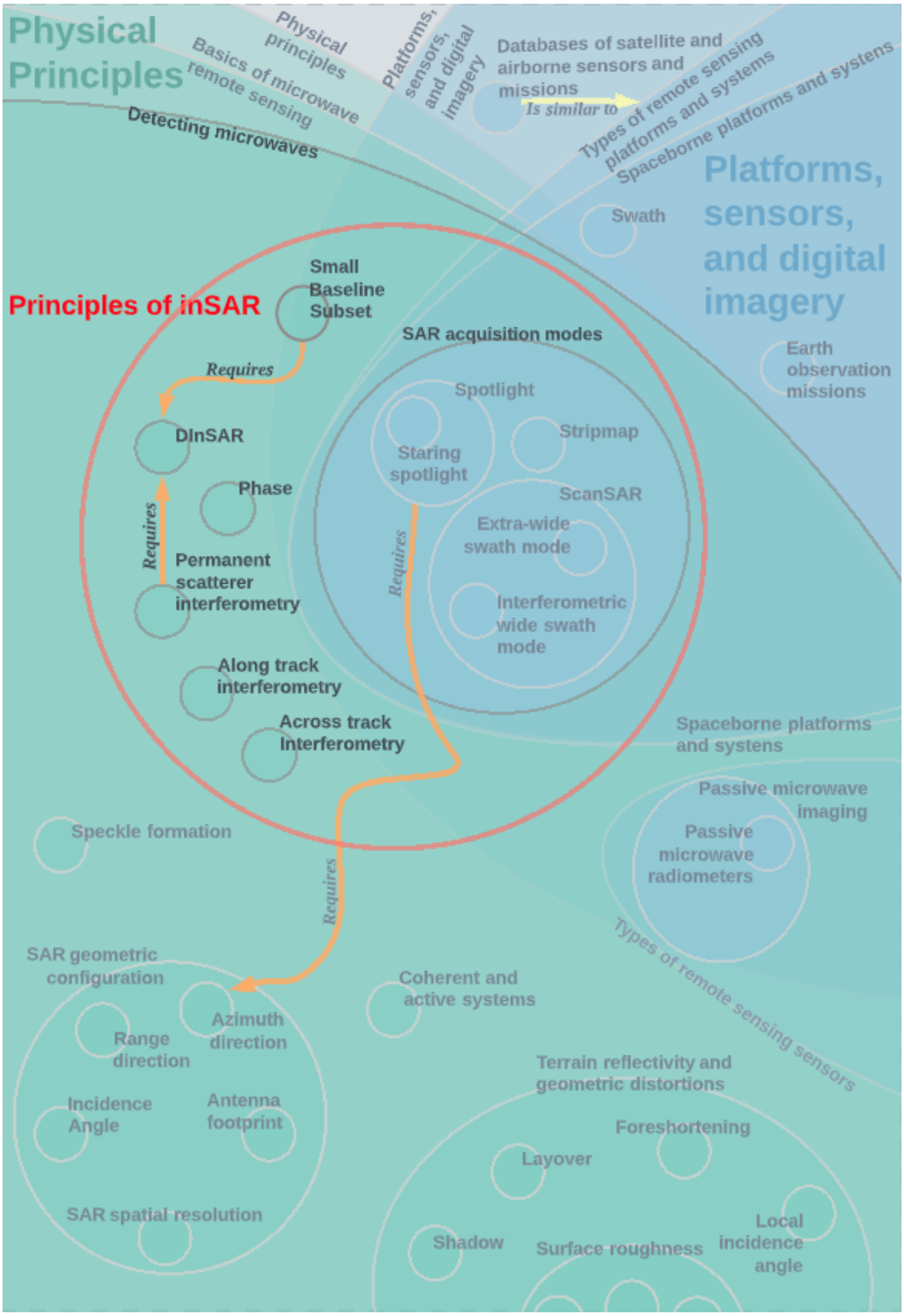


Figure 6.6: *The Core visualization 1: Semiology resulting from interaction with node representing the concept "Tessellation"*

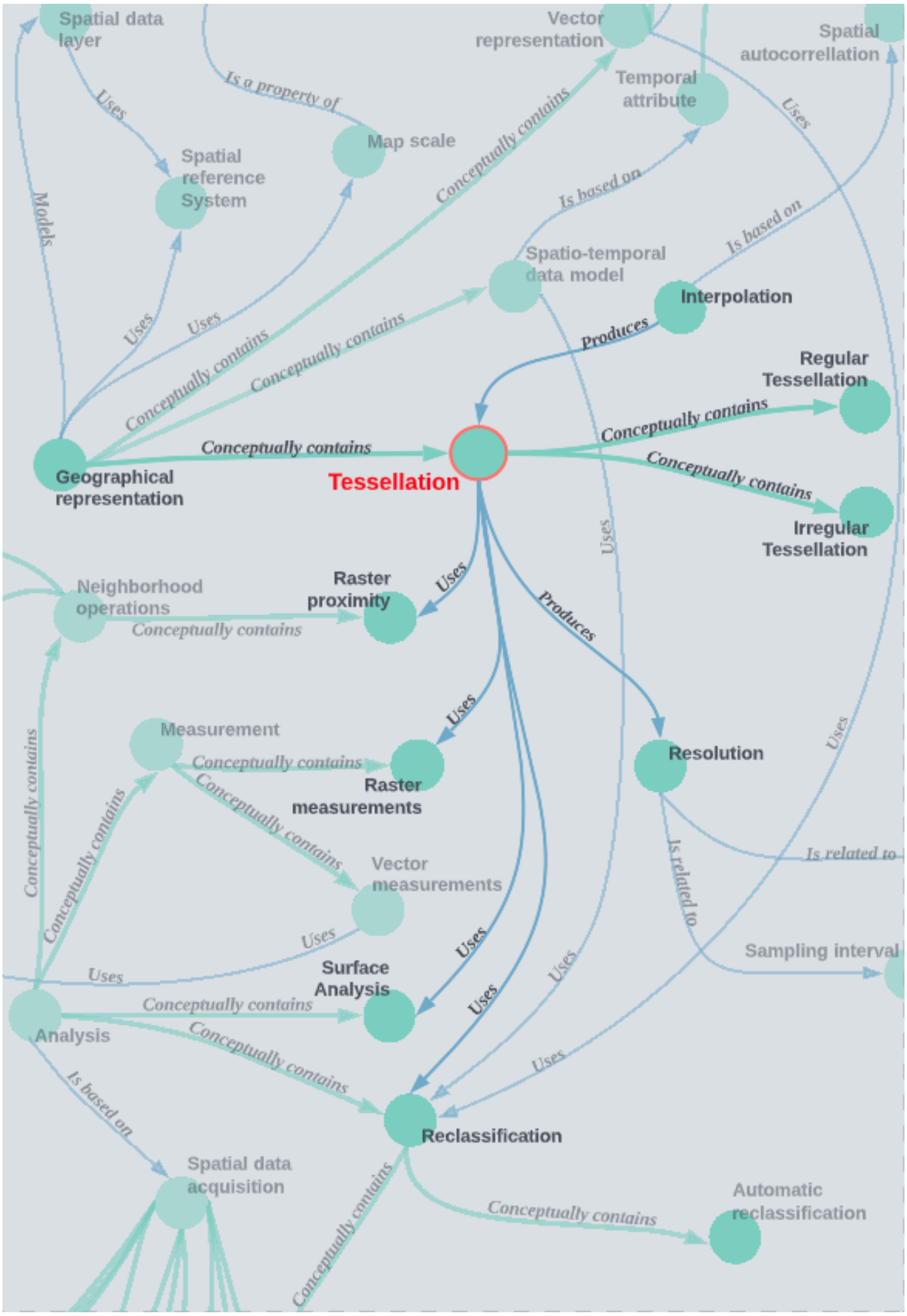
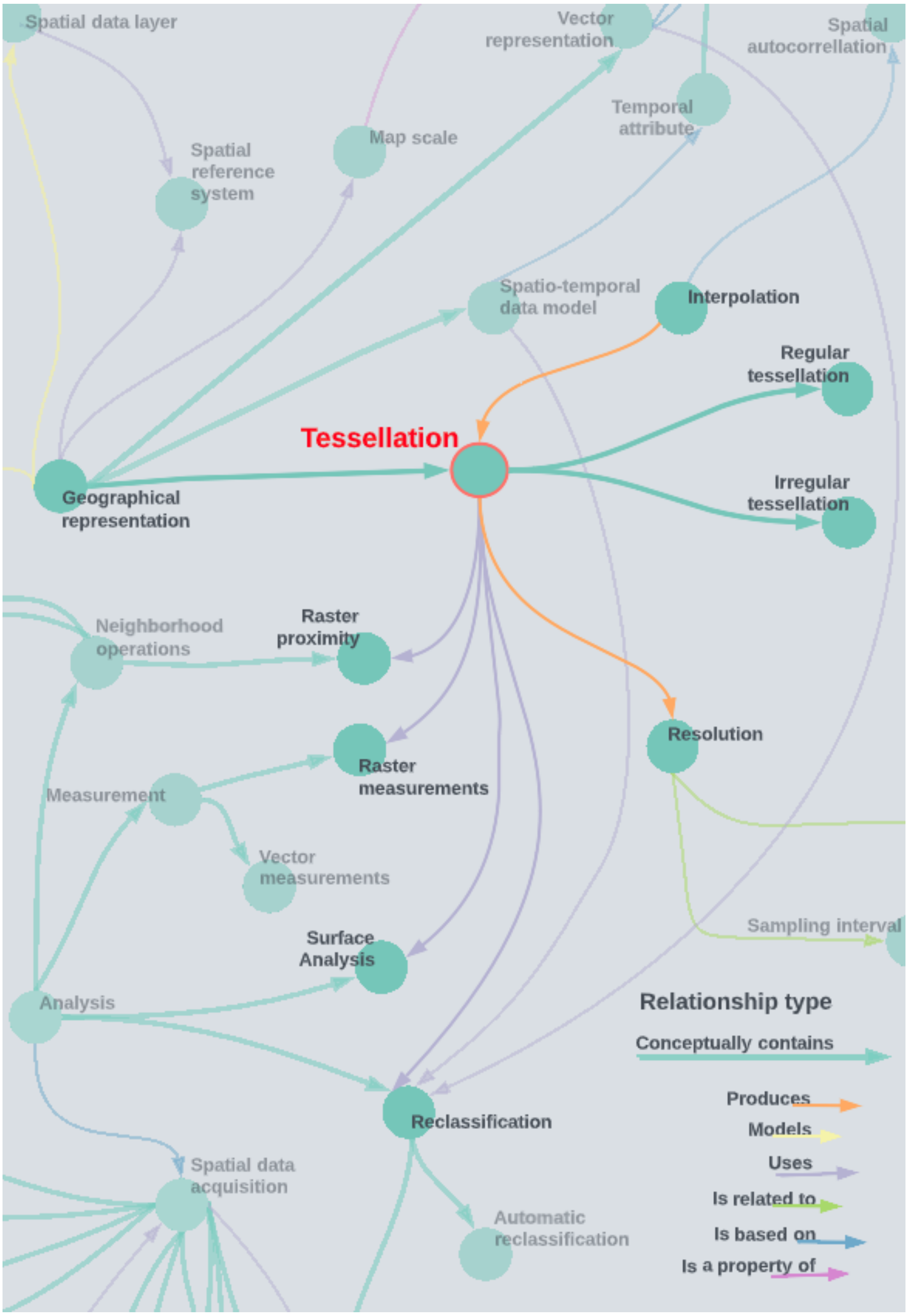


Figure 6.7: *The Core visualization 2: Semiology resulting from interaction with node representing the concept "Tessellation"*



6.4 DESCRIPTIONS OF VISUALIZATIONS

Semiology of the visualization in *Figure 6.4* represents the same semantics as that shown in *Figure 6.5* and that of *Figure 6.6* represents the same semantics as that shown in *Figure 6.7*. Between each of the two figures associated with any one map, the representational semiology is generally similar, with the exception of one attribute that differs completely from figure to figure.

6.4.1 BoK concept map figures

In the case of figures associated with the BoK concept map, the way hierarchical conceptual relational superstructures are represented in *Figure 6.4* differs from the way they are represented in *figure 6.5*. As described previously, the semantic structure of the BoK concept map has a focus on hierarchical conceptual relationships due to its use case. Identifying potentially good ways of representing these semantics should thus perhaps be a focus of the design enhancement process for this concept map. Using user testing to compare the learning utility of two potentially optimal ways of representing these semantics likely makes sense as a research endeavour. Hierarchical conceptual relational superstructures are represented with two sets of overlapping nested container polygons in *Figure 6.5*. Nested container polygons is likely an optimal representational form for hierarchical conceptual relational superstructures found in the section of the BoK concept map, in which the node representing the concept Principles of inSAR is located: The semantics of this section of this concept map, as with most of the map's other sections, have a hierarchical conceptual relational superstructure focus. As identified in chapter 3.1 of this paper, container polygons are likely an effective representation form for these types of semantics. The largest of these container polygons represent the concepts "Physical Principles" and "Platforms, Remote Sensing, and Digital Imagery," which are two of the thirteen parent concepts in the semantics of the BoK concept map. The visual representation resulting from nested nodes and container polygons with links connecting some nodes and container polygons is called an Euler spider diagram (Stapleton, 2005). In lieu of container polygons, hierarchical conceptual relational superstructures are represented in *Figure 6.4* with hierarchical network-structured visual representations that are Novakian in character: Nodes representing general concepts are located at the tops of the trees. Links representing conceptual containment relationships connected to these nodes extend downward to nodes representing more specific concepts located lower in the figure. Additionally, links representing conceptual relationships unrelated to generality and specificity horizontally connect nodes on different branches and different trees. Representing hierarchical conceptual relational superstructures found in the semantics of this figure with visual representations of this kind likely makes sense given the portrait orientation of the substrate, the number of nodes and links in the figure, and the number of levels of conceptual hierarchy in the semantics represented by the semiology shown in in the figure. The researcher was unable to find published academic studies, in which the learning utility of concept map semiology with a Novakian structure was compared with that of an Euler spider diagram. Thus, the comparison presented in this study is likely a timely research endeavour. The concept map semiology in both of these figures regarding hierarchical conceptual relational superstructures likely enables learner retrieval of knowledge about these semantics better than that currently found in the BoK concept map, which relies exclusively on node-link connections and link labels for this representation.

Aside from representational semiology regarding conceptual hierarchy, all representational semiology in *figure 6.4* is similar to that in *figure 6.5*. Like the semiology regarding conceptual hierarchy, this other semiology additionally perhaps better enables retrieval of knowledge about conceptual relationships than the existing LTB BoK concept map. In the concept map semiology shown in both figures, the visual variable of color hue is used in associative representation of categorical conceptual relationships, allowing a learner to more easily understand to what categories of knowledge concept-relationship-concept triples represented by this semiology belong. In *figure 6.4*, Nodes belonging to the conceptual category "Physical Properties" (those that are connected to the node representing this concept by one or more links representing an "is a subconcept of relation" in the existing LTB BoK concept map) are colored green, and those belonging to the conceptual category "Platforms, sensors, and digital imagery" are colored blue. Some nodes are contained by both categories, thanks to their being the destination node of one or more links representing the "conceptually contains" relationship, whose origin node or nodes belong or belongs to both categories. This green and blue color scheme takes inspiration from the colours of Earth's surface, the subject matter focus of the concept maps. The visual variable of colour hue is also associatively integrated into link design. Links carrying the label "conceptually contains" have the same color hue as their origin node. This color choice makes sense given the identity of the relationship represented by the link: The relationship is semantically a conceptual component of the concept represented by its associated origin node. Links representing relationship types other than conceptual containment have colors other than green and blue.

In *figure 6.5*, color hue is also used associatively in representation of a node's or container polygon's membership in a particular conceptual relational superstructure. Those representing semantics contained by the parent concept "Platforms, sensors, and digital imagery" are blue and those representing semantics conceptually contained by the parent concept "Physical principles" are green. The colors of all nodes and container polygons have an alpha value of 35 percent. This allows for color mixing where nodes and containers overlap, making visually evident the semantic overlap represented by this semiotic overlap. As is the case in *figure 6.4*, color hue is associatively integrated into the designs of link lines. In both figures, the visual variable of position is integrated associatively into the designs of some nodes that are placed in close proximity with each other because they are conceptually associated with each other. For example, all three nodes representing different types of interferometry are placed in close proximity with each other in both figures. In both figures, all labels and their associated semiotic components are large enough in size and sufficiently not overlapped to be legible. The legibility of labels is likely further enhanced by their spatial placement in relationship with their associated semiotic components in general accordance with cartographic conventions for label placement.

The representational semiology of both figures is likely also navigable, which likely enhances its learning utility. In both figures, the interacted-with node/container polygon is located close to the visual center of the figure. The node can therefore easily serve as a navigation launch pad. The visual variable of color hue is used selectively to indicate which node is the interacted-with node: The node has a red border, enabling easy visual discrimination of the node from nodes that aren't undergoing interaction, which don't have red borders. In *figure 6.5*, the visual variable of opacity is used orderedly to show relational proximity of nodes and links to the interacted-with node: The interacted-with node, links connected to this node, and nodes connected to these links have alpha values of 1.0; All other nodes and links have alpha values of .5. The visual variable of color value orderedly accomplishes this in *figure 6.4*. The difference between the color value of the border of nodes and representational semiology that surrounds the border is high. For the borders of other nodes and polygons, this difference is low. As previously mentioned, the set of nodes with labels rendered visible by the interaction is larger. As previously described, inclusion of more nodes and links than the interacted-with node, links connected to this node, and nodes connected to these links likely means that someone making efforts to retrieve knowledge about conceptual relationships shared among these node-link-node triples and those not included in this group likely won't become disoriented while doing this. However, the number of visible nodes and links found in both of the figures is likely small enough that someone viewing either of them won't be prone to map shock. Lucid representation of conceptual relational superstructures likely additionally helps mitigate learning-related disorientation associated with either of the maps. The navigability of concept map semiology in both of the figures is likely additionally enabled by the way links in both maps are designed. No links in either figure are particularly long. Additionally, the directions of link arrows and the voices of link labels likely make intuitive sense given the relationship type represented by each link. Arrow directions and label voices of links, for which this was likely not the case in existing BoK concept map have been reversed. For example, links labelled "is a prerequistive of" and "is a subconcept of" respectively read "requires" and "conceptually contains" in the figures, and the arrows in the figures point in directions opposite of what they point in the BoK concept map. Link line crossings are minimal in *figure 6.4* and non-existent in *figure 6.5*. Finally, particularly in the concept map shown in *Figure 6.4*, series of link lines that may be of particularly strong importance to someone using the maps to learn, such as, for example, series of links representing the "conceptually contains" relationship connect to nodes found in the series at 180-degree angles, allowing for someone navigating the series to easily transition at nodes from one link to another. Additionally, link lines are all curved in order to ensure that representation of concept-relationship-concept triples of particular importance for someone using the map to learn draws on Gestalt principles of both spatial proximity and continuity in conveying the relatedness of all components of this semiology.

6.4.2 The Core concept map figures

The figures associated with The Core concept map (*figure 6.6* and *figure 6.7*) vary in the way they represent pairwise conceptual relationships. Using user testing to compare two potentially optimal ways of representing these semantics likely makes sense as a research endeavour regarding this concept map because, as mentioned previously, pairwise conceptual relationships are a focus of this concept map's semantics. In *figure 6.6*, all links that don't represent conceptual containment have the same color. Labels are used to identify the conceptual relationship represented by each of the links. In *figure 6.7*, the visual variable of color hue is used associatively to indicate semantic variation in concepts represented by links, and a legend is used to identify the conceptual relationships represented by all links. The researcher could not find any past academic studies, in which these two potentially optimal ways of representing pairwise conceptual relationships in a concept map were compared. Carrying out such a comparison during a user test is thus likely a timely research endeavour.

Other representational semiology in *figure 6.6* and *figure 6.7* is designed to enable learning in ways similar to that of the semiology found in *figure 6.4* and *figure 6.5* (those associated with the BoK concept map) is, with a few important differences. In both figures, the visual variable of size is integrated into the design of semiology representing the conceptual containment relationship: Links representing this relationship are thicker than those representing representing other relationships. Selectively integrating visual variables into the design of these links allows for lucid representation of hierarchical conceptual relational superstructures. The concept map is therefore likely helpful for members of its target user group. As previously described, lucid representation of hierarchical conceptual relational superstructures may benefit cognitive processes related to learning of people with little knowledge of the map's subject material, according to at least one previously described study found in (Amadieu et al., 2009). The design of the representational semiology in these two figures additionally differs from that of the figures associated with the BoK concept map, thanks to the fact that color is not used to associatively represent a node or link's membership in a conceptual relational superstructure and conceptual relational superstructures are not represented with side-by-side Novakian hierarchical network structures. As previously explained, hierarchical conceptual relational superstructures are not a focus of the semantics of The Core concept map: Many nodes in the existing LTB The Core concept map are not connected to links representing conceptual containment, and most hierarchical conceptual relational superstructures in the map have relatively few levels of conceptual hierarchy. Representing hierarchical conceptual relational superstructures in this map with side-by-side Novakian tree structures and using the visual variable of color associatively in the design of nodes and links to show their membership in hierarchical conceptual relational superstructures doesn't make sense.

Chapter 7
Design enhancement stage 3

A second set of questionnaires and an in-person user study were used to evaluate the potential learning utility of the concept map semiology found in the four figures presented in the previous chapter. This chapter describes of the methodologies and results of both of these evaluation methods.

7.1 QUESTIONNAIRES

7.1.1 Questionnaire purpose

One questionnaire associated with each of the four figures described in the previous chapter were used to gather data that could help answer the following four questions:

qq1: How lucidly do the figures presented in chapter 6 communicate knowledge about conceptual relationships, as compared with existing LTB The Core and BoK concept maps?

qq2: How do the two chapter 6 figures associated with a particular LTB concept map compare with each other, with regards to lucid communication of knowledge about conceptual relationships?

qq3: How navigable is the concept map semiology found in chapter 6 figures, as compared with that of existing LTB concept maps?

qq4: How do the two chapter 6 figures associated with a particular LTB concept map compare with each, with regards to navigability?

7.1.2 Questionnaire distribution

The questionnaires were distributed once again on Amazon's Mechanical Turk (MTurk) service as well as on Prolific Academic, another similar service from which questionnaire participants can be crowdsourced. The total number of questionnaire participants for the questionnaire associated with each of the four figures presented in the previous chapter was, as follows: *Figure 6.4* (118), *Figure 6.5* (137), *Figure 6.6* (143), *Figure 6.7* (118). As was the case with the user needs assessment questionnaires, a number of questionnaire participants were disqualified if the researcher thought they didn't take seriously the task of completing the questionnaire. Respectively for questionnaires associated with *Figure 6.4*, *Figure 6.5*, *Figure 6.6*, and *Figure 6.7*, these numbers were 27, 11, 26, and 24.

7.1.3 Questionnaire sections

Section 1: Demographic information

As was the case with the user needs assessment questionnaires, questions in the first section of the second set of questionnaires helped the researcher to limit data considered during questionnaire results analysis to that provided by people belonging to a demographic similar to that of the concept maps' target users, ensuring compliance with user-centered design protocol. Only participation instances contributed by people who self-identified themselves as holding a master's degree or being enrolled in master's degree program in their responses to this questionnaire section's questions were analyzed.

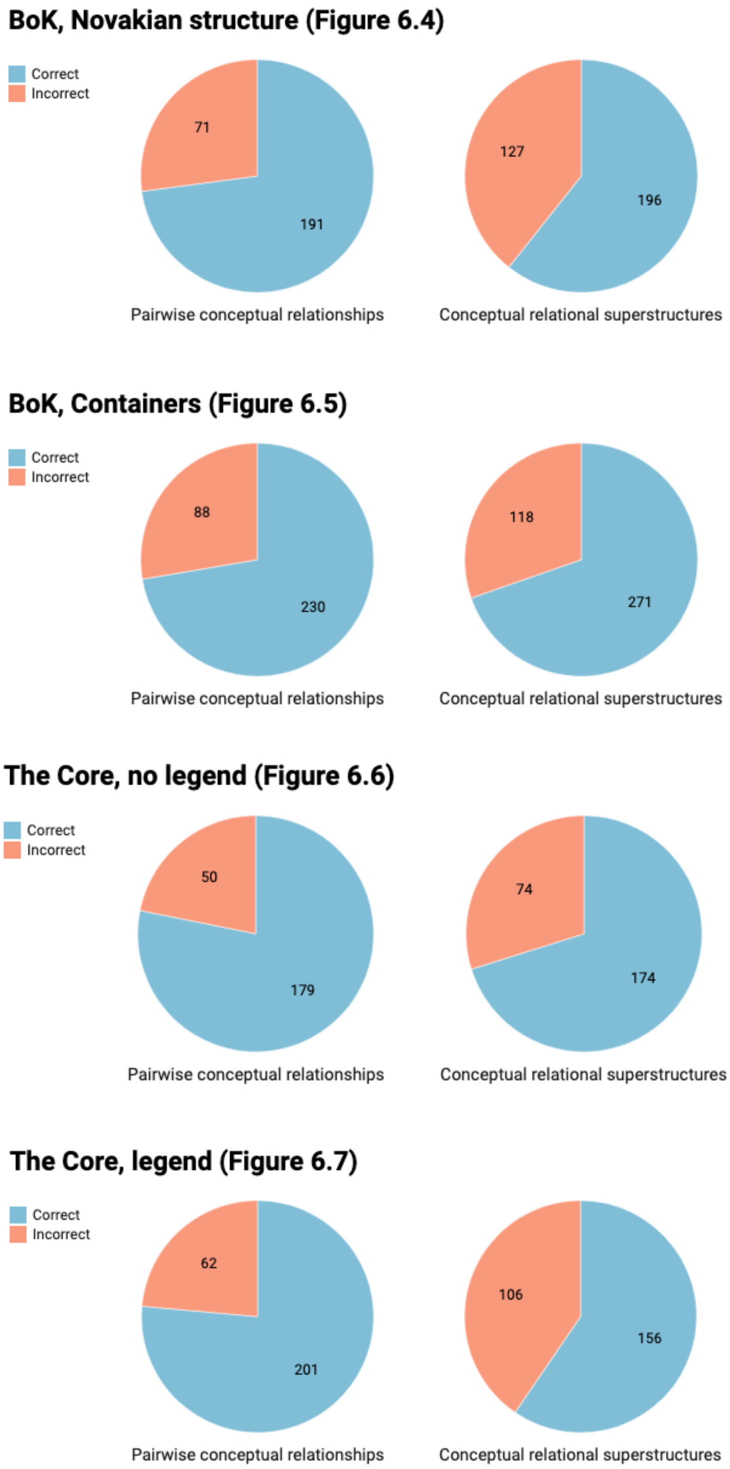
Section 2: Questions regarding retrieval of knowledge about conceptual relationships

As was the case with the first set of questionnaires, questions in the second sections of the second set of questionnaires regarded accuracy of retrieval of knowledge about conceptual relationships. Information yielded from data gathered by these questionnaire sections can be used to answer qq1 and qq2. Questionnaire participants were asked to view the figure associated with the questionnaire they were completing and then provide answers to questions about conceptual relationships (at both the pairwise and conceptual relational superstructure level) represented by the concept map semiology present in the figure they were viewing. People completing section 2 of the questionnaires regarding the figures associated with The Core concept map were asked to assess whether their knowledge of the concept represented by the node depicted as being interacted-with prior to participating in the questionnaire was not-at-all strong, somewhat strong, moderately strong, very strong, or expert level. The only participation instances considered during questionnaire results analysis were those, in which the response to this question was not-at-all strong, somewhat strong, or moderately strong. This data filtering again ensured that data came from questionnaire participation instances contributed by people whose knowledge of the concept map's subject matter was similar to that of people who typically interact with The Core concept map, ensuring compliance with user-centered design protocol. *Figure 7.1* shows information yielded from data gathered from answers to these questionnaire questions.

Qq1 can, to a certain extent be answered by comparing the pie charts shown in *figure 7.1* with those in *figure 5.3*. However, a direct comparison is not entirely possible because the set of people participating in both sets of questionnaires were different and were recruited from different sources. Additionally the set of concept map nodes and links people participating in the needs assessment questionnaires viewed were different from those viewed by people participating in the second set of questionnaires. Finally, the style of questions in the first set of questionnaires differed from those in the second set of questionnaires. For example, the needs assessment questionnaires regarding The Core concept map included both true and false questions, as well as multiple choice questions. However, second-round questionnaires regarding The Core concept map featured multiple choice questions only. Despite these differences between the two sets of questionnaires, some comparison of the results of both of them is nevertheless likely possible: The activities in which questionnaire participants were asked to engage while completing the second section of both sets of questionnaires were generally similar. When carrying out such a comparison, one can see that, for both The Core and the BoK concept maps, people interacting with concept map semiology found in the figures presented in the previous chapter retrieve knowledge from the concept map semiology presented in those figures at higher levels of accuracy than people interacting with the concept map semiology found in the existing The Core and BoK concept maps. For all four questionnaires regarding the figures presented in chapter 6, more than half of all answers to questions, regarding both pairwise conceptual relationships and conceptual relational superstructures, provided by questionnaire participation instances completing section 2 of the questionnaire were accurate. This accuracy rate can perhaps indicate that the concept map semiology presented in these figures has good learning utility.

Qq2 can be answered by comparing the two sets of pie charts associated with any particular concept map. People completing questionnaires regarding both The Core and BoK concept maps answered questions about pairwise conceptual relationships at similar levels of accuracy regardless of which figure associated with one of these concept maps they interacted with. However, for both concept maps, the level of accuracy at which questionnaire participants answered questions about conceptual relational superstructures varied relatively substantially depending on the form of concept map semiology that was present in the figure found in the questionnaire they completed. For the questionnaires regarding BoK concept map, people interacting with concept map semiology in which hierarchical conceptual relational superstructures were represented with nested container polygons answered questions about conceptual relational superstructures at a higher level of accuracy than people interacting with semiology, in which these semantics were represented with Novakian tree structures. For the questionnaires regarding The Core concept map, people interacting with concept map semiology, in which link labels identified the relationship represented by most links answered questions about conceptual relational superstructures at substantially higher levels of accuracy than people interacting with concept map semiology in which a legend was used to identify the relationship represented by most links and color hue was integrated associatively into link design.

Figure 7.2: *Number of correct and incorrect responses to questions about conceptual relationships*



.

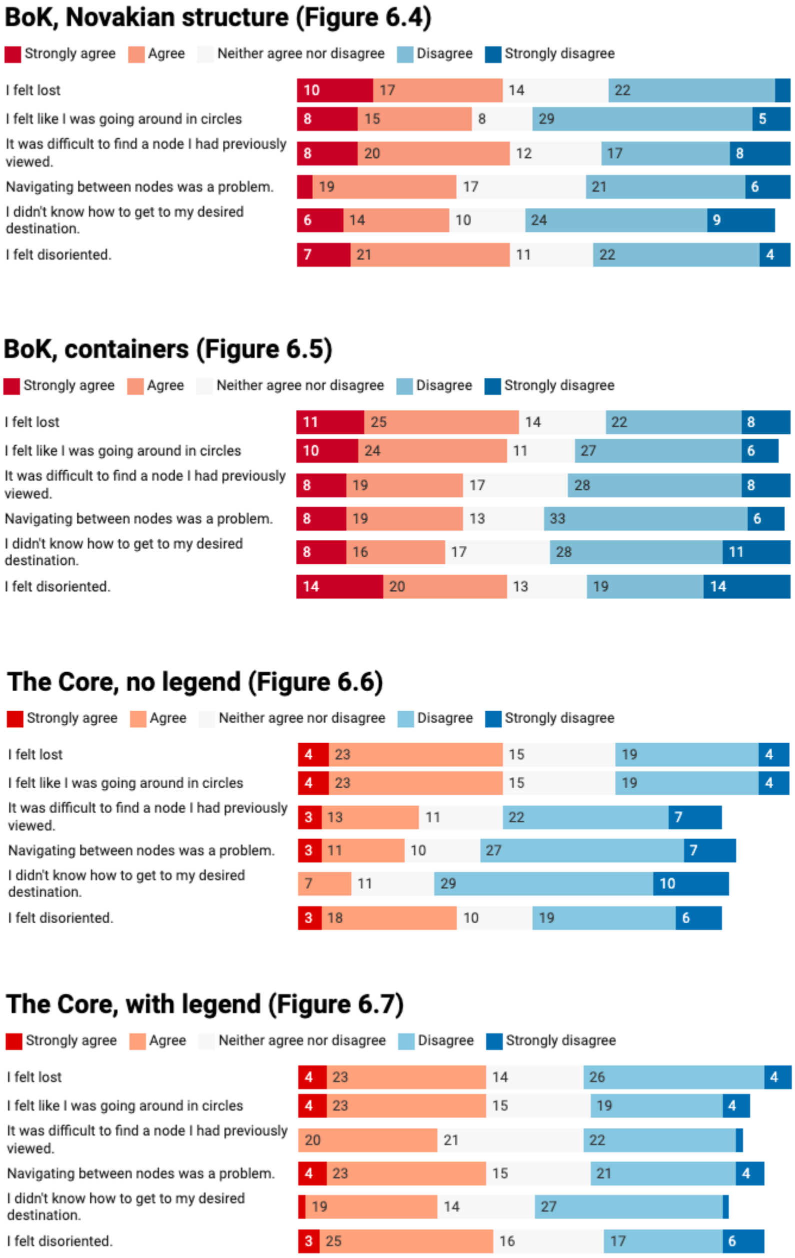
Section 3: Questions regarding retrieval of knowledge about conceptual relationships

As was the case with the user needs assessment questionnaires, the third section of the second set of questionnaires addressed concept map navigability by assessing disorientation questionnaire participants experienced while completing the questionnaire's second section. Questionnaire participants were once again asked to specify their level of agreement with each of the following five possible conclusions to statement "When using the node-link concept map to learn information...":

- I feel lost.
- I feel like I'm going around in circles.
- It's difficult to find a node I've previously clicked on.
- Navigating between nodes is a problem
- I don't know how to get to my desired location.
- I feel disoriented.

The stacked bar graphs found in *figure 7.2* communicate information derived from data provided by questionnaire participation instances, in which answers to questions in the third section were provided. QQ4 can be answered by comparing the two sets of stacked bar graphs associated with the BoK concept map and by comparing those associated with The Core concept map. QQ3 can to a certain extent be answered by comparing *figure 7.2* with *figure 5.4*. For both second round questionnaires associated with the BoK concept map, reported levels of disorientation were similar. Interestingly, these levels of disorientation were generally higher than those reported by participants in the user needs assessment questionnaire regarding the BoK concept map. Regarding The Core concept map, generally lower levels of disorientation were reported by participants in the second round questionnaire associated with *figure 6.6* than that associated with *figure 6.7*. Reported levels of disorientation associated with *figure 6.7* were similar to those associated with the user needs assessment questionnaire.

Figure 7.3: *BoK concept map-associated questionnaire participants' levels of agreement with five possible responses to the statements "When using the node-link concept map to learn information..."*



Note: Each number represents the number of participants selecting its associated agreement level.

7.2 USER STUDY

7.2.1 Procedure

An in-person user study involving eye-tracking and think aloud participant observation methods was carried out in order further assess the learning utility of concept map semiology found in *figure 6.4*, *figure 6.5*, *figure 6.6*, and *figure 6.7*. The study was geared towards answering the following research questions about the concept maps:

qq1: When presented with the opportunity to view both prototyped visualizations associated with a particular existing LTB concept map, do people prefer one or the other to retrieve knowledge about conceptual relationships?

qq2: When presented with the opportunity to view both prototyped visualizations associated with a particular existing LTB concept map, do people find one or the other more navigable while retrieving knowledge about conceptual relationships?

qq3: Does anything about the prototyped visualizations particularly enable or hinder navigation or retrieval of knowledge about conceptual relationships?

Participants were asked to view both *figure 6.4* and *figure 6.5* simultaneously and answer the same sets of questions found in first and second sections of the follow-up questionnaires regarding these figures. They were then asked to answer the two questions: "From which of the concept maps was retrieval of knowledge about conceptual relationships easiest?" and "Which of the concept maps was easiest to navigate?". They were then asked to view *figure 6.6* and *figure 6.7* simultaneously and answer the same sets of questions found in the first and second sections of the follow-up questionnaires regarding these figures, followed by the same two questions regarding ease of retrieval of knowledge about conceptual relationships and navigability they answered after viewing the questionnaire questions associated with the BoK concept map. The number of participants in the user study was four, a number in alignment with the recommendation from (Nielsen, 2000): "Elaborate usability tests are a waste of resources. The best results come from testing no more than 5 users and running as many small tests as you can afford." All user study participants were either students or teachers of geo-information science or earth observation subject areas. Knowledge of the concepts of Principles of inSAR and Tessellation, the two concepts represented by the node depicted as being interacted-with in the figures examined during the user study, held by user study participants prior to participating in the user study ranged from "not-at-all strong" to "moderately strong." A Tobii Lab Pro eye-tracking system can was used for eye-tracking and voice recording. User study participants viewed the figures being examined in the study at their actual sizes (148.5 mm x 210 mm) while seated at distance of 50 and 100 cm from the computer screen, a typical computer screen viewing distance. While viewing any of the two particular sets of prototyped visualizations, study participants were given 10 minutes to answer the sets of questions presented to them. Each set of questions associated with any particular concept map included nine that tested study participants' accurate retrieval of knowledge about conceptual relationships as well as a few other questions. Restricting the question-answering time to ten minutes allowed for the test to evaluate whether participants were able to accurately retrieve knowledge about conceptual relationships from the concept maps being viewed in a short amount of time.

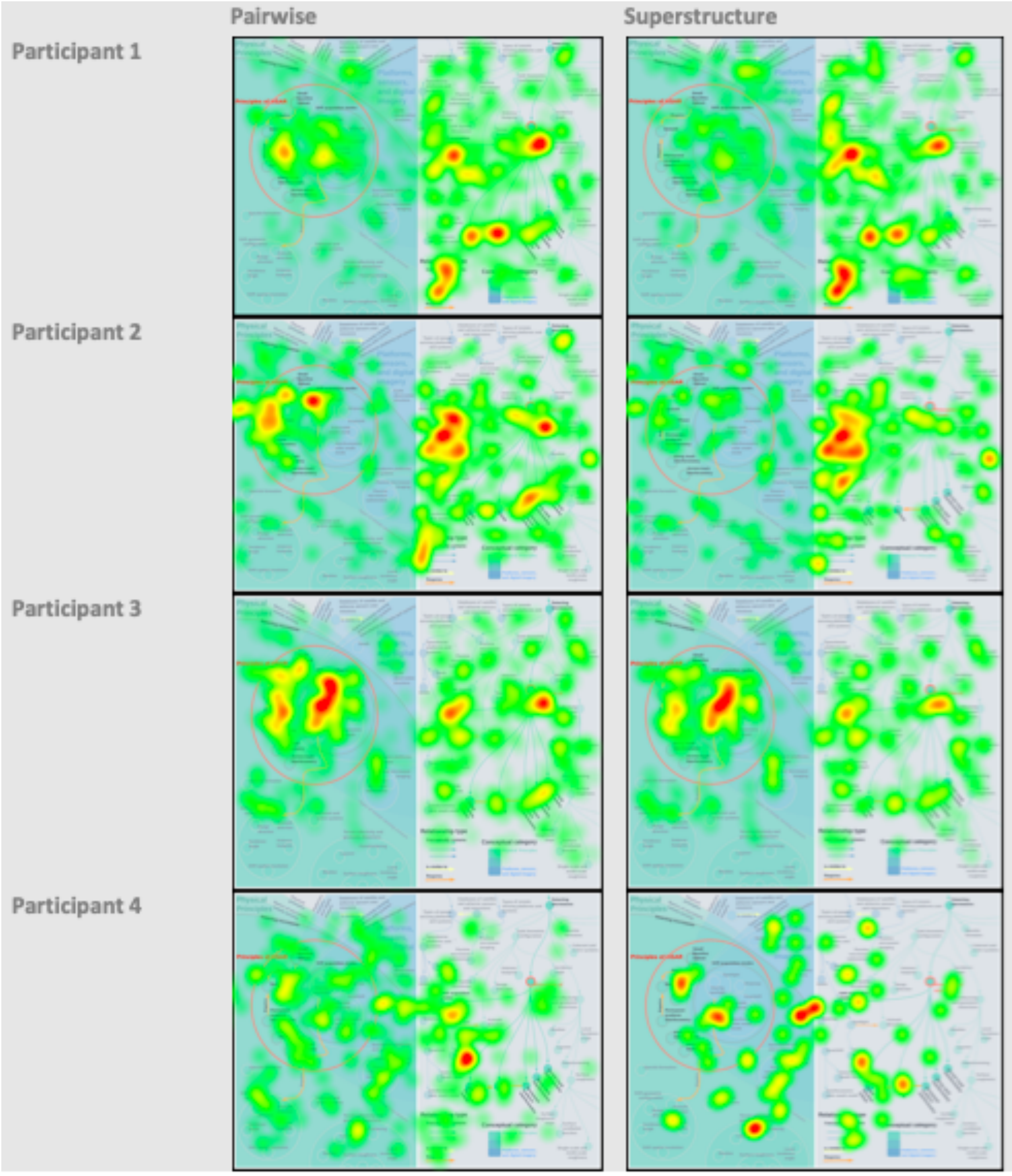
7.2.2 Results

Figure 7.4, *figure 7.5*, *figure 7.6*, and *figure 7.7* show heat maps and gazeplots communicating information about the eye movements the four user study participants engaged in during the user study. Information derived from the heatmaps and gazeplots can be used to help answer qq1 and qq2: If a user study participant's eye movements are concentrated on one or another of the two adjacent figures, this figure is presumably preferred by this user study participant for retrieval of knowledge about conceptual relationships or navigation. Heatmaps and gazeplots from the user study can additionally be used to track which parts of which of the two prototyped visualizations associated with a particular concept map user study participants viewed most often during the user study, helping answer qq3: If multiple user study participants' gazes were concentrated in a particular area, the arrangement of marks in this location may hinder retrieval of knowledge about conceptual relationships or navigation. Each of the tested sets of visualizations is shown twice in *figure 7.4*, *figure 7.5*, *figure 76*, and *figure 7.7*. The leftside visualizations show eye-tracking data captured during the first third of the ten minute session, during which the user study participants viewed the visualizations. The rightside visualizations show data captured during the second third of the ten minute session. In each set of questions user study participants were required to answer, most of the first third of questions regarded retrieval of knowledge about conceptual relationships at the pairwise level. The second third of questions dealt with retrieval of knowledge about conceptual relationships at the conceptual relational superstructure level. Comparing the gazeplots or heatmaps associated with a particular experiment participant in the left columns of one of these figures with those associated with this same participant in the right columns of this same figure allows one to see how this participant's eye movements changed over the course of the time period when the two images associated with the gazeplot or heatmap were viewed. Gaining an understanding of how the eye movements of a particular experiment participant changed over time can help in answering qq1 and qq2: It could be the case that an experiment participant over time comes to increasingly focus her gaze on one of the two visible figures because she comes to prefer using it to answer the questions presented to her because she finds the concept map semiology in the figure easier to retrieve knowledge from or more navigable than that found in the other figure. Comparing eye movements of a user study participant shown in a figure in one column with those shown in the corresponding location in the other column can additionally help one understand whether the participant's preference for one image or the other changed depending on the type of conceptual relationship (pairwise vs. superstructure) she was interested in retrieving knowledge about.

figure 7.8 shows user study participants' responses to questions "From which of the concept maps was retrieval of knowledge about conceptual relationships easiest?" and "Which of the concept maps was easiest to navigate?".

figure 7.9 Communicates some of the microphone recorded statements made by of user study participants engaged in think-aloud.

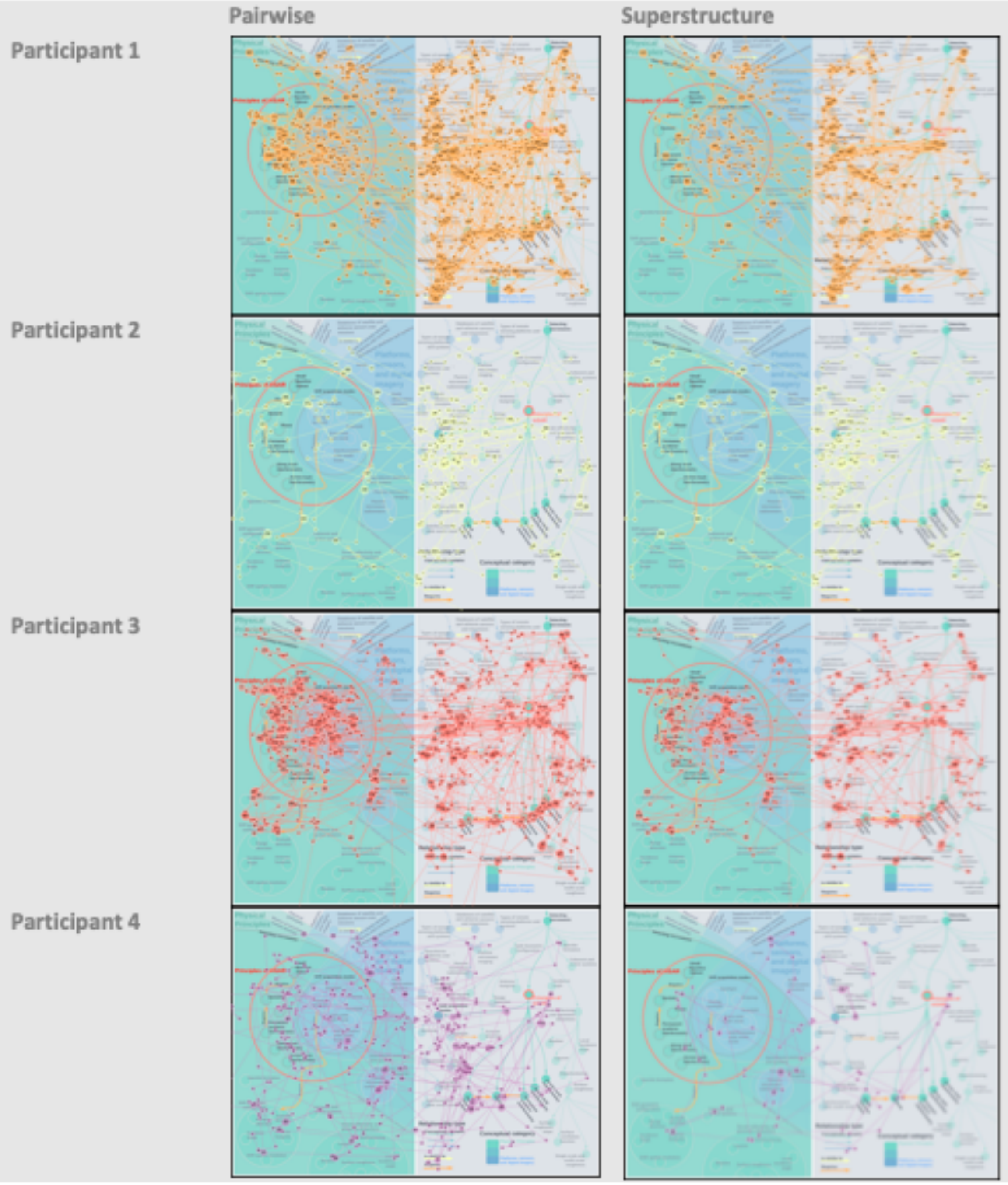
Figure 7.4: *BoK map eye-tracking heatmap*



7.2.3 Analysis

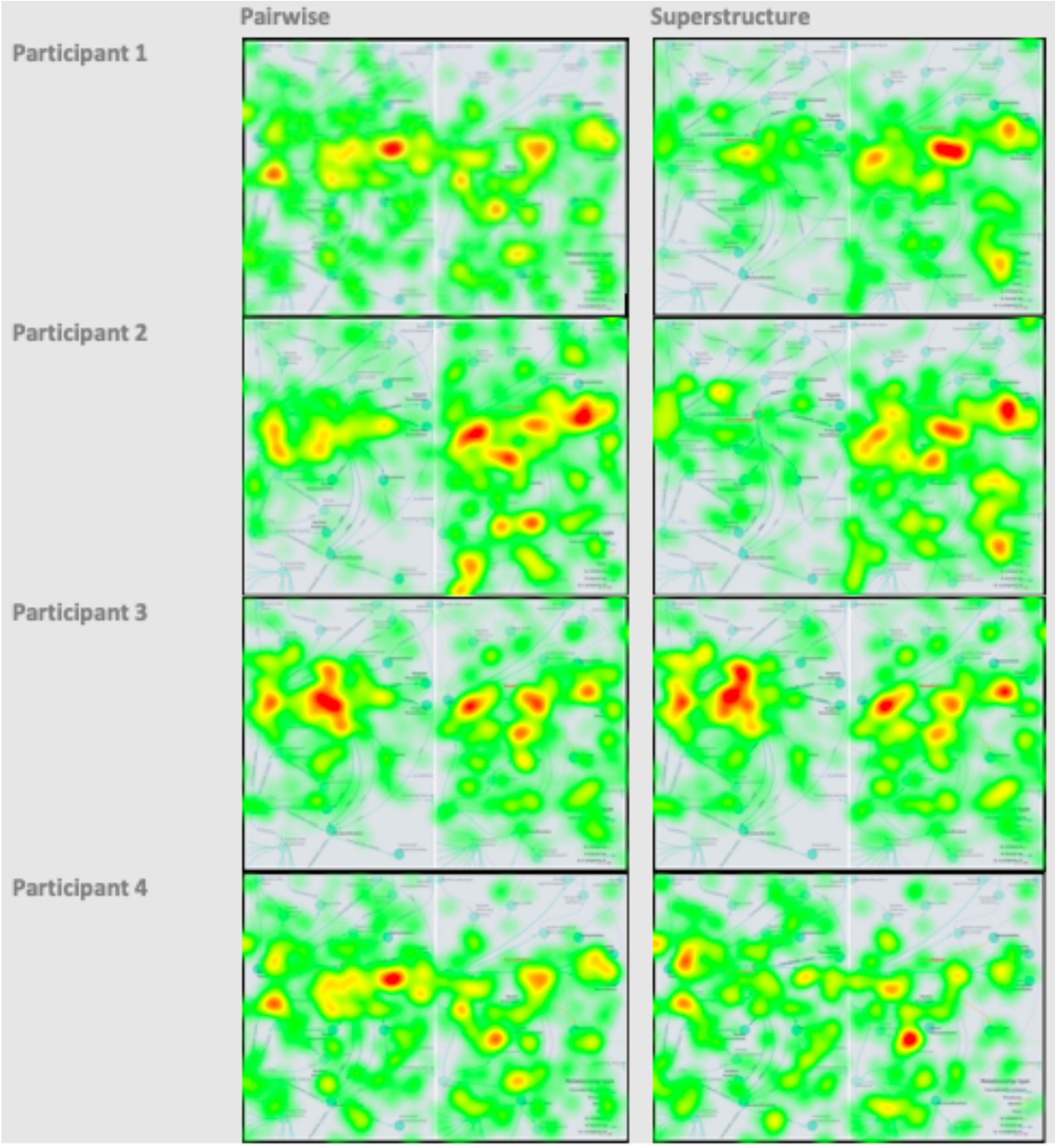
A review of data gathered from eye-tracking shows that when answering questions about conceptual relationships communicated by both the BoK and The Core concept maps, all user study participants viewed both figures associated with both maps to at least some degree. However, the degree to which each study participant viewed a particular figure within each of the two sets and the locations on a particular figure where gazes were most focused varied from participant to participant. For each participant, these things additionally var-

Figure 7.5: *BoK eye-tracking gazeplot*



ied from time to time. Information derived from this data perhaps indicates that for each of the two sets of figures, each of the user study participants used each of the two figures to retrieve knowledge about conceptual relationships to varying degrees and in different ways. The helpfulness or hindrance to learning of aspects of the design of the semiology found in both figures in both sets likely varies in degrees from person to person. Information presented in *figure 7.8* and *figure 7.9* corroborates this idea. Further research is necessary to identify the exact reasons behind a particular study participant's eye movements. However,

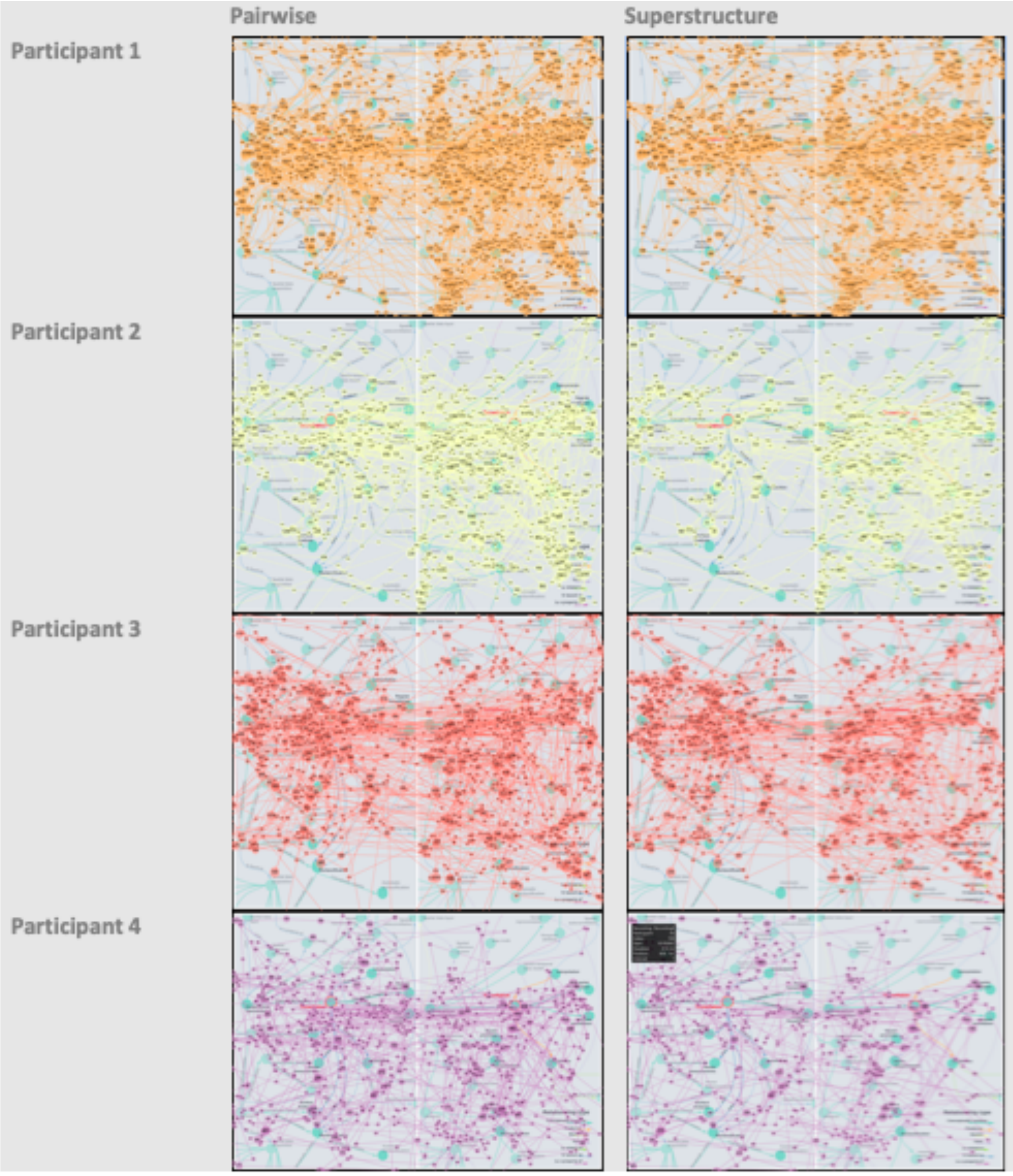
Figure 7.6: *The Core eye-tracking heatmap*



some reasons can be inferred with some knowledge of some participants' past experience with concept maps. For example, participant 1 was involved in the development of the existing BoK LTB concept map. This is perhaps the reason why this participant viewed the BoK concept map-associated image with Novakian-structured concept map semiology more often than the figure with nested container polygons: The concept map semiology in the former figure is more similar to that in the existing BoK LTB concept map than that in the latter. This user study participant perhaps preferred interacting with this concept map semiology because it was similar to that with which he is accustomed.

There are some similarities in eye movement behavior from participant to participant (*figure 7.10*). These similarities are likely due to two factors. First of all, gazes are likely

Figure 7.7: *The Core eye-tracking gazeplot*



to focus on semiology representing concepts and relationships often mentioned in questions user study participants were required to answer when viewing the figures. Secondly, according to Rayner (1998), when reading text, peoples' gazes often focus on passages that are difficult to understand. The same thing could perhaps be true of concept map semiology. If the design of the concept map semiology found in the figures tested in the user study rendered difficult comprehension of this semiology's semantics, gazes of multiple user study participants may concentrate in these places. Unsurprisingly, for all figures excepting that

Figure 7.8: *User study participants' answers to questions "From which of the concept maps was retrieval of knowledge about conceptual relationships easiest?" and "Which of the concept maps was easiest to navigate?"*

BoK			
		Container polygons	Novakian structure
Conceptual relationships	Participant 1		X
	Participant 2		X
	Participant 3	X	
	Participant 4	X	
Navigability	Participant 1		X
	Participant 2	X	
	Participant 3		X
	Participant 4		X

The Core			
		Container polygons	Novakian structure
Conceptual relationships	Participant 1		X
	Participant 2		X
	Participant 3	X	
	Participant 4	X	
Navigability	Participant 1		X
	Participant 2	X	
	Participant 3		X
	Participant 4		X

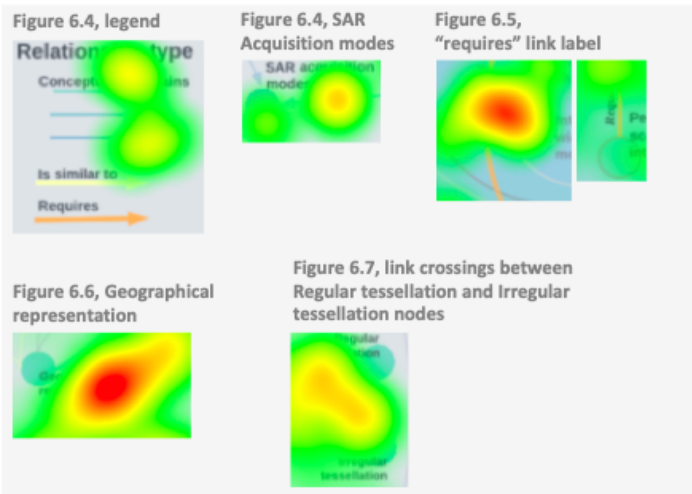
associated with *figure 6.5* (the BoK-associated figure in which container polygons represent conceptual hierarchy), gazes of all participants often focused on the label of the node depicted in the figures as being interacted with. This is likely due to the fact that that the concepts represented by these nodes are found in a large number of questions experiment participants were required to answer. Gazes may not have concentrated as substantially on the label of the container polygon depicted as being interacted with in *figure 6.5* because this label is so large that one does not need to gaze upon it to read it. Interestingly, for the BoK concept map figure, in which conceptual relational hierarchy is represented with a Novakian tree structure, the gazes of user study participants 1,2, and 4 concentrated on the upper left part of the legend but not on the other parts of the legend in this image (*figure 7.9*). This information could perhaps indicate that the design of this part of the legend renders difficult comprehension of the legend's semantics. This may be due a lack of labels in this part of the legend. Adding labels to this part of the legend might mitigate this problem. An additional location of concentrated gazes of multiple study participants in this image is the node representing the concept SAR acquistion nodes (*figure 7.9*). Questionnaire participants were asked to identify how the concepts Principles of inSAR and SAR acquistion modes relate with each other. Perhaps the nearly horizontal orientation of the link indicating that the concept Principles of InSAR conceptually contains the concept SAR acquisition modes makes it difficult to understand this relationship, as all other links in this image representing the conceptual containment relation are nearly vertical in orientation. Other locations of potentially difficult-to-comprehend semiology as indicated concentrated gazes of multiple user study participants are found in the BoK image with container polygons: The interior of the SAR acquisition modes container polygon, particularly around the location of link label "requires" and the link label "requires" located on to the far left side of the side of the "Principles of inSAR" container polygon. Perhaps the sans serif font of the "requires" label is difficult to read and understand. In the figures associated with The Core concept map, a location of concentrated gazes is around the node representing the concept geographical representation. Perhaps the overlap of links representing the "conceptually contains" rela-

Figure 7.9: *Comments made by user study participants during think-aloud*

"I really like it. It is like playing a game." (Referencing the user study generally)
"For some questions I preferred this map, for others I found the other more helpful." (Referencing the figures associated with The Core concept map)
"The right image is easier to navigate because there is less text. It is easier to find the keyword." (Referencing the figures associated with The Core concept map)
"Sometimes the arrows go from right to left, but we read left to right. Adapt the position of the concepts as much as possible to enable reading appropriately when users select a certain concept to focus on." (Referencing the figures associated with The Core concept map)
"The one on the left requires way too much time to digest the principles behind the visualization. I think personally that we should not try to visualize everything in one view but enable a simple selection of different views in much much simpler structures are visible. If you want to show the overall complexity, the left one does it perfectly, but it does not help a user. My preference is the right one, but I actually do not like both." (Referencing the figures associated with the BoK concept map)

tion at the location where the links connect with this node makes it difficult to discern in what direction they extend and therefore difficult figure out which nodes are the destination nodes of the relations. Finally, in the figures associated with The Core concept map, gazes of multiple user study participants concentrate around the space between links representing the conceptually contains relationship that connect the node labelled "Tessellation" with the nodes labelled "Regular tessellation" and "Irregular tessellation." Perhaps the link crossings in this location makes difficult comprehension of the relationships represented by the links.

Figure 7.10: *Locations of multiple user study participants' gaze concentrations*



Chapter 8
Conclusion

Node-link concept maps have the potential to be a powerful learning tool. This study identified the particular form of learning they have the power to facilitate: Thanks to the way their semiology shows how concepts composing a body of knowledge interrelate with each other, concept maps facilitate meaningful learning. A conceptual framework regarding good concept map design was developed integrating the researcher's own ideas with ideas from other scholars. The framework posits that the learning utility of a concept map depends on its semiology's lucid representation of conceptual relationships contained in its semantics and its navigability, and the framework identifies design principles relevant to these two factors. Guided by this framework, efforts are made to improve the learning utility of two existing node-link concept maps by enhancing their designs. The design enhancement process roughly followed usability engineering protocol for good user-centered design. This included user needs assessment, rapid prototyping of new design forms, and user testing of a selection of the new design forms. User testing involved both a questionnaire and an in-person user study.

The user test questionnaire found the prototyped design forms to have good learning utility in some regards: Semiology of all prototyped new design forms were found likely to enable more accurate retrieval of knowledge about conceptual relationships than that of the existing concept maps undergoing enhancement. This finding reveals that design principles relevant to lucid conceptual relationship representation in the researcher's conceptual framework and the researcher's approach to implementing them were likely good. However, the navigability of all but one of the tested new design forms was found to be similar or less optimal than that of the existing concept maps whose design was being enhanced. This finding reveals that design principles relevant to the navigability of concept map semiology in the researcher's conceptual framework and the researcher's approach to implementing them could likely be improved upon. One choice made during the implementation process that may not have been optimal was the decision to increase the number of labelled nodes and links made visible upon an interaction with a node. The ability of an LTB concept map user to view a larger number of nodes than the interacted-with node, links connected to this node, and nodes connected to these links upon interaction may not be as helpful to navigation as theorized. *Figure 6.6*, the one tested design form, whose learning-related disorientation was found to be lower than that of the existing LTB concept map, with which it is associated, was also found to lucidly communicate knowledge about conceptual relationships to particularly strong degree. These findings perhaps invite consideration of the actual implementation of this design form in The Core concept map, the existing LTB concept map, with which the design form is associated.

Within each set of tested design forms was one form that represented conceptual relationships in a way that might be considered innovative for concept map design: In one of the forms with innovative representation, nested polygons were used to represent hierarchical conceptual relational superstructures. In the other, the visual variable of color hue was associatively integrated into the design of links to show variation in the identity of the relationships the links represent, and a legend was used to identify the conceptual relationships signified by the various color hues. The design forms with these innovations were compared with other design forms representing the same semantics but in more traditional ways. The forms with innovative representation were found to have comparable learning utility with regards to lucid communication of knowledge about conceptual relationships as the forms with more traditional representation. This finding invites further research regarding the learning utility of the innovative design forms and perhaps concept map creators' integration of these design forms into their work. The in-person user study found that, when presented with the opportunity to use both of the tested design forms in each set simultaneously while engaged in a learning task, they tend to use both forms. However, the comparative degrees to which each of the compared forms is used and the ways in which they are used varies from person to person. This information indicates that if these LTB concept maps are in fact enhanced in alignment with the prototyped visualizations, users may benefit from having the opportunity to choose one or the other or combinations of particular attributes of one or the other when viewing the visualization. The in-person user study additionally identified spaces on each of the tested design forms where the design of marks may be less than ideal for learning. This finding invites further investigation regarding why the design of marks in these particular places are a hindrance to learning and how their designs could be improved upon to better facilitate learning.

This research project was limited in its exclusive use of navigability and lucid communication of knowledge about conceptual relationships as metrics of the learning utility of a concept map's design. The learning utility of a concept map's design likely also depends on other factors. In order to truly learn something, one must be motivated to do so. Ensuring that concept map designs are enhanced to encourage learner motivation them could prove to be a helpful endeavour. People may be more motivated to learn with a concept map with good aesthetics. Thus, a concept map's learning utility may depend on its aesthetics in addition to its navigability and its lucid communication of knowledge about conceptual relationships. Additionally, in order to truly learn knowledge, this knowledge must be committed to one's memory. Memorability should thus perhaps be another factor considered during the concept map design enhancement process.

Bibliography

Adesope, O. O., & Nesbit, J. C. (2013). Animated and static concept maps enhance learning from spoken narration. *Learning and Instruction*, *27*. https://doi.org/doi.org/10.1016/j.learninstruc.2013.02.002

Ahnert, R., Ahnert, S., Coleman, C., & Weingart, S. (Eds.). (2020). *The network turn: Changing perspectice in the humanities*. Cambrige University Press.

Ahuja, J. S., & Webster, J. (2001). Perceived disorientation: An examination of a new measure to assess web design effectiveness. *Interacting with Computers*, *14*.

Amadieu, F., van Gog, T., Paas, F., Tricot, A., & Mariné, C. (2009). Effects of prior knowledge and concept-map structure on disorientation, cognitive load, and learning. *Learning and Instruction*, *19*, 376–386. https://doi.org/10.1016/j.learninstruc.2009.02.005

Arruarte, A., Elorriaga, J. A., & Herrán, E. (2009). Learning the attachment theory with the CM-ED concept map editor. *Computers & Education*, *52*(2), 460–469. https://doi.org/10.1016/j.compedu.2008.09.015

Ausubel, D. P., Novak, J. D., & Hanesian, H. (1978). *Educational psychology: A cognitive view* (2nd). Holt, Rinehart; Winston.

Ausubel, D. (1968). *Educational psychology: A cognitive view*. Holt, Rinehart; Winston: New York.

Ausubel, D. (2000). *The acquisition and retention of knowledge: A cognitive view.* Kluwer Academic Publishers.

Bertin, J. (1983). *The semiology of graphics: Diagrams, networks, maps* (W. J. Berg, Trans.). The University of Madison Press.

Blake, R., & Holopogan, K. (1985). Orientation selectivity in cats and humans assessed by masking. *Vision Research*, *23*.

Blankenship, J., & Danserau, D. F. (2000). The effect of animated node-link displays on information recall. *The Journal of Experimental Education*, *68*(4), 293–308.

Buckley, P., Hardy, P., & Field, K. (2022). Cartography. In W. Kresse & D. Danko (Eds.), *Springer handbook of geographic information* (pp. 315–352). Springer. doi.org/10.1007/978-3-030-53125-6_13

Burkhard, R. (2004). Learning from architects: The difference between knowledge visualization and information visualization. *Proceedings. Eighth International Conference on Information Visualisation*, *4*, 519–524. https://doi.org/10.1109/IV.2004.1320194

Cañas, A., Carff, R., Hill, G., Carvalho, M., Arguedas, M., Eskridge, T., & Carvajal, R. (2005). Concept maps: Integrating knowledge and information visualization. In S. Tergan & T. Keller (Eds.), *Knowledge and information visualization. lecture notes in computer science* (pp. 205–219). Springer. 10.1007/11510154_11

Cañas, A., Novak, J., Okada, A., & Sherborne, T. (2014). Concept mapping using CmapTools to enhance meaningful learning. In A. Okada, S. Buckingham Shum & T. Sherborne (Eds.), *Knowledge cartography: Advanced information and knowledge processing* (Second, pp. 23–25). Springer.

Card, S. (2007). Information visualization. In A. Sears & J. A. Jacko (Eds.), *Human-computer interaction* (p. 365). Taylor; Francis.

Carpendale, M. (2003). Considering visual variables as a basis for information visualisation. *Department of Computer Science, University of Calgary, Canada, Tech. Rep., 2001-693-16*. http://dspace.ucalgary.ca/bitstream/1880/45758/2/2001-693-16.pdf

Chiou, C., Lee, L., & Liu, Y. (2012). Effect of novak colorful concept map with digital teaching materials on student academic achievement. *Procedia - Social and Behavioral Sciences.*, *64*, 192–201. https://doi.org/10.1016/j.sbspro.2012.11.023.

Colosimo, A., & Fitzgibbons, M. (2012). Teaching, designing, and organizing: Concept mapping for librarians. *Partnership: The Canadian Journal of Library and Information Practice and Research*, *7*(1), 1–15. https://doi.org/10.21083/partnership.v7i1.1800

Conklin, J. (1987). Hypertext: An introduction and survey september 1987, pp. 17-41, vol. 20. *Computer*, *20*, 17–41. https://doi.org/10.1109/MC.1987.1663693

Danserau, D., Dees, S. M., & Simpson, D. D. (1994). Cognitive modularity: Implications for counseling and the representation of personal issues. *Journal of Counseling Psychology*, *41*(4), 513–523. https://doi.org/doi.org/10.1037/0022-0167.41.4.513

Dansereau, D. (2005). Node-link mapping principles for visualizing knowledge and information. In S. Tergan & T. Keller (Eds.), *Knowledge and information visualization. lecture notes in computer science* (pp. 61–81). 10.1007/11510154_4

Drucker, J. (2011). Humanities approaches to graphical display. *Digital Humanities Quarterly*, *5*(1). http://www.digitalhumanities.org/dhq/vol/5/1/000091/000091.html

Eppler, Martin, J. (2006). A comparison between concept maps, mind maps, conceptual diagrams, and visual metaphors as complementary tools for knowledge construction and sharing. *Information Visualization*, *5*(3), 202–210. https://doi.org/10.1057/palgrave.ivs.9500131

Garlandini, S., & Fabrikant, S. (2009). Evaluating the effectiveness and efficiency of visual variables for geographic information visualization. In K. Hornsby, C. Claramunt, M. Denis & G. Ligozat (Eds.), *Spatial information theory. COSIT 2009*. Springer.

Garzotto, F. (2009). Navigation in hypermedia applications: Modelling and semantics. *Journal of Organizational Computing and Electronic Commerce*, *6*(3), 211–237. https://doi.org/10.1080/10919399609540278

Gibson, D. (2009). *The wayfinding handbook: Information design for public places*.

Golledge, R. G. . (1999). *Wayfinding behavior: Cognitive mapping and other spatial processes*. JHU press.

Hanewald, R., & Ifenthaler, D. (2014). Digital knowledge mapping in educational contexts. In D. Ifenthaler & R. Hanewald (Eds.), *Digital knowledge maps in education: Technology-enhanced support for teachers and learners* (pp. 3–15). doi.org/10.1007/978-1-4614-3178-7_1

Harrington, S., Naveda, J., Jones, R., Roetling, P., & Thakker, N. (2004). Aesthetic measures for automated document layout. *DocEng '04: Proceedings of the 2004 ACM symposium on Document engineering*, 109–111. https://doi.org/doi.org/10.1145/1030397.1030419

Head, M., Archer, M., & Yuan, Y. (2000). World wide web navigation aid. *International Journal of Human- Computer Studies*, *53*, 301–330.

Hook, P., & Börner, K. (2005). Educational knowledge domain visualizations: Tools to navigate, understand, and internalize the structure of scholarly knowledge and expertise.

In A. Spink & C. Cole (Eds.), *New directions in cognitive information retrieval* (pp. 187–208). Springer.

Jeffrey, C. (2017). Static and digital wayfinding systems: Can a wayfinding symbiosis be achieved. In A. Black, P. Luna, O. Lund & S. Walker (Eds.), *Information design: Research and practice* (pp. 509–526). Routledge.

Keller, T., & Tergan, S.-O. (2005). Visualizing knowledge and information: An introduction (S.-O. Tergan & T. Keller, Eds.). *Knowledge and Information Visualization*, 1–23.

Krieglstein, F., Schneider, S., Beege, M., & Daniel Rey, G. (2022). How the design and complexity of concept maps infuence cognitive learning processes. *Education Technology Research Development*, *70*, 99–118. `https://doi.org/https://doi.org/10.1007/s11423-022-10083-2`

Kruja, E., Marks, J., Blair, A., & Waters, R. (2001). A short note on the history of graph drawing. In P. Mutzel, M. Jünger & S. Leipert (Eds.), *Graph drawing*. Springer.

Legible. (n.d.). In *Merriam-webster*. Retrieved September 6, 2022, from `https://www.merriam-webster.com/dictionary/legibility`

Li, L. (2015). Development and evaluation of a web-based e-book with a concept mapping system. *Journals of Computers in Education*, *2*, 211–226. `https://doi.org/10.1007/s40692-015-0032-3`

Lynch, K. (1984). Reconsidering the image of the city. In L. Rodwin & R. Hollister (Eds.), *Cities of the mind. environment, development, and public policy*. Springer, Boston, MA.

Lynch, K. (1960). *Image of the city*. MIT Press.

MacEachren, A. (1995). *How maps work*. The Guilford Press.

Mackinlay, J. (1986). Automating the design of graphical presentations of relational information. *ACM Transactions on Graphics*, *5*(2), 110–141. `https://doi.org/doi.org/10.1145/22949.22950`

Montello, D. R. (2001). Spatial cognition. In N. J. Smelser & P. B. Baltes (Eds.), *International encyclopedia of the social & behavioral sciences* (pp. 14771–14775). Oxford: Pergamon Press.

Moore, J. P., Williams, C. B., North, C., & Johri, A. (2013). Promoting conceptual understanding in engineering statics through the use of adaptive concept maps. *ASEE Annual Conference & Exposition*. `https://doi.org/10.18260/1-2--22383`

Morrison, J. (1974). International yearbook of cartography. *International Yearbook of Cartography*, *14*, 115–127.

Munzner, T. (Ed.). (2015). *Visualization, analysis, and design*. Taylor & Francis Group.

Nair, S., & Narayanasamy, M. (2017). The effects of utilising the concept maps in teaching history. *International Journal of Instruction*, *10*(3), 109–126.

Nesbit, J., & Adesope, O. (2006). Learning with concept and knowledge maps: A meta-analysis. *Review of Educational Research*, *76*(3), 413–448. `https://doi.org/10.3102/00346543076003413`

Nielsen, J. (1992). The usability engineering life cycle. *Computer*, *25*, 12–22.

Nielsen, J. (1993). *Usability engineering* (2nd ed.). Academic Press.

Nielsen, J. (2000). Why you only need to test with 5 users. *Nielsen Norman Group*, 206–213.

Novak, J., & Cañas, A. (2006). The origins of the concept mapping tool and the continuing evolution of the tool. *Information Visualization*, *5*(3), 175–184. `https://doi.org/10.1057/palgrave.ivs.9500126`

Novak, J., & Cañas, A. (2010). The universality and ubiquitousness of concept maps. *Proceedings of Fourth International Conference on Concept Mapping*.

Novak, J. (1977). *A theory of education*. Cornell University Press.

Novak, J. (2004). The theory underlying concept maps and how to construct and use them.
O'Donnell, A. M., Danserau, D. F., & Hall, R. H. (2002). Knowledge maps as scaffolds for cognitive processing. *Educational Psychology Review*, *14*(1).
Palmer, S. (1992). Common region: A new grouping principle. *Cognitive Psychology*, *24*(3), 436–441.
Passini, R. (1992). *Wayfinding in architecture*. Van Nostrand Reinhold.
Plotnick, E. (1997). Concept mapping: A graphical system for understanding the relationship between concepts. *ERIC Digest*.
Price, G., & Wright, V. (2012). Aligning web-based tools to the research process cycle: A resource for collaborative research projects. *Journal of Interactive Online Learning*, *11*(3), 121–127.
Rayner, K. (1998). Eye movements in reading and in- formation processing: 20 years of research. *Psychological bulletin*, *124*(3), 372–422. https://doi.org/http://dx.doi.org/10.1037/0033-2909.124.3.372
Roth, R. (2017). Visual variables. In D. Richardson, N. Castree, M. Goodchild, A. Kobayashki, W. Liu, R. Marston, W. Liu & R. Marston (Eds.), *The international encyclopedia of geography* (pp. 1–11). Wiley.
Schölgens, D., Müller, S., Bauer, C., Tilly, R., & Schoder, D. (2016). Aesthetic measures for dcument layouts: Operationalization and analysis in the context of marketing brochures. *Proceedings of the 2016 ACM Symposium on Document Engineering.*, 21–30.
Schroeder, N., Nesbit, J., Anguiano, C., & Adesope, O. (2018). Studying and constructing concept maps: A meta-analysis. *Educational Psychology Review*, *30*, 431–455. https://doi.org/10.1007/s10648-017-9403-9
Schwartz, M. E. (2018). *What is wayfinding? part 2: The city as a model* [RSMDesign news]. https://rsmdesign.com/news/what-is-wayfinding-part-2-the-city-as-a-model
Shakhnov, V., Makarchuk, V., Zinchenko, L., & Verstov, V. (2013). Heterogeneous knowledge representation for VLSI systems and MEMS design, 189–194. https://doi.org/10.1109/CogInfoCom.2013.6719239
Stapleton, G. (2005). A survey of reasoning systems based on euler diagrams. *Electron. Notes.Theor. Comput. Sci., 134, 127-151*, *134*, 127–151.
Steinfeld, E. (2018). Designing a way-finding tool for people with cognitive difficulties.
Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, (22), 123–138.
Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review*, *14*(4), 560–589.
Triesman, A., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review*, *95*, 15–48.
Tünkler, V. (2021). Concept learning and teaching in social studies. In Ö. Akman, F. Atasoy & T. Gür (Eds.), *Education, social, health and political developments in turkey between 2000-2020* (pp. 176–193). ISRES Publishing, International Society for Research in Education; Science (ISRES).
Vaez, S., Burke, M., & Alizadeh, T. (2016). Urban form and wayfinding: Review of cogntive and spatial knowledge for individual's navigation. *ATRF 2016 - Australasian Transport Research Forum 2016, Proceedings*.
Wang, Z., Adesope, O., Sundararajan, N., & Buckley, P. (2018). Effects of different concept map activities on chemistry learning. *Educational Psychology*, *41*(2), 245–260.
Ware, C. (2021). *Information visualization: Perception for design* (Fourth Edition). Elselvier.

Ware, C., Purchase, H., Colpoys, L., & McGill, M. (2002). Cognitive measurements of graph aesthetics. *Information Visualization*, *1*(2), 103–110. https://doi.org/10.1057/palgrave.ivs.9500013

Wiegmann, D., Danserau, D., McCagg, E., Rewey, K., & Pitre, U. (1992). Effects of knowledge map characteristics on information processing. *Contemporary Educational Psychology*, *17*, 136–155.

Wong, C. (2010). Cognitive mapping on user interface design, 288–293. https://doi.org/10.1109/ICCAIE.2010.5735091

Woods, D. (1984). Visual momentum: A concept to improve the cognitive coupling of person and computer. *International Journal of Man-Machine Studies*, *21*, 229–244.

Zhou, N., Chen, X., & Wang, J. (2009). Study on methods of knowledge domain visualization. *International Conference on Innovation Management*, 15–18. https://doi.org/10.1109/ICIM.2009.9.

Appendix A
Needs assessment questionnaire: BoK

4GEO BoK Concept Map Needs Assessment Questionnaire:
K

ed)

Vhat best describes you?

- Geo-information science or earth observation professional with a master's degree in the field
- Professional in another field with a master's degree
- Pursuing formal education in a subject area related to geo-information science or earth observation at the master's degree level or higher.
- Pursuing formal education in a different domain at the master's degree level or higher
- None of the above

ed)

Prior to completing this questionnaire, how strong was your knowledge of earth observation concept **imaging radar**?

Not at all strong	Somewhat strong	Strong	Very strong	Expert
○	○	○	○	○

The node-link concept map communicates that **imaging radar** is a concept of which of the following concepts:

- [ ] Monitor marine
- [ ] Detecting microwaves
- [ ] Microwave portion of electromagnetic spectrum
- [ ] Basics of microwave remote sensing
- [ ] Soil permitivity
- [ ] Types of remote sensing sensors
- [ ] Polarization
- [ ] Antenna footprint
- [ ] Radar antennas and antenna calibration
- [ ] Principles of synthetic aperture radar (SAR)
- [ ] Monitor land
- [ ] Synthetic aperture radar (SAR) geometric configuration

The node-link concept map communicates which of following concepts are requisites of **imaging radar**?

- Monitor marine
- Detecting microwaves
- Microwave portion of electromagnetic spectrum
- Basics of microwave remote sensing
- Soil permitivity
- Types of remote sensing sensors
- Polarization
- Antenna footprint
- Radar antennas and antenna calibration
- Principles of synthetic aperture radar (SAR)
- Monitor land
- Synthetic aperture radar (SAR) geometric configuration

he node labelled **"Types of remote sensing sensors"** is larger than that elled "**Imaging Radar"** because **imaging radar** is a subconcept of **types remote sensing sensors**.

- True
- False

According to the node-link concept map, how do the concepts **imaging** **dar** and **interaction of microwaves with matter** relate with each other?

- **Imaging radar** is a subconcept of **interaction of microwaves with matter**.
- **Interaction of microwaves with matter** is a subconcept of **imaging radar**.
- **Imaging radar** and **interaction of microwaves with matter** are both subconcepts of **basics of microwave remote sensing**.
- **Basics of microwave remote sensing** is a subconcept of both **interaction of microwaves with matter** and **remote sensing**.

According to the node-link concept map, how do the concepts **imaging** **dar** and **physical properties** relate with each other?

- **Imaging radar** is a subconcept of **physical properties**.
- **Physical properties** is a subconcept of **imaging radar.**
- **Imaging radar** and **physical properties** are both subconcepts of **basics of microwave remote sensing**.
- **Basics of microwave remote sensing** is a subconcept of both **imaging radar** and **physical properties**.

ed)

feel lost.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

feel like I'm going around in circles.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

It is difficult to find a node I have previously clicked on.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

Navigating between nodes is a problem.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I don't know how to get to my desired location.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I feel disoriented.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree

I find EO4GEO BoK's node-link concept map navigable when I am using it
earn information.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

What aspect(s) of this node-link concept map enable navigation?

What aspect(s) of this node-link concept map hinder navigation?

Do you have any suggestions for ways EO4GEO BoK's node-link concept p could be improved upon to be more navigable for people learning the rmation the map communicates?

- [ ] Apply different color hues to links representing different relationship types to make the categorical semantic variation more lucid.
- [ ] Remove links labelled "is a subconcept of," enlarge the parent nodes, and place nodes representing subconcepts of the parent nodes inside the parent nodes.
- [ ] Use the active instead of the passive voice in link labels (e.g. "requires" instead of "is a prerequisite of") and reverse the directions in which associated link arrows point.
- [ ] Increase the widths of link lines representing the most important relationships.
- [ ] Vary the size of each node differently from the current logic, which is governed by the number of links connected to the node.
- [ ] When a node is clicked on, make visible more links and nodes than those immediately connected to the clicked-on node.
- [ ] Show labels of links even when a node isn't clicked on.
- [ ] Reduce the number of link crossings.
- [ ] Other - Write In
- [ ] Other - Write In
- [ ] Other - Write In
- [ ] Other - Write In
- [ ] Other - Write In

Appendix B

Needs assessment questionnaire: The Core

e Core of GIScience 2020 Concept Map needs assessment
estionnaire

Vhat best describes you?

- Geo-information science or earth observation professional with a master's degree in the field
- Professional with a master's degree in a different field
- Pursuing formal education in a subject area related to geo-information science or earth observation at the master's degree level or higher
- Pursuing formal education in a different domain at the master's degree level or higher
- None of the above

ed)

Prior to completing this questionnaire, how strong was your knowledge of geoinformation science concept **vector representation**?

Not at all strong	Somewhat strong	Moderately strong	Very strong	Expert
○	○	○	○	○

The node-link concept map communicates that **vector representation** is ed by **vector overlay.**

- True
- False

he node-link concept map communicates that **a discrete field** is modelled a **vector representation.**

True

False

he node-link concept map communicates that a **vector representation** is a d of **area representation**.

True

False

he node-link concept map communicates that a **reclassification** is used **ector representation.**

True

False

he node-link concept map labelled **"vector representation"** is larger than that labelled **"point resentation"** because a **point representation** is a kind of **geographical resentation**.

True

False

According to the node-link concept map, how do the concepts **area representation** and **geographical representation** relate with each other?

- **Geographical representation** is a kind of **area representation**.
- **Area representation** is a kind of **geographical representation**.
- **Vector representation** is a kind of both **area representation** and **geographical representation**.
- Both **area representation** and **geographical representation** are kinds of **vector representation**.

According to the node-link concept map, how do the concepts **Triangulated Irregular Networks (TIN)** and **Tessellation** relate with each other?

- **Triangulated Irregular Network (TIN)** is a kind of **tessellation.**
- **Tessellation** is a kind of **triangulated irregular network (TIN)** .
- **Triangulated irregular network (TIN)** and **tessellation** are both kinds of **geographic representation.**
- **Triangulated irregular network (TIN)** and **tessellation** are both kinds of **vector representation.**

ed)

I feel lost.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I feel like I'm going around in circles.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

It is difficult to find a node I have previously clicked on.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

Navigating between nodes is a problem.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I don't know how to get to my desired location.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I feel disoriented.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

ed)

I find The Core of GIScience 2020's node-link concept map navigable
en I am using it to learn information.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
○	○	○	○	○

What aspect(s) of this node-link concept map's design enable navigation?

What aspect(s) of this node-link concept map's design hinder navigation?

Do you have any suggestions for ways The Core of GIScience 2020's
de-link concept map could be improved upon to be more navigable for
ople learning the information the map communicates?

- [ ] Apply different color hues to links representing different relationship types to make the categorical semantic variation more lucid.
- [ ] Remove links labelled "is a kind of," enlarge the parent nodes, and place nodes representing kinds of the parent nodes inside the parent nodes.
- [ ] Use the active instead of the passive voice in link labels (e.g. "uses" instead of "is used by") and reverse the directions in which associated link arrows point.
- [ ] Increase the widths of link lines representing the most important relationships.
- [ ] Vary the size of each node differently from the current logic, which is governed by the number of links connected to the node.
- [ ] When a node is clicked on, make visible more links and nodes than those immediately connected to the clicked-on node.
- [ ] Show labels of links even when a node isn't clicked on.
- [ ] Minimize the number of link crossings
- [ ] Other - Write In
- [ ] Other - Write In
- [ ] Other - Write In
- [ ] Other - Write In
- [ ] Other - Write In

Appendix C
Follow-up questionnaire: BoK

llow-up questionnaire: BoK

ed)

Vhich of the following best describes you?

- Geo-information science or earth observation professional with a master's degree in the field.
- Professional with a master's degree in a different field.
- Pursuing formal education in a subject area related to geo-information science or earth observation at the master's degree level or higher.
- Pursuing formal education in a different domain at the master's degree level or higher.
- None of the above

ledge retrieval questions

Prior to completing this questionnaire, how strong was your knowledge of geo-information science concept interferometric synthetic aperture radar **SAR)**?

- Not at all strong
- Somewhat strong
- Moderately strong
- Very strong
- Expert

Principles of inSAR, Phase

- **Principles of inSAR** conceptually contains **phase**.
- **Phase** conceptually contains **principles of inSAR**.
- **Principles of inSAR** requires **phase**.
- **Phase** requires **Principles of inSAR**.

Detecting microwaves, Principles of inSAR

- **Detecting microwaves** conceptually contains **principles of inSAR**.
- **Detecting microwaves** is similar to **principles of inSAR**.
- **Principles of inSAR** conceptually contains **detecting microwaves.**
- **Principles of inSAR** requires **detecting microwaves**.

Spotlight, Azimuth Direction

- **Spotlight** requires **Azimuth Direction**.
- **Azimuth Direction** requires **Spotlight**.
- **Spotlight** is similar to **Azimuth direction**.
- **Azimuth direction** is similar to **spotlight**.

Spotlight, Staring spotlight

- **Spotlight** conceptually contains **staring spotlight**.
- **Staring spotlight** conceptually contains **spotlight.**
- **Spotlight** requires **staring spotlight**.
- **Staring spotlight** produces **spotlight**.

Small baseline subset, Phase

- **Small baseline subset** conceptually contains **phase**.
- **Phase** conceptually contains **small baseline subset**.
- **Small baseline subset** and **phase** both conceptually contain **principles of inSAR.**
- **Principles of inSAR** conceptually contains both **small baseline subset** and **phase**.

Principles of inSAR, SAR acquisition modes.

- **Principles of inSAR** conceptually contains **SAR acquisition modes.**
- **SAR acquisition modes** conceptually contains **Principles of inSAR**.
- **Principles of inSAR** requires **SAR acquisition modes**.
- **SAR acquisition modes** requires **principles of inSAR**.

Swath, Stripmap

- **Swath** conceptually contains **stripmap**.
- **Stripmap** conceptually contains **swath**.
- Both **swath** and **stripmap** both conceptually contain **spaceborne platforms and systems**.
- **Spaceborne platforms and systems** conceptually contains both **swath** and **stripmap**.

Principles of inSAR, Spaceborne platforms and systems

- **Principles of inSAR** conceptually contains **spaceborne platforms and systems**.
- **Spaceborne platforms and systems** requires **principles of inSAR**.
- **Principles of inSAR** and **spaceborne platforms and systems** both conceptually contain **stripmap**.
- **Stripmap** conceptually contains both **spaceborne platforms and systems** and **principles of inSAR**.

Staring spotlight, Azimuth direction

- **Staring spotlight** conceptually contains **azimuth direction**.
- **Spotlight** conceptually contains both **azimuth direction** and **staring spotlight**.
- **Staring spotlight** requires **azimuth direction**.
- **Azimuth direction** requires **staring spotlight**.

ived disorientation questions

I felt lost.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I felt like I was going around in circles...

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

It was difficult to find a node I had previously viewed.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

Navigating between nodes was a problem.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I didn't know how to get to my desired destination.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I felt disoriented.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

knowledge retrieval questions

I found retrieval of knowledge about conceptually relationships from the de-link concept map easy.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I found the node-link concept map navigable.

Strongly	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

What aspects of the node-link concept map enable retrieval of knowledge ut conceptual relationships?

What aspects of the node link concept map hinder retrieval of knowledge ut conceptual relationships?

What aspects of the node-link concept map enable
igation?

What aspects of the node-link concept map hinder
igation?

Do you have any suggestions for ways the node-link concept map could
made more navigable and easy to retrieve knowledge from?

Appendix D
Follow-up questionnaire: The Core

sign enhancement: The Core, Legend-Final

luction

Vhich of the following best describes you?

- Geo-information science or earth observation professional with a master's degree in the field.
- Professional with a master's degree in a different field.
- Pursuing formal education in a subject area related to geo-information science or earth observation at the master's degree level or higher.
- Pursuing formal education in a different domain at the master's degree level or higher.
- None of the above

ledge retrieval questions

Prior to completing this questionnaire, how strong was your knowledge of geo-information science concept **tessellation**?

- Not at all strong
- Somewhat strong
- Moderately strong
- Very strong
- Expert

Tessellation, Regular tessellation

- **Tessellation** conceptually contains **regular tessellation**.
- **Regular tessellation** conceptually contains **tessellation**.
- **Tessellation** produces **regular tessellation**.
- **Regular tessellation** produces **tessellation**.

Resolution, Tessellation

- **Resolution** produces **tessellation**.
- **Tessellation** produces **resolution**.
- **Resolution** uses **tessellation**.
- **Tessellation** uses **resolution**.

Tessellation, Surface analysis

- **Surface analysis** produces **tessellation**.
- **Tessellation** produces **surface analysis**.
- **Surface analysis** uses **tessellation**.
- **Tessellation** uses **surface analysis**.

Interpolation, Tessellation

- **Interpolation** conceptually contains **tessellation**.
- **Tessellation** conceptually contains **interpolation**.
- **Interpolation** produces **tessellation**.
- **Tessellation** produces **interpolation**.

Analysis, Raster proximity

- **Analysis** conceptually contains **raster proximity**.
- **Raster proximity** conceptually contains **Analysis**.
- **Neighborhood operations** conceptually contains both **analysis** and **raster proximity**.
- **Raster proximity** and **analysis** both conceptually contain **neighborhood operations**.

Analysis, Automatic reclassification

- **Automatic reclassification** conceptually contains **analysis.**
- **Analysis** conceptually contains **automatic reclassification**.
- **Reclassification** conceptually contains both **analysis** and **automatic reclassification**.
- Both **analysis** and **automatic reclassification** both conceptually contain **reclassification**.

Vector representation, Spatio-temporal data model

- **Vector representation** conceptually contains **spatio-temporal data model**.
- **Spatio-temporal data model** conceptually contains **vector representation**.
- **Vector representation** and **spatio-temporal data model** both conceptually contain **geographical representation**.
- **Geographical representation** conceptually contains both **Spatio-temporal data model** and **vector representation**.

Interpolation, Resolution

- **Tessellation** conceptually contains both **interpolation** and **resolution**.
- **Resolution** and **interpolatio**n both conceptually contain **tessellation**.
- **Interpolation** produces **resolution**.
- **Resolution** produces **interpolation**.

knowledge retrieval questions

I felt lost.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
○	○	○	○	○

When using the node-link concept map to answer the questions on the vious page...

I felt lost.	I felt like I was going around in circles.	It was difficult to find a node I had previously clicked on.	Navigating between nodes was a problem.	I didn't know how to get to my desired location.	I felt disoriented.
○	○	○	○	○	○

I felt like I was going around in circles.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

It was difficult to find a node I had previously clicked on.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I didn't know how to get to my desired location.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I felt disoriented.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

ed)

I found retrieval of knowledge about conceptually relationships from the de-link concept map easy.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

I found the map navigable.

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

What aspects of the node-link concept map enable retrieval of knowledge
out conceptual relationships?

What aspects of the node link concept map hinder retrieval of knowledge
out conceptual relationships?

What aspects of the node-link concept map enable
igation?

What aspects of the node-link concept map hinder
vigation?

Do you have any suggestions for ways the node-link concept map could
made more navigable and easy to retrieve knowledge from ?

Appendix E
User study questions: BoK

er study questions: BoK

ed)

Which of the following best describes you?

- Geo-information science or earth observation professional with a master's degree in the field.
- Professional with a master's degree in a different field.
- Pursuing formal education in a subject area related to geo-information science or earth observation at the master's degree level or higher.
- Pursuing formal education in a different domain at the master's degree level or higher.
- None of the above

ledge retrieval questions

Prior to completing this questionnaire, how strong was your knowledge of geo-information science concept interferometric synthetic aperture radar **SAR)**?

- Not at all strong
- Somewhat strong
- Moderately strong
- Very strong
- Expert

Principles of inSAR, Phase

- **Principles of inSAR** conceptually contains **phase**.
- **Phase** conceptually contains **principles of inSAR**.
- **Principles of inSAR** requires **phase**.
- **Phase** requires **Principles of inSAR**.

Detecting microwaves, Principles of inSAR

- **Detecting microwaves** conceptually contains **principles of inSAR**.
- **Detecting microwaves** is similar to **principles of inSAR**.
- **Principles of inSAR** conceptually contains **detecting microwaves.**
- **Principles of inSAR** requires **detecting microwaves**.

Spotlight, Azimuth Direction

- **Spotlight** requires **Azimuth Direction**.
- **Azimuth Direction** requires **Spotlight**.
- **Spotlight** is similar to **Azimuth direction**.
- **Azimuth direction** is similar to **spotlight**.

Spotlight, Staring spotlight

- **Spotlight** conceptually contains **staring spotlight**.
- **Staring spotlight** conceptually contains **spotlight.**
- **Spotlight** requires **staring spotlight**.
- **Staring spotlight** produces **spotlight**.

Small baseline subset, Phase

- **Small baseline subset** conceptually contains **phase**.
- **Phase** conceptually contains **small baseline subset**.
- **Small baseline subset** and **phase** both conceptually contain **principles of inSAR.**
- **Principles of inSAR** conceptually contains both **small baseline subset** and **phase**.

Principles of inSAR, SAR acquisition modes.

- **Principles of inSAR** conceptually contains **SAR acquisition modes.**
- **SAR acquisition modes** conceptually contains **Principles of inSAR**.
- **Principles of inSAR** requires **SAR acquisition modes**.
- **SAR acquisition modes** requires **principles of inSAR**.

Swath, Stripmap

- **Swath** conceptually contains **stripmap**.
- **Stripmap** conceptually contains **swath**.
- Both **swath** and **stripmap** both conceptually contain **spaceborne platforms and systems**.
- **Spaceborne platforms and systems** conceptually contains both **swath** and **stripmap**.

Principles of inSAR, Spaceborne platforms and systems

- **Principles of inSAR** conceptually contains **spaceborne platforms and systems**.
- **Spaceborne platforms and systems** requires **principles of inSAR**.
- **Principles of inSAR** and **spaceborne platforms and systems** both conceptually contain **stripmap**.
- **Stripmap** conceptually contains both **spaceborne platforms and systems** and **principles of inSAR**.

Staring spotlight, Azimuth direction

- **Staring spotlight** conceptually contains **azimuth direction**.
- **Spotlight** conceptually contains both **azimuth direction** and **staring spotlight**.
- **Staring spotlight** requires **azimuth direction**.
- **Azimuth direction** requires **staring spotlight**.

knowledge retrieval questions

From which of the node-link concept maps you viewed while answering estions 3-11 was retrieval of knowledge about conceptual relationships siest?

Map on the left side of the computer screen	Map on the right side of the computer screen
○	○

Which of the node-link concept maps you viewed while answering estions 3-11 was easier to navigate?

Map on the left side of the computer screen	Map on the right side of the computer screen
○	○

What aspects of the node-link concept map enable retrieval of knowledge out conceptual relationships?

What aspects of the node link concept map hinder retrieval of knowledge out conceptual relationships?

What aspects of the node-link concept map enable
vigation?

What aspects of the node-link concept map hinder
vigation?

Do you have any suggestions for ways the node-link concept map could
made more navigable and easy to retrieve knowledge from?

Appendix F
User study questions: The Core

er study questions: The Core

ledge retrieval questions

Prior to completing this questionnaire, how strong was your knowledge of geo-information science concept **tessellation**?

- Not at all strong
- Somewhat strong
- Moderately strong
- Very strong
- Expert

Tessellation, Regular tessellation

- **Tessellation** conceptually contains **regular tessellation**.
- **Regular tessellation** conceptually contains **tessellation**.
- **Tessellation** produces **regular tessellation**.
- **Regular tessellation** produces **tessellation**.

Resolution, Tessellation

- **Resolution** produces **tessellation**.
- **Tessellation** produces **resolution**.
- **Resolution** uses **tessellation**.
- **Tessellation** uses **resolution**.

Tessellation, Surface analysis

- **Surface analysis** produces **tessellation**.
- **Tessellation** produces **surface analysis**.
- **Surface analysis** uses **tessellation**.
- **Tessellation** uses **surface analysis**.

Interpolation, Tessellation

- **Interpolation** conceptually contains **tessellation**.
- **Tessellation** conceptually contains **interpolation**.
- **Interpolation** produces **tessellation**.
- **Tessellation** produces **interpolation**.

Analysis, Raster proximity

- **Analysis** conceptually contains **raster proximity**.
- **Raster proximity** conceptually contains **Analysis**.
- **Neighborhood operations** conceptually contains both **analysis** and **raster proximity**.
- **Raster proximity** and **analysis** both conceptually contain **neighborhood operations**.

Analysis, Automatic reclassification

- **Automatic reclassification** conceptually contains **analysis.**
- **Analysis** conceptually contains **automatic reclassification**.
- **Reclassification** conceptually contains both **analysis** and **automatic reclassification**.
- Both **analysis** and **automatic reclassification** both conceptually contain **reclassification**.

Vector representation, Spatio-temporal data model

- **Vector representation** conceptually contains **spatio-temporal data model**.
- **Spatio-temporal data model** conceptually contains **vector representation**.
- **Vector representation** and **spatio-temporal data model** both conceptually contain **geographical representation**.
- **Geographical representation** conceptually contains both **Spatio-temporal data model** and **vector representation**.

Interpolation, Resolution

- **Tessellation** conceptually contains both **interpolation** and **resolution**.
- **Resolution** and **interpolatio**n both conceptually contain **tessellation**.
- **Interpolation** conceptually contains **resolution**.
- **Resolution** conceptually contains **interpolation**.

Knowledge retrieval questions

From which of the two concept maps you viewed while answering estions 3-11, was retrieval of knowledge about conceptual relationships siest?

- Map on the left side of the screen
- Map on the right side of the screen

Which of the two node-link concept maps you viewed while answering estions 3-11 was easier to navigate?

- Map on the left side of the computer screen
- Map on the right side of the computer screen

What aspects of the node-link concept map enable retrieval of knowledge out conceptual relationships?

What aspects of the node link concept map hinder retrieval of knowledge out conceptual relationships?

What aspects of the node-link concept map enable
vigation?

What aspects of the node-link concept map hinder
vigation?

Do you have any suggestions for ways the node-link concept map could
made more navigable and easy to retrieve knowledge from ?