Concept Mapping in Ill-Structured Domains:

Using Cognitive Flexibility Theory to Guide Future Design
Abstract

Concept maps are technologies which visually display the organization of knowledge. Traditional concept maps which are characterized by heretical rigidity and generalizability of concept definitions work well in knowledge construction processes in knowledge domains guided by high predictability and structure, but in knowledge domains characterized by unpredictability and whose concepts cannot be universally defined, traditional concept maps may contribute to overgeneralizations and misconceptions. Cognitive flexibility theory (CFT) is a framework for constructing knowledge in ill-structured domains. A feature of cognitive flexibility theory called context sensitive selective highlighting (CSSH) reorganizes how knowledge is conceptualized based on individual contexts rather than an abstract set of rules. I propose that concept maps integrated with the feature of CSSH is a technology that can help to reduce misconceptions and overgeneralizations of concepts in ill-structured domains and help learners develop more flexible patterns of knowledge construction in domains whose concepts are not universally operationalized across all contexts.

Keywords: cognitive flexibility theory, concept mapping, context sensitive selective highlighting, ill-structured domains, mindtools, well-structured domain
Introduction

In education, we often speak of two types of knowledge domains. The first, well-structured domains, are comprised of concepts whose conceptualizations can be abstracted across all situations and can be learned through universal definitions. Concepts in well-structured domains are predictable, unchanging, and orderly. The second, ill-structured domains, are comprised of concepts whose conceptualization cannot be abstracted across situations and are best learned through individual examples rather than universal definitions. Concepts in ill-structured domains are operationalized differently context-to-context (Spiro et al., 1987; Spiro, Feltovich, & Coulson, 1996). In contrast to well-structured domains, ill-structured domains are unpredictable, fluid in operation, and disorderly. Educators of subjects in well-structured domains such as physics can teach concepts using abstract definitions because the characteristics and relationships among concepts in physics (e.g. gravity) are typically constant and predictable across all individual situations. In contrast, educators of subjects in ill-structured domains such as ecology—a science domain in which concepts’ definitions are not universally agreed upon and whose operationalization may change situation-to-situation—may face greater challenges than do teachers in well-structured domains because the concepts being taught cannot be universally operationalized. Unfortunately, ill-structured concepts, which are best understood in situated contexts rather than abstractly, are often taught as if they operate uniformly across contexts, contributing to the formation of reductive biases and misconceptions (Coulson, Feltovich, & Spiro, 1986; Spiro, Feltovich, & Coulson, 1989).

This article suggests a reconceptualization of concept mapping technology and synthesizes three seminal frameworks which together can help explain how to conceptualize
Conceptions in ill-structured domains and potentially reduce misconceptions rooted in over abstraction of concepts. Previous work has explored how technology-enabled learning environments, such as hypertext systems modeled on features derived from cognitive flexibility theory (Spiro, Coulson, Feltovich, & Anderson, 1988), can be designed to decrease analogic errors and reductive bias in medical students (Spiro, et al., 1989). This article builds upon this body of research by exploring how integrating features of cognitive flexibility theory into new forms of concept mapping (Novak, 1984) can help learners build flexible understandings of concepts housed in situated contexts of ill-structured domains. Both Novak’s (1984) framework of concept mapping and Jonassen and Reeves’ (1996) framework of Mindtools are reviewed and considered as guiding perspectives in conceptualizing concept map 2.0.

I provide an overview of cognitive flexibility theory and common knowledge construction errors associated with using learning in ill-structured domains, Next, I discuss Novak’s framework for concept mapping and Jonassen’s framework for mindtools and review relevant literature regarding how mindtools, including concept maps, have been studied in knowledge construction processes. Lastly, I suggest direction for a new type of concept map which integrates guiding principles of cognitive flexibility theory into the structure of concept maps using an example from the ill-structured domain of ecology.

Cognitive Flexibility Theory

Cognitive Flexibility Theory (CFT) is a framework which outlines features of advanced knowledge construction by which learners obtain deep meaning of content material and learn to flexibly apply knowledge in diverse contexts (Spiro et al., 1988). Spiro and Jehng (1990) describe cognitive flexibility in terms of one’s ability to restructure knowledge in order to meet
the demands of changing situations. In other words, CFT emphasizes knowledge construction that is adaptive in order to utilize existing knowledge, specific to unique contexts.

The principles of CFT map well onto learning in *ill-structured domains* (ISDs). By ISDs, I mean domains in which concepts and their relationships to each other hold inconsistent patterns of pertinence and function (Spiro, Vispoel, Schmitz, & Boerger, 1987). An example of an ill-structured domain is the field of *ecology*. Peters (1991) argues that ecology is a domain in which operationalization of concepts and their interrelationships is difficult because of inconsistencies in application and pertinence across individual cases. From this conceptualization of ecology as an ISD (explained in more detail below), CFT would be an appropriate framework with which to guide assumptions for learning subject matter as well as guide design features for concept mapping as a learning aid.

CFT addresses the following knowledge construction deficiencies of learning in ill-structured domains, some of which correspond well to issues of how concepts are defined and operationalized. Ecology is used as an example discipline to explain how learners may experience difficulty constructing knowledge in ill-structured domains.

1. *Oversimplification of complex and irregular knowledge structures*. Treating concepts of a domain as compartmentalized and functioning independent of each other. Ecology contains concepts which may function to different levels of importance depending on specific context. Ignorance of the variability in which concepts are understood case-by-case may contribute to learners conceptualizing phenomena as predictable and static when they are in fact unpredictable and adaptive to specific contexts.

2. *Overreliance on top-down processing*. Much like a traditional concept map in which a knowledge domain is represented hierarchically and highly structured, when faced with problem
solving or analyzing a specific context or case, overreliance on top-down processing causes the learner to apply abstract generic abstractions of a knowledge domain instead of utilizing knowledge derived from the case itself to inform conceptualization.

3. Content-independent conceptual representation. Treating concepts as having universal pertinence and functionality across all contexts. In ecology, learners may conceptualize terms’ relevance and applications as uniform, regardless of situation, dynamic, or environment. Because of difficulties operationalizing concepts, universal definitions of terms is troublesome.

Context sensitive selective highlighting: A feature of CFT

To facilitate content representation discussed above, CFT proposes guiding learners’ knowledge construction in ISDs through *context sensitive, selective highlighting* (CSSH). CSSH refers to situation-specific organization of schemas, organized to individual situations rather than schemas which are prepackaged and generalizable across many situations (Spiro, Klautke, Cheng, & Gaunt, 2017). As a feature of learning aids, such as concept mapping, CSSH allows case specific visual reorganization of concepts and relationships based on pertinence. The theme of CSSH addresses issues of content representation by encouraging the learner to acknowledge ISDs as complex and irregular providing opportunities to construct “bottom-up” understanding of concepts which are difficult to operationalize abstractly or “top-down and allowing the learner to visually observe the flexibility and fluidity of concepts functionalities and significance.

Spiro, Coulson, Feltovich, and Anderson (1988) provided early demonstration of CSSH by creating a hypertext environment—a system of texts which can be navigated through the use of links—called the *Cardio-World Explorer* which linked textbook chapters to situation-specific application. The Cardio-World Explorer allowed medical students to visualize how individual situations require reordering of concept significance. In other words, it insured that learners
realized how situated conceptual knowledge is. Spiro et al. (1988) revealed how CSSH as a feature of learning aids may reduce misconceptions in ill-structured domains using a hypertext system. In this paper, several misconceptions characterized by biases to over rely on analogies were discussed, outlining how oversimplification does not fit well constructing knowledge for ISDs. The findings in Spiro et al. (1988) support the present article’s claim that there is a need to explore how to construct knowledge in ISDs in ways which minimize potential misconceptions due to over-abstract understanding of concepts. This article suggests that concept maps may be able to serve as learning aids in ill-structured domains similar to the Cardio-World Explorer.

**Concept Mapping**

*Concept maps* are visual representations of a person’s or group’s understanding. In other words, they are graphical tools for organizing and representing knowledge (Novak & Canas, 2006). Typically, a map will consist of nodes and links which represent a network of ideas (Novak, 2002; Novak & Gowin, 1984). Davies (2011) describes concept mapping as allowing students to understand the relationships between concepts and the domain to which they belong and that mapping tools such as concept maps have existed for some time but have only recently been come of age in teaching. Well-structured knowledge domains are learned well through traditional concept maps which emphasize generalizability across contexts and high rigidity among concept relationships. Concept maps that are highly rigid and convey generalizability do not work well in ill-structured domains because the relationships between nodes in these domains is dependent on individual contexts. I propose that concept maps which integrate features of CFT such as CSSH can aid in knowledge construction in ill-structured domains. With their potential for visual representation of knowledge, concept maps with CSSH can promote
CFT-based knowledge construction by allowing learners to see how concepts operate differently in different contexts of an ill-structured domain.

Jonassen (1996) pioneered the term *mindtools* which outlines a constructivist perspective to using computer technology to engage users to critically think about the content they are studying. In a 1998 *TechTrends* article, Jonassen, Carr, and Yueh discuss what they call *systems modeling tools* which are categorized under *dynamic modeling tools*. The aim of dynamic modeling tools is to represent dynamic relationships among concepts. Systems modeling tools are a type of dynamic modeling tool which are particularly useful in complex learning in ill-structured domains because of their ability to represent complex mental representations of specific phenomena. Systems modeling tools emphasize the notion that concept relationships are not static, rather they are fluid and dependent on context.

Concept maps have been evaluated as a tool for both assessment and as illustrative construction (Toth, Suthers, & Lesgold 2002). In a study which explored concept mapping as a learning tool, Contrady and Bogner (2012) found that the complexity of students’ concept maps was correlated to their scores on knowledge tests as well as long-term knowledge in difficult subject matter, supporting the notion that concept maps may support learning in ill-structured domains which are often characterized by complex relationships. Concept maps have also been explored as an assessment tool. In a study by Reiska et al. (2015) concept maps were examined as tools for indicating scientific literacy. The study indicated a correlation between concept maps with high quality scientific propositions and high test scores.

**The future: context sensitive selective highlighting concept mapping**

Although concept maps have been shown to be useful for improving knowledge retention and integration (O’Donnell, Dansereau, & Hall, 2002; Nesbit & Adescope, 2006), their
application can be improved to aid knowledge construction. Recent work by Kapricke and Blunt (2011) investigated concept maps as learning aids and suggested that current applications of concept mapping may not be as effective as other knowledge construction strategies such as retrieval. Their findings indicated that students who used concept mapping, traditionally an activity which organizes concepts hierarchically, did not show enhanced performance for verbatim recall and inference questions relative to the students who used retrieval as the main strategy for studying. These results support the notion that well-structured representations of knowledge are not compatible for learning in ISDs and that processes that prompt reconstruction of knowledge may yield higher retention of content as well as improve how that content is applied in later situations.

Glowacka et al. (2013) developed an interactive, adaptive search platform called the Reinforced Learning Retrieval (RLR) system to investigate how visualization of terms may influence the reconstruction of existing knowledge. The RLR provided an interactive concept map which was used to search for a greater quantity, diversity, and quality of knowledge sources. The RLR provided a network of resources based on user-controlled search criteria such as level of interest and level of relevance. In other words, this system is dynamic and context-sensitive, with their results suggesting that learning through a technological medium that represents the pertinence of different sources of knowledge as dynamic is more effective in producing transfer than traditional, hierarchically designed search queries which produced little diversity and almost no context-sensitivity. Their work suggests that a system characteristic of CSSH may improve the diversity and quality of information gathered when constructing knowledge in ISDs.

An example of CSSH maps in the field of ecology. With consideration to previous work which has explored how different visual representation systems of ill-structured knowledge
influence knowledge construction, I propose continued innovation in the form of using CSSH in the technology of concept maps. CSSH concept maps will be capable of reorganizing concepts and concept relationships in an ill-structured domain according to pertinence for individual situations. For example, in ecology, there is no universally agreed upon definition of the term *stability* (Peters, 1991). Stability may mean diversity in terms of quantity of species; rainforests are species rich environments whose climate allows for many species of plants and animals to thrive. Stability may also mean “regular” perturbation or change in population; Colinvaux (1978) illustrates the relationship between the vedalia beetle and cushiony cotton scale, specifically, how the vedalia beetle population rises and falls as it prays on a fluctuating number of cushiony cotton scales. In the case of the vedalia beetle, the existence of their population actually relies on the notion that a small number of cushiony cotton scales will escape predation and find a safe place of hiding to rebuild numbers until the beetle inevitably discovers the scales, thus, continuing the cycle of regular perturbation. A traditional concept map would not be able to capture the situated nuance of the term *stability* because traditional concept maps rely on high rigidity of concept definitions and seek to generalize across situations. A CSSH concept map would list all possible concepts and rearrange itself based on the context of interest. In other words, a concept map integrated CSSH would be programmed to visualize the concept of stability differently in the context of a rain forest compared to the context of the vedalia beetle feeding on the cushiony cotton scale. I believe this flexible visualization of concept relationships is critical in promoting CFT guided knowledge construction in ill-structured domains.

**Implications for research**

The development of concept mapping as a teaching and learning tool for teachers and students provides opportunities for future research in education (Davies, 2011). Though previous
work has investigated concept mapping as an assessment tool (e.g. Akinsanya & Williams, 2004; Reiska et al., 2015), further work must be conducted in order to better understand how testing conditions and prior knowledge may influence how valid concept mapping is as a testing method. Spiro et al. (2017) discusses CSSH as being a potential feature of assessment tools for knowledge in ill-structured domains. Future work interested in assessment of knowledge in ill-structured domains may consider how concept maps with features derived from CFT such as CSSH may or may not serve as valid instruments of assessment.

Because there is a dearth of work which has attempted to integrate CSSH into concept maps, exploratory studies aimed towards developing a clearer model for what a CSSH concept would look like and consist of are needed. In other words, since there is such a small body work of which to test the validity of a CSSH concept map in terms of learning and assessment, preliminary studies must be conducted to shed light on the construction of such concept maps. Another topic for future research to explore is the usability of CSSH concept maps as learning and assessment tools (ICT, 2006), that is, even if researchers develop a model of which to create CSSH concept maps, do students and teachers find these maps helpful in developing and testing knowledge in ill-structured domains?

**Conclusion**

Ill-structured domains consist of concepts which may not be properly defined nor operationalized by abstract definitions nor highly structured representations of concept relationships. Because of this, there is a need in research to better understand how to build and test knowledge in ill-structured domains. Concept maps have existed for some time as visual organizers of concepts in knowledge domains, yet recently they have been increasingly researched in terms of their potential as assessment tools and learning tools. Early work in
Cognitive Flexibility Theory, a framework which has guided research aimed towards learning in ill-structured domains, described context-sensitive selective highlighting (CSSH) which describes the reorganization of concepts’ pertinence and meaning based on individual situations. In order to address the need for more adequate assessment and learning tools in ill-structured knowledge domains, concept maps which derive node and relationship characteristics of CSSH-which has previously shown to reduce misconceptions in ill-structured domains (Spiro et al., 1988)- may be of interest to future researchers in the field of education. Implications of such research would provide a more sound understanding of how learners can construct knowledge in ill-structured domains as well as help to inform teachers how to implement classroom tools, such as concept maps, to promote adequate learning in and provide valid assessment of knowledge housed in ill-structured domains.
References


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