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Article · September 2015

DOI: 10.1177/1541931215591050

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Concept Mapping as a Methodology to Develop Insights on Cognition During Collaborative Information Seeking

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The importance of collaborative information seeking (CIS) during team decision-making is starting to be examined within the human factors community. Without the ability to collaborate to seek and retrieve information, a team cannot make accurate decisions. One area of particular importance to CIS is individual and team cognition. Through previous research, we know that cognition is critical to the performance of many collaborative efforts. Yet, there has been little research on the relationship of cognition to CIS. Consequently, appropriate methods to use and how to use them have not been clearly identified. One useful approach to understanding cognition during CIS is to implement a concept mapping methodology. In this paper, we discuss concept mapping and utilize it in a laboratory study focused on understanding the role of cognition during CIS. Through analysis of CIS oriented individual and team concept maps, we gained insights into how people cognitively perceive CIS.

COLLABORATIVE INFORMATION SEEKING, TEAM DECISION MAKING, & COGNITION

Collaborative information seeking (CIS) is a critical aspect of team decision-making, allowing teams to seek and retrieve needed information to make a correct and accurate decision. Specifically, CIS is defined as "*the study of the systems and practices that enable individuals to collaborate during the seeking, searching, and retrieval of information*" (Foster, 2006). During the team decision-making process it is integral that a team successfully finds information, or it will be difficult to make accurate decisions. Traditionally, CIS has been studied in the information sciences community. Consequently, CIS research has only been minimally investigated from a human factors perspective.

The process of collaboratively seeking information is highly cognitive, and its relationship to team cognition has been previously outlined by McNeese & colleagues (2014). However, a great deal of work still needs to be done to better understand the role of cognition in CIS. We know that individual and team level cognition are directly linked to team decision-making performance (Salas, Cooke, & Rosen, 2008). Therefore, it is vitally important that we not only investigate CIS from a human factors perspective but also the role of both individual and team cognition in CIS.

In order to develop research focused on CIS and cognition, we must first identify appropriate methods. One useful approach to understanding cognition during CIS is to implement a concept mapping methodology. In this paper, we discuss concept mapping methodology and utilize it in a laboratory study focused on understanding the role of cognition during CIS. Through analysis of CIS oriented concept maps, we gained insights into how people cognitively perceive CIS.

CONCEPT MAPPING AS A RESEARCH METHODOLOGY FOR UNDERSTANDING COGNITION & CIS

Concept maps are graphical tools for organizing and representing knowledge (Novak & Cañas, 2006). Joseph Novak created the research concept in 1972 in an attempt to understand changes in children's knowledge of science. Since then, concept mapping has become both an important research topic *and* methodology. Concept maps are a powerful tool that allows researchers to understand an individual or team's cognitive structure and content (Novak & Cañas, 2006). Declarative (knowledge of what) and procedural (knowledge of how) knowledge are both represented within concept maps (Jonassen & Marra, 1994). More specifically, concept maps afford the ability to be specifically aimed at declarative or procedural knowledge.

This study seeks to understand the development of individual and team based declarative and procedural knowledge/cognition within the context of CIS. In addition, this study also explores the development of team processes during CIS. Concept maps have been utilized many times to understand mental models and team mental models (Mohammed, Ferzandi, & Hamilton, 2010). The ability to accurately capture one's cognitive structure has led many to view a concept map as a graphical representation of a mental model.

Traditionally, a concept map consists of many attributes: *Concepts*, *Linkages*, *Propositions, Hierarchy,* and *Cross-links*. In addition, a concept map should be focused on a specific topic. When a person is presented with the task of concept mapping, they must be aware of the topic they are being asked to map. A *focus question* is a question that is given to the concept mapper that clearly specifies the aim and context of the concept map. The content for the map may be given to the concept mapper or the mapper may be asked to produce it.

In this study, concept maps were used to capture participants' cognitive structures and content associated with CIS. The maps focused on both declarative and procedural knowledge collection. Investigating both declarative and procedural knowledge will help us better understand how people think about CIS and explain the cognitive and interactional processes of CIS.

Individual declarative concept maps are an excellent way to capture individual and team level cognition. Declarative concept maps are used to identify and describe declarative

knowledge regarding a topic. Declarative knowledge involves describing and identifying the "what" of a topic, as opposed to the "how". Therefore, in this study, these maps allow for participants to describe what they think about the topic of CIS. The identification of important CIS attributes and the relationships between those attributes are described within declarative concept maps.

Team procedural concept maps are important to understanding both the approach teams take to completing CIS and the development of team cognition during CIS. Procedural knowledge explains the process of how something occurs. In this study, these concept maps help describe how the teams collaboratively sought information. The focus of these maps is the actual CIS process.

METHODOLOGY

Participants

A total of 40 undergraduate student participants completed the study, resulting in 8 teams of triads and 8 teams of dyads. Both dyads and triads were utilized to replicate realistic common team sizes (Salas et al., 1992). Participants reported working on an average of 8 student teams, and indicated being comfortable working within teams.

Pilot Study- Concept Generation

Of the sixteen teams, five were used as pilots (3 dyads and 2 triads). The pilot studies were critical in generating a *parking lot* (concept pool) of concepts that would later be used during the main study to aid with concept mapping.

The "parking lot" concepts were developed after co-located teams participated in a set of CIS tasks. Three separate but related tasks on the topic of finding information pertinent to pancreatic cancer (Task 1- 15 minutes, Task 2 5 minutes, Task 3- 10 minutes) were presented to the teams (more information on tasks can be found in McNeese, Reddy, Friedenberg, 2014). This topic was chosen (and piloted) because it is specific enough to allow teams to find the necessary information to complete the task. After the participants completed their tasks, they identified relevant CIS concepts from the tasks (Langan-Fox & Langfield-Smith 2000). Team members would individually develop as many concepts as they could and then the team would come together and rank them based on importance, eventually identifying the top 15-20 most important concepts.

To understand what concepts were most important across all the teams and to create a parking lot of concepts, two members of the research team analyzed the concepts that each team identified as most important. The researchers did this analysis together because they had to discuss related concepts and synonyms of concepts across all teams. Consequently, a total of 87 concepts were analyzed and a total of 22 concepts were chosen as being most important across all pilot teams- based on overlap across teams. These concepts were used as the parking lot for participants' concept mapping during the main research study.

Main Study Procedure

For the study, participants sat at separate laptops but were in physical proximity to each other. They first completed an informed consent form and demographic survey. After those items were completed, the researchers described the study. After the participants ensured the researchers that they understood the study, the researchers then presented the teams with CIS tasks (same tasks as pilot studies). The work that took place during the CIS tasks was audio and video recorded. After the teams completed the tasks or the time allocated for all the tasks expired, the team members were separated to conduct the next part of the study.

Concept maps and the process of developing them were explained. The participants were given a tutorial on how to produce a declarative concept map relating to choosing a college major. The researchers helped the participants develop a concept map on this topic and then provided feedback on the map. Once the participants were comfortable with concept mapping process, each team member produced an individual declarative concept map.

Participants produced an individual declarative concept map using the focus question being *How would you explain how you view collaborative information seeking?* Participants worked at individual whiteboards and were given the *parking lot* or concept pool produced during the pilot studies. Each participant was explicitly told that they could use as many or as few of the concepts in the pool, and that they could also generate their own concepts. While the participants were given the concept pool, they still had to generate the spatial hierarchy of the map and the named relationships between concepts (propositions). Participants had twenty minutes to complete the individual declarative concept map. Photographs were taken of all the declarative concept maps to help in the data analysis (Figure 1).

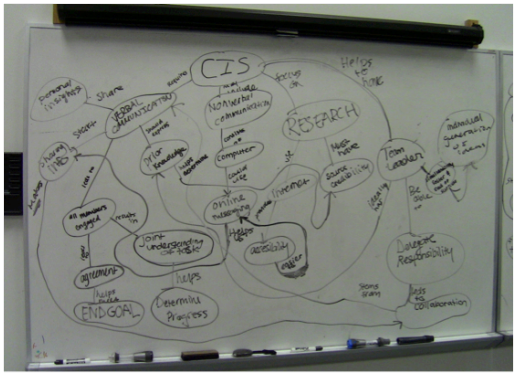

Figure 1: An Individual Declarative Concept Map of CIS

Once all participants produced declarative concept maps, the team came back together to produce a procedural concept map. The focus question for this concept map was *How would you describe the model or process your team used to engage in collaborative information seeking and sharing?* The researchers explained that the team should map their entire CIS process from beginning to end, noting where and when they perceived individual and team cognition to have played a role. The team was given thirty minutes to complete the procedural map. Unlike the individual declarative concept maps, a parking lot was not provided during the team procedural concept mapping. This approach was utilized because the teams had increased time and all the participants were available to help

generate concepts. The team procedural concept mapping process was audio and video recorded. Photographs of the procedural concept maps were also taken. Upon completing the study, each participant was paid a total of $30.00.

ANALYSIS OF INDIVIDUAL AND TEAM CONCEPT MAPS

Individual Declarative Concept Maps

The individual declarative concept maps were analyzed using a quantitative content analysis (Henno & Reiska, 2008). The maps were aggregated and analyzed together for the characteristics of frequency and centrality. Additional measurements- concept count, proposition count, branch point count, linking phrase count, and taxonomy score- were analyzed for each individual map (Cañas, Bunch, & Reiska, 2010). Comparing the most frequent and central concepts across all maps has the potential to help us understand the overall importance of the concepts. This analysis depends primarily on a frequency analysis of the concepts, propositions, and linking phrases in the map. Then, dependent on the frequency counts of each aspect of the map, a taxonomy score is derived (1-5 (5 being high)) indicating the value and strength of the map. This analysis is helpful in understanding and assessing the map's overall quality, but also with assessing the content within the map.

The following steps were taken for the analysis of concept's frequency and centrality across individual maps, team maps, and across all maps. First, after the concept maps were photographed and saved, CmapTools (Cañas et. al., 2010) was used to translate the maps into a digital format. Then using an extension of CmapTools, CMap-analysis, the counts of the concepts in each individual map were reported (Cañas et. al., 2010). Next, each list of concepts from Cmap-analyis was exported and added to a Microsoft Excel spreadsheet. Then, all concepts from each individual's maps were combined and counted for frequency within the specific team. This same process was repeated for all the teams. Once the concepts were counted for frequency at the specific team *and* across all teams level, they were then sorted to identify frequency of concepts from high to low.

After analyzing for frequency, CmapTools was again used to count for centrality. Centrality is defined as the sum of the number of links going into and out of a given concept (Cañas, Bunch, & Reiska, 2010). For each map, CmapTools reports every concept and corresponding numbers of links in and out. The centralities for the concepts were copied into an Excel spreadsheet, totaled for each team, and then totaled for all teams together. The most central concepts not only indicate perceived importance, but also identify how participants cognitively oriented to them in the map. The more central a concept, the more cognitive significance the participant has assigned to the concept.

Team Procedural Concept Maps

The team procedural concept maps were analyzed qualitatively using a method first introduced by Zaff & colleagues (1993), and later adapted by Brewer (2005). The process outlined in this methodology includes multiple steps: (1) transcribing the concept maps to digital, (2) reviewing/editing the maps, (3) coding the maps, and (4) interpreting the maps.

The digital transcription of the concepts maps was completed utilizing CMaps. In addition, videos of the concept mapping were also reviewed. Both the transcripts and videos serve as tools for verifying concepts, ensuring that information is not missing, and ensuring that the map accurately represents what the team meant to describe.

The goal of this analysis is to understand how teams approach CIS and the interactive and cognitive processes used to complete it. Due to the significant variance among and between the concept maps, it was necessary for the maps to have common features across them in order for analysis and comparison to take place. The maps already had one feature that was constant among them, a start to finish line. But in order to analyze the content of the map, the concepts needed to be coded to allow for commonalities across them. The concepts were color-coded based on an iterative process of emerging themes throughout the map. A thematic color-coding method conducted by Brewer (2005) was adapted for this study. Figure 2 shows a team map after it has been thematically color-coded- yellow- resources, red- CIS task, blue- decision-making, purple- information, pink- individual, light blue- team understanding or cognition, orange- process of searching, dark green- presenting information, lime green- collaboration and communication.

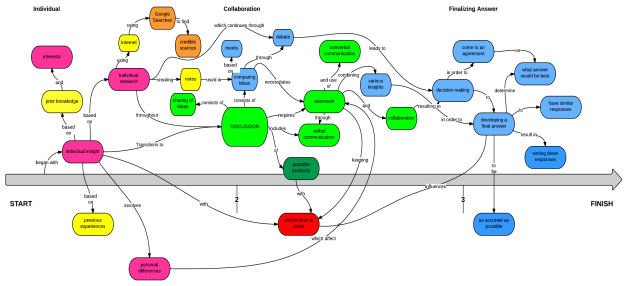

Figure 2: Team Procedural Concept Map After Thematic Color Coding (Zoom in to see concepts)

Once coding is completed, the maps need to be interpreted for meaning. Due to the affordances of a concept map, much information is available for interpretation (concepts, propositions, linkages). The goal of interpreting a concept map should be to summarize the information throughout the map in a way that develops themes. Zaff & colleagues (1993) highlight a means of interpreting the maps by identifying "kernels." A kernel is a cluster of different concepts that are connected or relate back to one important concept. The graphical structure of a concept map helps the researcher to identify important kernels based on spatial proximity. In addition, the color-coding of different concepts aids in the identification of kernels.

In addition to identifying kernels, relationships between important concepts and clusters of concepts can be identified from a procedural concept map to produce overall map themes. This allows the researcher to better understand the procedural nature of work – specifically, in this case CIS work.

The analytical goals for the team procedural maps in this study were to identify critical concepts relevant to CIS, the process of CIS, and themes that occurred within the team concept map. To achieve these goals, the maps were analyzed

for kernels (key concepts/clusters of concepts) and the overall process of CIS based on connected concepts, and the relationships among concepts that led to themes. Each concept map was analyzed using this method and then analysis across all maps occurred to develop overall themes.

FINDINGS: INTERPRETING THE CONCEPT MAPS

Individual Declarative Maps

The quantitative analysis of the individual maps led to significant insights. The analysis found that the individual declarative concept maps were of a high quality with an average of 21 concepts, 24 propositions, and a 3.5 taxonomy score. In addition, the content of the concept maps varied greatly highlighting that the most central concepts varied widely depending on the individual map. The variation of the most central concepts within the map is significant because it identified that at an individual level there was significant variations in the perception and importance of CIS related concepts.

When the analysis of the most frequently used concepts and most central concepts are compared, there are some interesting similarities and differences (Tables 1 & 2-Top 5 only presented due to space constraints).

Concepts (Sorted)	Frequency (# of times concept used across all teams)
Research	24
Internet	22
End Goal	21
Prior Knowledge	20
Agreement	17

Concepts (Sorted)	Centrality (# of links across all teams)
Research	81
Sharing Information	57
End Goal	52
Internet	51
Collaboration	50

Table 1 & 2: Frequency & Centrality of Concept Across All Individual Declarative Maps

First, *research* is the most frequent and central concept across all of the maps. This is not surprising considering that CIS activity is grounded in finding information, which is the basis for research. Yet, it is important to know that participants viewed the activity of research within CIS as being greatly important. In addition to *research*, the concepts of *internet, end goal,* and *prior knowledge* were found in the top five from both the centrality and frequency metric perspective. For the most part, many of the concepts are viewed as being important to both centrality and frequency. While many of the concepts overlapped in regards to frequency and centrality, there were some significant differences.

The differences between the two metrics show that the concept of *sharing information* is viewed quite differently in terms of most frequent and most central. *Sharing information* is the 2nd most central concept, yet the 13th most frequently used concept. This shows a major incongruence between the two metrics and an area of research that needs to be further investigated. There could possibly be a difference in the perception of the concepts importance (frequency) and the actual importance (centrality).

Second, computer based technologies, such as the concepts of *Internet, Computer, Email* and *Online Messaging* were more prevalent in the most frequently used concepts than they were in the most central concepts. This could indicate that the participants perceived these technologies as being more critical and important to CIS than they actually were in reality. Finally, an interesting theme across both metrics of centrality and frequency was how low frequency of the concepts of *collaboration* and *communication*. One would suspect that the role of such concepts would be viewed as being of high importance due to the emphasis on both collaboration and communication being directly linked to *collaborative* information seeking. While they are present in the analysis, they are not as high as many other concepts.

Team Procedural Maps

After all of the team procedural concept maps were individually analyzed for aspects of the CIS approach, themes, and key concepts and kernels, they were then collated, reviewed, and analyzed for findings across all of the maps. Selected findings across all maps are presented below. Due to space considerations, key concepts & kernels are briefly presented.

CIS Approaches

There were 3 main CIS approaches identified and used in the maps. Each team procedural concept map aligned with either an *Individual to Team* (7 teams)*, Team to Individual* (3 teams), or *Team* (1 team) approach.

When detailing the content of each approach, the concept maps made it straightforward to identify what occurred during each approach.

During the *Individual to Team* approach, team members simply start out searching for information on their own to develop background knowledge. They then come together as a team and collaborate to understand the team goals and how to work together. This collaboration then consists of team members constantly communicating and working together in continuous concert or working together individually and occasionally sharing information.

The *Team to Individual* approach simply consisted of the team discussing the task together at the beginning of teamwork. The team then decides on how to approach the task and they divide up the work and work individually while sharing information.

Finally, the *Team* approach is very unique because it consists of team members working together throughout all the tasks, constantly communicating and collaborating. When analyzing the concept maps, this map was much different than any other map due to it being highly unstructured and mainly consisting only of collaborative/ decision-making concepts.

Themes

Strong Relationship Among Collaboration and Decision-Making

The strongest theme identified within the maps is the importance between the collaborative and decision-making

concepts. In almost every map, team members linked collaboration to decision-making. It is clear that participants view collaboration as the main predecessor leading up to the decisions being made during CIS. Most of the team procedural concept maps were very decision-oriented, and the main methodology teams made decisions through was collaboration. Without collaboration, most teams would not be able to make CIS decisions.

Structured and Iterative Nature of CIS Depending on Approach

The team procedural concepts maps did an excellent job of capturing the structured and in some cases iterative nature of CIS work. The structure and iteration depended on the approach that the team used but both aspects of work were apparent in all of the teams except for the team that used the *Team* approach. Teams often mapped out a structure within the overall CIS approach that would indicate that they were building based on previous tasks and information, doing many of the same activities throughout all of the tasks. An example of the iterative nature of CIS is teams often switching back and forth from discussing and collaborating on the task to researching individually. This process is constant throughout many of the maps and represents one of the many ways in which CIS may occur.

Individual Work Within Team Based Work & The Transition Between the Two

There is integration of individual cognition and work within the larger collaborative process. From the maps, it is apparent that there are points in time where team members were working on completing individual tasks during the larger collaborative effort. Depending on the team and the approach, more or less individual work may occur during CIS. But, it was apparent that individual work is critical to the overall activity of CIS. Building on this point, in all of the maps, except for one, there is either the transition to or from individual to team work. The maps help to define when individual or team based work is taking place. In many cases there are blurred lines between the two because a transition is occurring. Another reason for a blurring of the two types of work is due to the continuously iterative switching back and forth between the two during the entire CIS activity.

Important Concepts and Kernels

Important concepts and kernels that appear in many of the team procedural concept maps were *collaborate, communication, discussion,* and *research*.

The concept of collaborate was at the heart of many of the concept maps. It was not only used multiple times, but concepts of similar notions were also frequently used. Numerous other concepts also connect in and out of the concept of collaborate. Its importance in many of the maps can be noted specifically by its frequent use and the centrality of the concept itself within the maps. This was the most important concept in most of the maps.

FUTURE WORK & CONCLUDING THOUGHTS

Due to the power and flexibility of concept maps, multiple different analyses can be conducted on them. We are currently using these existing maps to perform a second analysis, focused on the development of a team mental model specific to CIS. Using the analysis constructed shared mental model (AC-SMM) methodology (Johnson & O'Connor, 2008), we are able to aggregate the individual maps to gather a team map, representative of a team mental model.

In this paper, we have described how concept maps helped us better understand a specific aspect of teamwork, CIS. Using this approach, we gained insights about the importance of multiple CIS related concepts, and their relation to each other. It is our hope that not only do these results shed more light on the cognitive aspects of CIS, but that this paper also explains how concept maps are a useful methodology for capturing such data.

ACKNOWLEDGEMENT

This work was supported by NSF grant 0844947. We would also like to thank our participants for their time.

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