THE ROLE OF TEAM COGNITION IN COLLABORATIVE INFORMATION SEEKING
DURING TEAM DECISION-MAKING

A Dissertation in
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by
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Team decision-making is a process composed of many activities. One important activity is collaborative information seeking (CIS). CIS takes place when “two or more individuals work together to seek needed information in order to satisfy a goal” (Karunakaran & Reddy, 2012). Consequently, CIS can play an important role in team decision-making. Current CIS research has focused on (1) examining the social and interactional aspects of CIS in organizational and other settings and (2) developing technical approaches to support CIS activities. However, most CIS research has overlooked the cognitive aspects of CIS. In particular, there is little research examining CIS from a team cognitive perspective.

Often, the development of team cognition positively improves the team decision-making process (Cooke et al., 2003). Specifically, the development of team mental models, a team cognitive construct, has often been identified as a way to help teams complete their work (Lim & Klein, 2006). However, the relationship of CIS and team cognition has never fully been explored.

In this dissertation, my four main research objectives were to (a) explore how teams approach CIS; (b) develop a conceptual understanding of team cognition during CIS; (c) understand the impact and affect of a co-located and distributed setting on team’s CIS approaches and the development of team cognition, and (d) develop design guidelines for information technologies that will support multiple CIS approaches and the development of team cognition during CIS. To meet my research objectives, I conducted two separate qualitative laboratory studies of undergraduate student teams engaged in multiple CIS tasks. The first study focused on co-located, synchronous CIS. In this study, I utilized qualitative methods such as cognitive interviews, observations, and concept mapping to examine how teams approached CIS and to identify if and how team cognition developed during CIS activities. The second study examined teams using a collaborative system in a distributed, synchronous CIS environment. The second study employed cognitive interviewing to investigate CIS approaches and team cognition in the distributed environment.

Through these studies, I make contributions to three different research fields – (1) Human Factors, (2) Information Sciences, and (3) Computer Supported Cooperative Work. Specifically, I (1) identify different approaches that teams take to CIS, (2) explain the role and development of team cognition in CIS, and (3) describe how teams approach CIS and develop team cognition in both the co-located and distributed environments. Through this research, I hope to further our
empirical understanding of CIS especially in regards to cognition. I also hope to provide some design guidance for the development of more effective CIS tools that account for the role of team cognition.
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*It’s always too early to quit. Persevere.*
Chapter 1

Introduction

This chapter introduces the real world problem and research gaps that motivate this dissertation. The research objectives and questions of this dissertation are also presented. In addition, I outline the research approach I utilize to answer my research questions. Finally, a detailed overview of each chapter is presented.

1.1 Problem Motivation

Team decision-making is a highly complex process dependent on multiple steps. Within the overall team decision-making process, collaborative information seeking (CIS) is an important component that begins early in the process and continues throughout the entire process. CIS refers to the activity of a team collaborating to search for information (Foster, 2006). The process of CIS is important to the team’s effectiveness, efficiency, and overall success. If a team fails to find appropriate information, it is likely they will also fail addressing the initial task or problem. There are many factors that can potentially impact the success of a team’s CIS activity; yet one significant issue that has not yet been explored in CIS research is team cognition. Team cognition research indicates that the development of team cognition positively improves the team decision-making process (Cooke et al., 2003). Specifically, the development of team mental models, a team cognitive construct, has been identified as a means to increase team performance (Lim & Klein, 2006). However, the relationship of CIS and team cognition has never fully been explored. The following two scenarios illustrate the impact team cognition and team mental models can have on CIS:

Two separate teams of three people are working on a project that requires them to address a specific problem. In order to solve the problem and provide adequate answers the teams must find specific information relevant to the problem. Each of these teams is identical in that they have the same knowledge level, experience, and technology available to them.

Team 1 begins a project attempting to identify what information needs to be found in order to successfully address the problem. Each team member presents the
information that he or she perceives as being important to the problem. Unfortunately, all three members perceive the problem differently. This results in each team member suggesting searches for different information. The team attempts to discuss and work through their differences, but fails to come to a consensus. This results in the team separating and individually searching for information based on what they individually feel is the correct way to solve the problem. Eventually, the team comes back together and reports their findings. They try to discuss the found information in an attempt to move forward with their search but still have difficulties. Each team member is again adamant that they are correct in their perception of the problem and their individual search. They ignore each other’s ideas and refuse to accept a plan that would move the team forward. The team eventually fails to find the correct information and does not address the problem within the given time constraint.

Team 2 starts a project by reviewing the problem together. Each team member explains how he or she perceives the problem. Two of the team members view the problem the same but the third member struggles to understand it. The two team members that already understand the problem work together to help their team member understand it. Over time, the third team member gains an understanding of the problem. Consequently, the team now collectively views and understands the problem in the same way. Next, the team discusses what information they should seek to address the problem. While each team member has different ideas, the team works through all of the ideas. They listen to each other justify their ideas. Eventually, the team develops a common understanding of the information needed to successfully address the problem. Next, the team articulates how they want to search for information. They quickly decide that they will each take a specific part of the problem and search individually for information relevant to it. The team makes it clear that while they are individually searching for information they will constantly share what they are finding. Over time they become so comfortable working together that they begin to anticipate what each other is doing, leading to less explicit communication within the team. This results in the team quickly finding the correct information needed to address the problem within the given time constraint.

The above scenarios are based on two separate teams that participated in one of the studies highlighted in this dissertation. One team efficiently found the correct information while the other team never found the information needed to address the problem. Simply, one team successfully collaboratively sought information and the other did not. Why? A significant reason why team 2 was more successful in CIS was due to the development of team cognition. Team 2 worked towards developing a shared understanding of the problem, the information needed, and how to search for information. This allowed the team to effectively find and share information, resulting in successful CIS. In contrast, team 1 never developed a shared understanding and this was one of the main reasons why team 1 was unsuccessful in their CIS activities.

Exploring CIS and team cognition raises many questions: Does team cognition develop during CIS? How does it develop? Does a team mental model develop within the context of CIS? How are teams approaching CIS and what affect does that have on team cognition? What affect
do co-located and distributed settings have on these questions? These are some of the questions that this dissertation addresses.

CIS is a critical aspect of the team decision-making process. If a team fails to find the correct information needed to solve a problem, they might not be able to successfully complete the decision-making process. Consequently, we need to better understand the CIS process - in particular the cognitive aspects of CIS. In this dissertation, I examine the role of cognition in CIS with a particular focus on team cognition.

1.2 Research Motivations

This dissertation focuses on multiple research areas. I will briefly describe the gaps within the team decision-making, collaborative information seeking, and team mental models research areas.

Team Decision-Making

Team decision-making grew from the research domain of individual decision-making. Within individual decision-making, information seeking is often explicitly acknowledged as a fundamental step within the decision-making process (Simon, 1960; Mintzberg et al., 1976; Klein & Zsambok, 1997). Yet, the team decision-making literature often does not explicitly account for CIS. In Chapter 2, three of the best known team decision-making models/theories are reviewed, focusing on the role of information and CIS within them: Functional Theory of Group Decision-Making (Gouran & Hirokawa, 1996), Multi-level Theory of Team Decision-Making (Hollenbeck et al., 1995), and Macrocognition in Teams Model (Fiore, et al., 2010). Within these theories/models, information is clearly important, especially in the beginning phases of each theory/model. Yet, while information is mentioned many times, the process of how the team is seeking or gathering information is never described. These models are very comprehensive and outline many processes in detail but surprisingly do not account for CIS. If we seek to understand team decision-making at an in-depth level, then we must acknowledge and study the importance of CIS within the overall process of team decision-making.

Collaborative Information Seeking

Traditionally, information seeking has been researched at the individual level (Shah, 2010b). Yet, as work and organizations have become more collaborative (Karsten, 1999; Reddy & Dourish, 2002) the realization to study information seeking from the team or organizational level has
become apparent. This resulted in a domain of research referred to as collaborative information seeking (CIS). One of the most widely used definitions comes from Foster (2006) who defines CIS as “the study of the systems and practices that enable individuals to collaborate during the seeking, searching, and retrieval of information.” CIS is a recent research area, which helps explain why little is known about the actual steps that make up the CIS process or how people approach CIS. While researchers have often identified how teams go about finding information, very few have attempted to articulate the step-by-step process of CIS. This has resulted in very few models of CIS being found within the research (Reddy & Jansen, 2008; Shah, 2009).

CIS has been examined primarily through two broad streams of research - (1) understanding the social and interactional aspects of CIS in organizational and other settings (Reddy & Jansen, 2008) and (2) developing technical approaches to supporting CIS activities (i.e. SearchTogether (Morris & Horvitz, 2007), Cerchiamo (Golovchinsky et al., 2008) CoSense (Paul & Morris, 2009), Coagmento (Shah, 2010a)). Through this research, we have a better understanding of CIS activities in a variety of different domains including health (Reddy & Spence, 2008), education (Hyldegård, 2006), and web search (Morris, 2013). We are also learning about particular details of CIS such as what triggers CIS activities (Reddy & Jansen, 2008), what set of features best support CIS activities (Shah, 2012), and the challenges that individuals face in managing CIS activities. Both the social and technical perspectives have been influential in describing what takes place in terms of interaction between collaborators during CIS activities. As we develop a better understanding of the interactional aspects of CIS, we must also start to examine the cognitive aspects of CIS. In particular, we need to understand CIS from a team cognitive perspective. Understanding team cognition within CIS has the potential to further our understanding of why and how CIS occurs. Consequently, to develop a full understanding of CIS, we must understand the cognitive as well as the social and technical issues related to CIS. While researchers acknowledge cognition as being influential and important (Shah & González-Ibáñez, 2011), it has not been the primary focus of CIS research.

Team Mental Models
The construct of a team mental model grew out of an individual mental model. A mental model is a cognitive representation that allows individuals to describe, predict, and explain knowledge and behavior (Norman, 1983). Team mental models are “team members’ shared understandings and mental representations of knowledge about key elements of the team’s relevant environment” (Klimoski & Mohammed, 1994; Mohammed & Dumville, 2001). The overlying assumption of
team mental model research is that teams who possess strong mental models will be more effective and perform at a higher level (Cannon-Bowers, Salas, & Converse, 2001). Team cognition and team mental models have been studied in both co-located and distributed settings with mixed results. Many researchers have argued that there is no single team mental model shared among teammates, rather multiple mental models exist and are shared among teammates at any given time throughout the team decision-making process (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994). Knowing that a team mental model consists of many specific models raises the question of whether there is a team mental model specific to the context of CIS. To this point, no one has ever explored the relationship between team mental models and CIS.

1.3 Research Objectives

The four main research objectives of this dissertation study are to (a) explore how teams approach CIS; (b) develop a conceptual understanding of team cognition during CIS; (c) understand the impact and affect of a co-located and distributed setting on team’s CIS approaches and the development of team cognition, and (d) develop design guidelines for information technologies that will support multiple CIS approaches and the development of team cognition during CIS.

The four main research questions that will address the objectives of this study and the gaps in the research are:

RQ1: What are the different team approaches (cognitive) of CIS?
   (a) How does a co-located and distributed environment affect the approaches?

RQ2: Does team cognition develop within the different approaches identified within RQ1?
   (b) How does team cognition develop during the approaches?
   (c) What specific cognitive activities take place that help develop team cognition during CIS?
   (d) How does a co-located and distributed environment affect the development of team cognition during CIS?

RQ3: Within team cognition, does a team mental model develop within the context of CIS in a co-located and distributed setting?

RQ4: How can knowledge about CIS approaches and CIS specific team cognition be used to support development of CIS tools and systems?
Each of these research questions is built on existing research gaps. Table 1 below links the research questions to the specific research gap.

<table>
<thead>
<tr>
<th>Research Gaps</th>
<th>Research Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is a lack of understanding regarding specific step-by-step approaches in which teams collaboratively seek information. (Shah, 2009; Evans &amp; Chi, 2008; Reddy &amp; Jansen, 2008)</td>
<td>RQ1: What are the different team approaches (cognitive) of CIS?</td>
</tr>
<tr>
<td></td>
<td>-How does a co-located and distributed environment affect the approaches?</td>
</tr>
<tr>
<td>The main focus in CIS research has been on the social interaction that takes place during the process and the development of technical advances. Therefore, the relationship between team cognition and CIS has very rarely been looked at. (Karunakaran &amp; Reddy, 2012; Reddy &amp; Jansen, 2008)</td>
<td>RQ2: Does team cognition develop within the different approaches identified within RQ1?</td>
</tr>
<tr>
<td></td>
<td>-How does team cognition develop during the approaches?</td>
</tr>
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<td></td>
<td>-What specific cognitive activities take place that help develop team cognition during CIS?</td>
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<td></td>
<td>-How does a co-located and distributed environment affect the development of team cognition during CIS?</td>
</tr>
<tr>
<td></td>
<td>RQ3: Within team cognition, does a team mental model specific to CIS context develop in a co-located and distributed setting?</td>
</tr>
<tr>
<td>The literature has often identified that a team mental model consists of multiple models. No one has explored if a team mental model exists during CIS. (Mohammed, Ferzandi, &amp; Hamilton, 2010; Lim &amp; Klein, 2006)</td>
<td>RQ3: Within team cognition, does a team mental model specific to the context of CIS develop in a co-located and distributed setting?</td>
</tr>
<tr>
<td>Many CIS tools and systems have mainly considered how people interact during the process of CIS. Future design needs to consider the impact of both interaction and team cognition during CIS. (Shah &amp; González-Ibáñez, 2011; Morris &amp; Horovitz, 2007; Capra, et al., 2012)</td>
<td>All RQs</td>
</tr>
<tr>
<td>The settings of both co-located and distributed have been studied in both CIS and team cognition. Yet, the affect of each setting is not known on different CIS approaches or the development of team cognition during CIS. (Golovchinsky et al., 2008; Hansen &amp; Järvelin, 2005; Shah 2010b)</td>
<td>All RQs</td>
</tr>
</tbody>
</table>

Table 1. Research Gaps and Research Questions
1.4 Research Approach

To address the research gaps and answer the research questions, I conducted two separate qualitative laboratory studies of undergraduate student teams engaged in multiple CIS tasks. The first study focused on co-located, synchronous CIS, while the second study examined distributed, synchronous CIS. The motivation for conducting two studies in different settings was to understand the impact that the different contexts would have on CIS activities. There are a variety of differences between these two settings and the impact they could potentially have on how teams approach CIS and develop team cognition is important to understand. Understanding CIS and how team cognition develops in a co-located setting could be completely different when the context changes to a distributed environment. The differences are critical and important to understand.

I specifically choose undergraduate students as my population to study in both studies because they actively participate in CIS on a regular basis. In recent years, undergraduate classes have increased the amount of required team-related activities. Therefore, due to the increased teamwork, undergraduate students routinely collaborate to seek information. Their experience with CIS will allow me to focus on the approaches of CIS and how team cognition is developed, rather than explaining to the participants how to collaboratively seek information.

Below I highlight the two studies:

**Study 1:** The first study consisted of teams of two or three participants participating in a lab-based CIS study. The first step consisted of the team completing multiple CIS tasks in a synchronous, co-located environment. I used the tasks to understand the approaches utilized to collaboratively seek information. In addition, I also attempted to understand how team cognition developed during the CIS tasks. I used qualitative methods, specifically knowledge elicitation methods, such as cognitive interviewing and concept mapping to help answer the research questions. Cognitive interviewing allows individuals to explain their thought process by revisiting specific instances in time. These interviews helped me both understand the process of CIS, as well as the development of team cognition.

Another powerful research tool for understanding an individual or team’s cognitive structure and content is concept maps (Novak & Cañas, 2006). Declarative (knowledge of what) and procedural (knowledge of how) knowledge are both represented within concept maps.
Concept maps can also be specifically aimed to be a declarative map or a procedural map (both were collected in this study). Concept mapping allows researchers to capture data that will lead to understanding this study's objectives. Specifically, concept maps have been utilized many times to understand mental models and team mental models (DeChurch & Mesmer-Magnus, 2010; Johnson, 2005; 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. A full explanation of the research methods can be found in Chapter 3.

**Study 2:** The second study consisted of two team members participating in a lab-based study similar to study 1. The main difference in this study and study 1 was the context of use – Study 2 was done in a distributed setting and utilized the CIS system Coagmento (Shah, 2010a). All communication and CIS teamwork occurred through Coagmento. Participants were given the same tasks as in study 1 with the same amount of time. After the CIS tasks were completed, the participants participated in a cognitive interview. A complete description of this study’s research methods can be found in Chapter 6.

**1.5 Dissertation Overview**

The remainder of this dissertation is as follows:

- **Chapter 2 Background**- This chapter provides a review of team decision-making research, team cognition and team mental model research, and individual and collaborative information seeking research. For each domain of literature, the review is focused on theoretical issues and empirical findings.

- **Chapter 3 Study 1- Co-located: Study Design and Methodology**- In this chapter, I describe study 1’s research design, specifically focusing on the procedures of the study. In addition, data and analysis methods are outlined.

- **Chapter 4 Study 1- Findings: Understanding CIS Approaches and The Development of a Team Mental Model in a Co-located Environment**- This chapter
highlights the main findings of Study 1. Specifically, approaches to CIS, CIS team cognitive activities, and the development of a team mental model within the context of CIS are presented.

- **Chapter 5 Study 1- Co-located Discussion** - This chapter discusses the analysis presented in Chapter 4. Areas of focus within the chapter are: the development of team cognition in CIS, the implications of different approaches for CIS, design recommendations for aiding CIS and the development of team cognition, and methods for measuring team cognition during CIS.

- **Chapter 6 Study 2- Distributed: Study Design and Methodology** - In this chapter, I start by presenting literature relevant to the distributed setting and CIS / team cognition. I then describe study 2’s research design, specifically focusing on the procedures of the study and the Coagmento system. In addition, data and analysis methods are outlined.

- **Chapter 7 Study 2- Findings: CIS Approach and Team Cognition Development in Distributed Environment** - This chapter highlights the main findings of Study 2. Specifically, approaching CIS in a distributed setting, a team mental model of distributed CIS, and Coagmento’s impact on CIS and team cognition are presented.

- **Chapter 8 Study 2- Distributed Discussion** - This chapter discusses the analysis presented in Chapter 7. Specifically, I highlight the conflicted perspectives regarding CIS in the distributed medium. I also outline specific design recommendations aimed at improving aspects of Coagmento.

- **Chapter 9 Connecting the Studies: Co-located and Distributed CIS** - In this chapter, I review both studies by highlighting the similarities and differences between the co-located and distributed setting. The impact of each setting is explored through the utilization of multiple CIS approaches and the development of team cognition.

- **Chapter 10 Conclusion** - In concluding, I outline the contributions of this dissertation, indicate future research agendas, and present a final concluding remark on the work presented within the dissertation.
Chapter 2

Background

In this chapter, I draw on multi-disciplinary research from the fields of Human Factors (HF), Information Sciences (IS), and Computer Supported Cooperative Work (CSCW). This chapter is divided into three main sections- (1) Theories/Models of Team Decision-Making, (2) Team Cognition and Team Mental Models, and (3) Collaborative Information Seeking (CIS).

The first section describes team decision-making by reviewing three prominent theories and models: Functional Theory of Group Decision-Making (Orlitzky & Hirokawa, 2001), Multi-level Theory of Team Decision-Making (Hollenbeck et al., 1995), and Macrocognition in Teams Model (Letsky et al., 2007). These theories and model are often identified as the most widely regarded and cited perspectives on team decision-making. Within each theory/model the role and importance of information is identified within the overall decision process. Each theory/model will be reviewed with specific focus on the role of information and CIS. Information seeking has long been viewed as a fundamental process within the overall individual decision-making process. Yet, while information seeking is explicitly acknowledged as being important within individual decision-making literature, its importance is less emphasized within the three models that are reviewed.

In the second section, a brief overview of team cognition is presented. Then, a more in-depth review on the team cognition construct known as a team mental model is provided. Team cognition, and specifically team mental models, are often identified as positively influencing team decision-making (Cannon-Bowers, Salas, Converse, 1993). Within this section, the conceptualization, development, measurement, and empirical findings of the team mental model construct will be reviewed. In addition, the relationship of team mental models and CIS will be explored.

Finally, the third section will outline research on CIS. The conceptualization, development of models, and empirical results of CIS will be explored. Traditionally, CIS has focused on two streams of research- social and technical- lacking team cognitive work. In addition to a review of the social and technical streams, a review of cognitive research in CIS will
be presented. Also, a review of the role of cognition within individual information seeking will be presented.

2.1 Team Decision-Making

The aim of this section is to provide a high-level understanding of team decision-making by reviewing three of the most prominent team decision-making theories/models: Functional Theory of Group Decision-Making (Orlitzky & Hirokawa, 2001), Multi-level Theory of Team Decision-Making (Hollenbeck et al., 1995), and Macrocognition in Teams Model (Letsky et al., 2007). A secondary goal of this section is to describe the role information plays within each theory/model. Information is an important component of each of these models, but information seeking is often not explicitly acknowledged. Information sharing is often identified as an overall step within the team-decision making process, yet little emphasis is put on information seeking.

This gap in the theories/models is important because teams may have difficulty completing the decision-making process without seeking and retrieving information to solve their problems. Yet, even knowing this, these widely respected theories/model do not explicitly mention the role of CIS. Searching for and finding information is often left unidentified within many team decision-making theories/models.

2.1.1 Teams: What are they?

A team is more than a collection of people. A team is a “social entity composed of members with high task interdependency and share valued common goals” (Dyer, 1984). This definition has been utilized and revised many times, most notably by Salas and colleagues (1992) who defines a team as "a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common and valued goal/object/mission, who have each been assigned specific roles or functions to perform, and who have a limited life span of membership". By these definitions, a team can take forth many characteristics, goals, and attributes. In its most simple definition, and the definition this dissertation utilizes, a team is two or more people working together to solve a common goal.
Many researchers have discussed the differences between teams and groups. Teams and groups often share many characteristics and dynamics that lead some to couple them into the same category but they should not always be classified in the same manner. The characteristics and dynamics shared between the two often result in related performance, yet it’s important to acknowledge that although all teams are groups, the converse is not always true (Connors, 2006; Klimoski & Mohammed, 1994). Teams are a subset of the larger identification that is groups. Teams, as opposed to many groups, may have multiple, different responsibilities and roles (Cannon-Bowers, Salas, & Converse, 2001; Cooke et al., 2004). Because team members have many specific roles and responsibilities, they are better utilized to solve and work on complex tasks (for example: emergency command and control, disaster relief, and emergency surgery).

Teams can be viewed as a highly specialized group.

Now that the concept of a team has been explained, prominent theories of team decision-making will be presented.

### 2.1.2 Functional Theory of Group Decision-Making

The functional theory of group decision-making is mainly focused on the outcomes that result from human interaction and the processes that must take place in order for the group to be considered effective. The basis of the theory is rooted in the decision-making work of John Dewey (functional psychology), Robert Bales (interaction process analysis), and Irving Janis (groupthink). Taking from the functional approach to groups, this theory assumes the following:

1. Groups are goal oriented,
2. performance and behavior within a group varies and can be evaluated,
3. the interaction processes of the group vary and can be evaluated,
4. various internal and external factors influence the groups performance outcomes through interaction processes (Fiore et al., 2010; Hollingshead et al., 2005).

These assumptions have led the functional theory of group decision-making to only focus on explaining how groups are effective at coming to decisions. The effectiveness of groups accounts for why some groups make better decisions than others. The functional theory of group decision-making maintains that effective group decision-making is based on a set of functions to
satisfy a set of critical task requirements (Gouran & Hirokawa, 1996; Hirokawa, 1980; Orlitzky & Hirokawa, 2001). In other words, effectiveness or performance of the group is dependent on their ability to carry out the interactions or communication needed to meet the required tasks and sub-tasks. The variation in each group’s interaction and communication can explain why different groups perform better or worse on certain tasks. Specifically, the amount and quality of group interactions directly affect how successful the group is in completing critical task requirements (Fiore et al., 2010).

Similar to many theories, the functional theory of group decision-making has changed over time. Most research pertaining to the functional theory of group decision-making focuses on the group’s abilities to satisfy five functions during the group decision-making interaction (Orlitzky & Hirokawa, 2001). The following five functions are thought to be the most critical functions for effectiveness and success during group decision-making (Hirokawa, 1985; Orlitzky & Hirokawa, 2001).

**Problem Analysis**- The group must develop a thorough and accurate understanding of the problem presented to them. Utilizing the information given to the group, the group must develop an understanding of: a) the nature of the problem, b) the extent, criticality, and seriousness of the problem, c) the likely causes of the problem, d) consequences of not solving the problem.

**Establishment of Evaluation Criteria**- The group must understand and define what a successful response to the problem is. Part of this process involves the group understanding standards by which alternatives (choices) will be judged and a satisfying response is selected.

**Generation of Alternative Solutions**- The group must develop realistic alternatives to the presented problem. This must not only be one alternative decision choice, rather many that are considered to be realistic for the situation. Ultimately, one of the alternative solutions needs to be assumed to be the correct solution.

**Evaluation of Positive Consequences of Solutions**- The group must understand and analyze the positive merits of each developed alternative solution. Since there will be multiple alternatives and multiple opinions of the positive merits of each, this is a critical moment within the group decision-making process.

**Evaluation of Negative Consequences of Solutions**- Much like the evaluation of positive merits for each alternative, the group must also weigh the negative consequences. The negative and positive consequences will vary among group members, so they must work towards a common understanding.
The functional theory of group decision-making highlights that the performance and subsequent effectiveness of the group is dependent on each of the five functions. If a group completely understands the problem given to them, develops multiple solutions to the problem, then weighs the positive and negative outcomes of each solution to pick the solution with the most positive merits, then the functional theory of group decision-making indicates that group will be effective.

**Role of Information and CIS** - Within this theory, information is specifically noted as being important to the first function of *problem analysis*. The theory outlines that the group must utilize given information to develop an understanding of: a) the nature of the problem, b) the extent, criticality, and seriousness of the problem, c) the likely causes of the problem, d) the consequences of not solving the problem. This is the only part of the theory where information is explicitly announced, yet there is a clear assumption that it is needed in all other functions. Furthermore, the theory refers to information that is *given* to the group, not found. Information seeking is never explicitly noted as a critical step or process that the group must complete during the group decision-making process.

### 2.1.3 Multi-level Theory of Team Decision-Making

The multi-level theory of team decision-making is often identified as the best-known theory of team decision-making (Hancock & Szalma, 2008). This theory is most applicable to teams that are hierarchical and have distributed expertise (Hollenbeck et al., 1998). In this theory, hierarchal refers to status differences among the members of the team. Building on this, some team members have more responsibility and input to make the team’s decision than others. Distributed expertise refers to the concept that each team member has a different amount of expertise to the team. Varying levels of expertise result in unequal knowledge and information among team members. The multi-level theory of team decision-making focuses on the attributes of hierarchal and distributed because it claims that these features are most commonly found within real world teams (Hollenbeck et al., 1995).

The multi-level theory of team decision-making is grounded within the Brunswick lens model, stating that humans make judgments of other people or objects based on probabilistic cues or attributes found within the environment (Hammond, 2000). Hollenbeck and colleagues (1995)
used this model to identify that team level decisions are dependent on three levels of decision-making before the team level is reached: decision level, individual level, and dyadic level. Within each level, critical decision variables are identified. These variables are important outcomes that must develop during each level. Once the critical variables for the three lower levels (decision, individual, and dyadic) are identified, they are then aggregated to develop a team level decision.

**Decision Level:** Of the four levels, the lowest is the decision level (Hollenbeck et al., 1995). The critical decision variable at this level is known as *decision informity*, defined as “the degree to which each team member has all information necessary to perform his or her role in the decision-making process” (Hollenbeck et al., 1998). This takes the approach that decisions are nested under individuals. An individual might have the required information to solve one specific problem, yet lack the information to solve a different one. When aggregated to the team level, *decision informity* is referred to as *team informity*. Team informity is simply the degree to which the team has distributed information within and among the team. If information is effectively distributed, then it is assumed that accurate team decisions will be made.

**Individual Level:** The next level is known as the individual level (Hollenbeck et al., 1995). The critical variable within this level is *individual validity*, defined as “the degree to which any one staff member can make recommendations to the leader that are predictive of the correct decision for the team” (Hollenbeck et al., 1998). When aggregated to the team level, *individual validity* becomes *staff validity*. This notion refers to the average level of individual validity among the team, resulting in the accuracy of each team members’ recommendations.

**Dyadic Level:** The last level before the aggregated team level is the dyadic level (Hollenbeck et al., 1995). The critical decision variable among this level is *dyadic sensitivity*, defined as “the degree to which a team leader correctly weights each staff member’s recommendation to arrive at a team's decision” (Hollenbeck et al., 1998). At the team level, *dyadic sensitivity* is referred to as *hierarchical sensitivity*. Hierarchical sensitivity captures the “overall optimality of a leader’s use of his or her staff” (Hollenbeck et al., 1998).

The six variables (*decision informity, team informity, individual validity, staff validity, dyadic sensitivity, hierarchical sensitivity*) are the foundation of the multi-level theory of team-decision-making and attempt to explain how teams make accurate decisions that result in overall team performance.
Role of Information and CIS - The multi-level theory of team decision-making starts with the premise that there is distributed expertise among all team members based on each member having different levels of knowledge and information. The decision level of the theory outlines decision informity, where each team member has all the information necessary to perform his or her role in the decision-making process. Aggregated to the higher team level, team informity describes that the information each team member has must be distributed across the team for an accurate and effective team level decision to be made. This level of decision-making is highly dependent on information, yet how that information is acquired is never mentioned or outlined. There is an assumption that the information will be there. Similar to the functional theory of group decision-making, it is assumed that information plays a key role in the other parts of the theory but there is little if any discussion of how this information is acquired.

2.1.4 Macrocognition in Teams’ Model

The concept of macrocognition grew out of cognitive engineering and is an attempt to describe how cognition emerges in natural environments (Cacciabue & Hollnagel, 1995; Letsky et al., 2007). Specifically, macrocognition is defined as “the internalized and externalized high-level mental processes employed by teams to create new knowledge during complex, one-of-a-kind, collaborative problem solving” (Letsky, 2008). Macrocognition falls under the realm of naturalistic decision-making (Klein & Zsambok, 1997), and seeks to understand the relationship of context and cognitive processes (sensemaking, transactive memory) in their natural settings. Macrocognition is often termed as real world cognition, whereas microcognition is cognition found within in a laboratory setting (Letsky et al., 2007). Through the work of Warner and colleagues (2005), a model of macrocognition in teams argues that both internalized and externalized processes occur during the team decision-making process.

The internalized and externalized mental processes that are utilized by teams create new information and knowledge that the team uses to solve their problem. The internalized processes are cognitive in nature and are often not externalized through observable communication (talking, writing, drawing, gesturing). These processes, although more difficult to measure than the externalized processes, can be measured through qualitative means (concept mapping, think-
alouds) (Letsky et al., 2007). Externalized processes are actions that can be measured through observation.

The macrocognition in teams model consists of four stages of team collaboration. Unlike the previous two theories, these stages are not sequential, rather very dynamic. Internalized and externalized cognition occur throughout all stages and are not limited to a specific sequence pattern (Letsky, 2008).

**Knowledge Construction:**
- Identification of necessary information
- Selection of team members
- Addressing the communication environment
- Individual team members development of their own mental model
- Development of individual and team task knowledge

**Collaborative Team Problem Solving**
- Majority of team collaboration occurs here
- Focus on team development of alternative solutions

**Team Consensus**
- Work towards agreement
- Achieve agreement among the alternative solutions

**Outcome Evaluation and Revision**
- Testing and validating team solution
- Iterative loop for developing other solutions, if needed

Along with the stages, 14 internalized and externalized cognitive processes found within the stages have also been identified (Letsky et al., 2007).

**Individual Knowledge Building**
- Iterative Information Collection
- Individual Task Knowledge Development
- Individual Mental Model Development

**Team Knowledge Building**
- Pattern recognition and Trend Analysis
- Team Mental Model Development
- Recognition of Expertise
- Sharing Unique Knowledge
- Uncertainty Reduction
- Knowledge Interoperability

**Developing Shared Problem Conceptualization**
- Visualization and representation of meaning
- Building common ground
- Knowledge sharing and transfer
- Team Shared Understanding
• **Team Consensus Development**
  - Critical thinking
  - Mental simulation
  - Intuitive Decision Making
  - Iterative Information Collection
  - Solution Option Generation
  - Storyboarding
  - Team Pattern Recognition
  - Negotiation of Solution Alternatives

• **Outcome Appraisal**
  - Feedback structure
  - Replanning
  - Team Pattern Recognition

As team decision-making research moves forward, many researchers believe that the macrocognition in teams model is one of the top theories/models in the domain (Fiore et al., 2010). The model’s popularity is due to it benefiting from integrating multiple aspects and years of team decision research within the overall model itself. In recent years, a wave of macrocognition in teams research has become one of the leading perspectives to use when discussing team decision-making.

*Role of Information and CIS* - Under the *knowledge construction* stage, it is highlighted that the team must identify necessary information related to the problem from the onset. Then, within the cognitive processes, the process of iterative information collection is found within individual knowledge building and team consensus development. Of the three theories that have been reviewed, this process most explicitly discusses processes/activities similar to CIS.

### 2.1.5 Summary

Clearly, information is important, especially in the beginning phases of each theory/model. Yet, while information is mentioned many times, the process of how the team should seek such information is never explicitly noted. Each of these models is comprehensive and outlines many detailed processes, but not information seeking. The lack of focus on CIS within the team decision-making literature highlights a research gap. If information cannot be found or is inaccurate, the entire decision making process could potentially be flawed. For this reason, more
research that focuses on CIS within the context of team decision-making is needed. CIS should not be an implicit assumption, rather a specific aspect of the team decision-making process.

2.2 Team Cognition

Traditionally, team cognition research has viewed teams as information processing units that allow for the attention, encoding, storage, retrieval, and processing of information (Hinsz, Tindale, & Vollrath, 1997). While these processes are found at an individual level, communication is the key process that ultimately allows teams to process information at a team level (Fiore & Salas, 2004; Salas, Cooke, & Rosen, 2008).

The team aspect of team cognition is a result of the interaction that takes place among individual team members. The interaction of team members results in the “sharing” of individual cognition throughout the team. Yet, team cognition is not simply the sum of individual team members’ cognition (Cooke, Gorman, Winner, 2007), rather, it is new team-based cognition that is developed through the interaction of team members. The development of team cognition includes components of each individual member’s cognition, but is more complex than the simple aggregation of all team members’ individual cognition. Cooke and colleagues (2007) emphasize that there are many activities that team members can carry out independently that do not lead to team cognition because there must be team-level interaction for team cognition to exist. For these reasons, team cognition is an emergent phenomenon that develops depending on the situation and context (Cooke et al., 2004). In addition, team cognition is both a process (communication) and a product (team mental model) (Larson & Christensen, 1993; Fiore & Salas, 2004).

An increase in teamwork has led to a variety of cognitive issues to examine. Team cognition is a wide-ranging research area containing many perspectives (Table 2). For this study, I chose to look at team cognition through the perspective of shared team knowledge and understanding. Often, when team cognition is studied as a construct, it is studied using this perspective (Mohammed, Ferzandi, & Hamilton, 2010).
Table 2. Areas of Team Cognition Research

<table>
<thead>
<tr>
<th>Team Cognition Research Area</th>
<th>Description</th>
<th>Related Works</th>
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<tbody>
<tr>
<td><strong>Team Performance</strong></td>
<td>The development of team cognition is often viewed as being linked directly to a team’s performance.</td>
<td>Cooke et al., 2004; Salas et al., 2008</td>
</tr>
<tr>
<td><strong>Team Training</strong></td>
<td>The utilization of team training has the ability to affect the development of team cognition, and subsequently, team performance.</td>
<td>Cannon-Bowers et al., 1998; Salas &amp; Cannon-Bowers, 2001</td>
</tr>
<tr>
<td><strong>Team Leadership</strong></td>
<td>Leadership is linked as helping or hurting the development of team cognition depending on the leadership style.</td>
<td>Kozlowski et al., 2009; Zaccaro et al., 2009</td>
</tr>
<tr>
<td><strong>Shared Team Knowledge &amp; Understanding</strong></td>
<td>Sharing knowledge and developing common ground are the basis for the development of the team cognitive structure known as a team mental model.</td>
<td>Mohammed et al., 2010; DeChurch &amp; Mesmer-Magnus, 2010; Lim &amp; Klein, 2006</td>
</tr>
<tr>
<td><strong>Team Stress</strong></td>
<td>Stress often has a negative impact on the development of team cognition.</td>
<td>Cannon-Bowers &amp; Salas, 1998; Pfaff, 2012</td>
</tr>
<tr>
<td><strong>Temporal Limitations</strong></td>
<td>Situations where time is limited have the potential to hinder the development of team cognition.</td>
<td>Marks et al., 2001; Mohammed et al., 2009</td>
</tr>
<tr>
<td><strong>Situational Awareness</strong></td>
<td>Being aware of team member’s actions and the overall context often increases the availability for the development of team cognition.</td>
<td>Endsley, 1995; Gorman et al., 2006</td>
</tr>
</tbody>
</table>

The benefits to understanding team cognition have been highlighted many times by researchers (Fiore & Salas, 2004). Most notably, (1) team cognition allows researchers to better understand the processes that take place during teamwork, (2) it has the ability to be a predictive variable of team performance, and (3) provides insight into identifying and overcoming problems in teams (Cannon-Bowers & Salas, 2001; Fiore & Salas, 2004). Within team cognition research, a major premise is that team cognition directly affects team performance (Salas, Cooke, & Rosen, 2008). Specifically, breakdowns in team cognition lead to decreased performance (Wilson et al., 2007; Collyer & Malecki, 1998) and the development of team cognition positively improves
performance (Cooke et al., 2003). Therefore, the development of team cognition has the potential to improve the team’s overall performance during CIS activities.

2.3 Team Mental Models

Shared knowledge has long been studied within team cognition. Within shared knowledge, the construct of a team mental model has been developed. Over time, this construct has proven to be impactful and very important to understanding team cognition. A review of the team mental model construct follows.

2.3.1 Conceptualization and Definitions

Similar to most cognitive constructs, the mental model was originally conceptualized at the individual level. The notion of a mental model grew out of cognitive science and psychology, and is now one of the most well-respected and well-known cognitive constructs. Over the years, many definitions of mental models have been presented, yet almost all of them point to knowledge and internalized representations as being key components. Possibly the most straightforward definition of a mental model comes from Holyoak (1984) who defined it as “a psychological representation of the environment and its expected behavior.” Johnson-Laird (1983) has attributed these models as having the ability to understand phenomena and make inferences based on the environment and previous knowledge. A more systematic perspective on mental models is provided by Rouse and Morris (1986), who define a mental model as a “mechanism whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states.” In sum, a mental model is a cognitive representation that allows individuals to describe, predict, and explain knowledge and behavior (Norman, 1983).

As the wealth of knowledge pertaining to mental models grew and the importance of teamwork was realized, the team mental model construct was introduced by Cannon-Bowers, Salas, & Converse (1990). The purpose of such a construct was to further understand the cognitive processes of teams within ever-changing situations/context and to help understand the differences in performance across teams. Team mental models are “team members’ shared
understandings and mental representations of knowledge about key elements of the team's relevant environment” (Klimoski & Mohammed, 1994; Mohammed & Durnville, 2001). The overlying assumption of team mental model research has been that teams who possess strong, accurate, and similar team mental models will be more effective and perform at a higher level than teams that have not developed these models (Cannon-Bowers, Salas, & Converse, 2001). Over time, the notion that strong team mental models increase and enhance team performance has proven to be true (Cooke et al., 2003). Overall, the knowledge and research foundation associated with team mental models has grown, leading to a better understanding of team mental model development, measurement, and performance implications (DeChurch & Mesmer-Magnus, 2010b; Mohammed, Ferzandi, & Hamilton, 2010).

Many researchers have argued that there is no single team mental model shared among teammates, rather multiple mental models exist and are shared among teammates throughout the team decision-making process (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994). The content of a team mental model was initially divided into four different types of team knowledge that led to four different types of mental models: equipment, task, team interaction, and team models (Cannon-Bowers, Salas, & Converse, 1993). The equipment model encapsulates the different types of technology and equipment that the team uses to conduct team tasks. The task model represents the perceptions of the teams procedures, tasks, and environment. The team interaction model captures each team members’ understanding, assumptions, and perceptions of their teammates norms, responsibilities, and interactions. Finally, the team model represents teammates’ understanding of each other’s knowledge, skills, and attributes. As the team mental model construct evolved, the four content models were broken down into two models to reduce unnecessary complexity.

Matheiu and colleagues (2000) introduced two major content models that encompassed all four of the previous models. The two new content models were: taskwork (a combination of the equipment and task models) and teamwork (a combination of the team interaction and team models). Taskwork mental models capture the task related goals of the team, as well as the processes that are related to achieve those goals. Teamwork mental models include interpersonal communication and interactions, along with the knowledge and skills of teammates. These two content models have better allowed researchers to examine both within one research study. The taskwork and teamwork models have also become fixtures within the team mental model literature (Mathieu et al., 2000). The previous four models content were so closely aligned to each other that that researchers had difficulty articulating the difference between them. Although a
majority of researchers agree that a team mental model consists of teamwork and taskwork models, some researchers, such as Lim & Klein (2006), argue that there are many mental models (more than four) that are ultimately absorbed within the greater team mental model.

Along with the content of the model, team mental models are also classified by two properties: accuracy and similarity. Accuracy relates to how precise and close a team mental model is to the “real world” (Edwards et al., 2006). Along with its accuracy to the real world, accuracy has also been described by how much each teammate’s knowledge structure is related to or “mimics” an expert’s structure (Hamilton, 2009; Webber et al., 2000a). The similarity property of team mental models represents shared knowledge, referring to how “similar” each team members’ mental model is among each other. Similarity is often referred to within the literature as “sharedness”, which has been defined as “the degree to which members’ mental models are consistent or converge with one another and does not signify identical mental models” (Cannon-Bowers, Salas, & Converse, 1993; Mohammed, Ferzandi, & Hamilton, 2010). If the team mental model is strong, then both accuracy and similarity are working jointly to align the model to accurately represent reality and share key components of the model among all team members.

2.3.2 Team Mental Model Development

Possibly one of the most important and hardest challenges within team mental model research is understanding and identifying how people shift their individual mental models to team mental models. The team mental model convergence process has helped provide insight into this process and added to the overall understanding of the construct.

When teams are first formulated, they go through an introductory period where team members familiarize themselves with each other and the overall goals of the team. This introductory period is strongly linked to and reliant on information sharing (Stasser & Titus, 2006) and knowledge building (Scardamalia & Bereiter, 2006). Shared information often comprises overall team knowledge, which then helps to develop the team mental model. During this process, team members communicate their individual mental models to the rest of the team. This enables the team to be aware of each team members’ cognition. While team members are relaying their own mental model, it is implicitly being evaluated and discussed among the team to determine which components of the individual mental model should carry over to the team mental model. The communication that takes place during this time allows for individual team members’
mental models to be refined based on what they are learning from each other’s models. While individual models are shared verbally, observation is also integral to conceptualizing a team mental model. Team members observing each other helps them to understand their individual team responsibilities and work habits. Strong communication and observation allow for team members to describe, explain, and predict future events based on a team mental model. Research has indicated that high levels of communication and observation strengthen overall team mental models (Graham et al., 2004). Furthermore, experience also impacts the team mental model. Team members’ experience has a profound impact on the overall team mental model as it guides their individual model. Mohammed & Dumville (2001) have described this founding period of team mental model development as the team learning process. As noted above, this process encompasses the development, modification, and refinement of mental models through team discussion.

The next step to developing the team mental model is reaching team mental model convergence. The process of mental model convergence is continuous process that occurs as team communication and interaction is ongoing. The collection of information and observation of team members’ behavior leads individuals to evolve their individual mental models to team mental models, requiring a cognitive shift in focus from individual to team (McComb, 2007). According to McComb and colleagues (2010), the process of mental model convergence maintains three distinct phases, which are referred to as orientation, differentiation, and integration. Team members must:

1. Orient themselves to their unique domain,
2. create their own view of the situation, which may or may not be similar to their fellow team member’s views,
3. allow their individual perspective to evolve into a team view.

Once each team member has completed these three phases and the team has a shared understanding of the team mental model, the convergence point has been reached and the team mental model has been created. Even though the team mental model has been created, it’s important to note that team members will continue to return to the three phases. A team mental model is never static; rather it is dynamic and constantly changing due to team members’ interactions and the context.
2.3.3 Team Mental Model: Empirical Findings

One of the main assumptions of the team mental model is that if the model is accurate and similar it has the potential to improve team performance. A comprehensive review of the literature by Mohammed and colleagues (2010) has provided a strong basis for understanding how the team mental model properties (similarity and accuracy) affect team performance. A brief review of the performance findings in Mohammed’s Metaphor No More: A 15 Year Review of the Team Mental Model Construct highlights the relationship between team mental models and performance.

Most team mental model research focuses on the impact similarity has on team performance. Multiple studies have shown that when a team mental model encompasses a strong similarity property, the performance of the team increases (Edwards et al., 2006; Lim & Klein, 2006; Mathieu et al., 2000). Meta-level reviews of similarity and team performance have also been conducted, indicating a positive relationship between the two (DeChurch & Mesmer-Magnus, 2010a). The similarity property has also been found to be an effective predictor of team performance in both taskwork (Lim & Klein, 2006) and teamwork models (Rentsch & Klimoski, 2001). Between the two models (taskwork and teamwork), the similarity property has been linked to be a stronger indicator of increased team performance in the taskwork model as opposed to the teamwork model (Lim & Klein, 2006; Mathieu at al., 2008).

Although the majority of team mental model research focuses on the similarity property, studies have also considered the impact of the accuracy property on team performance. Unlike the similarity property, the accuracy property is not directly supported as being a strong predictor of team performance. While the similarity property has consistently been linked to strong team performance, the accuracy property is highly varied, and has shown both a negative or positive relationship in regards to team performance (Mohammed et al., 2010). Some studies have found a clear relationship among accuracy and performance (Cooke et al., 2003; Edwards et al., 2006; Lim & Klein, 2006), while others have noted no relationship (Mathieu et al., 2005; Webber et al., 2000b). Like the similarity property, accuracy has been measured within taskwork and teamwork models, resulting in inconclusive findings. Studies have found that accuracy within the taskwork and teamwork models strengthens team performance (Lim & Klein, 2006). On the other hand, Cooke and colleagues (2001) found that only taskwork accuracy positively influenced performance.

The relationship between team mental models and team performance is the most widely acknowledged and researched empirical finding within the team mental model literature. Yet,
while performance is at the forefront, team mental model research is broad and has focused on many empirical areas. The focus of this review is not large enough to encompass many of the areas. However, a model created by Mohammed and colleagues (2010) (Figure 1) does an excellent job outlining the many research areas within the literature. The model highlights the antecedents, moderators, and outcomes of team mental models. Within all three categories, many focuses have been studied on multiple levels and in varying depth.

![IMO Model of Team Mental Model Research](Mohammed et al., 2010)

**2.3.4 Team Mental Model Measurement**

Twenty years ago when the team mental model construct was developed, the most challenging aspect to it was identifying ways to accurately capture and measure it (Klimoski & Mohammed, 1994; Mohammed, Klimoski, & Rentsch, 2000). Because it was a purely cognitive construct, researchers faced many difficulties in accurately identifying the model through measurement. Plenty of conceptual ideas were identified, but very few applicable mechanisms were presented (Cannon-Bowers, Salas, & Converse, 1993). Fortunately, as the research surrounding team mental models has grown, effective measurements have been configured. While many measurements are readily available now, there is still not one single methodology that is viewed as the most appropriate way to capture mental models. This has led to many researchers arguing the effectiveness of various measurements.

Team mental models can be studied quantitatively or qualitatively. Yet, most researchers have employed a quantitative perspective. The lean towards quantitative research occurs mainly
because the team mental model construct is rooted in psychology and cognitive science, both communities that heavily utilize quantitative methods. Studying cognition from a qualitative focus is challenging because it is difficult to compare cognition across multiple structures and people. Yet, there are significant benefits to studying cognition using a qualitative approach. Qualitative methods typically provide a deep and rich understanding of the data. For cognitive research, this understanding could be very impactful in understanding the complex phenomena that is cognition, as well as accounting for many dynamic contexts. Regardless of the measurement being quantitative or qualitative, team mental model measurements need to capture all knowledge (content and structure) within the model (Langan-Fox & Langfield-Smith, 2000).

Mohammed, Kilmoski, & Rentsch (2000) produced one of the first detailed overviews of team mental model measurements. Measurement techniques of pathfinder, multi-dimensional scaling (MDS), interactively elicited cognitive mapping, and text-based cognitive mapping are reviewed within the article. The authors indicate that all of these techniques hold promise for the future of team mental model measurement, but that one is not any better than the other. In many cases, using more than one of these techniques in cohesion with another might be beneficial to fully capturing the team mental model. With so many measurement techniques available, it can be difficult to decide which to use. The research questions and the study context should be taken into account when choosing a measurement technique.

One of the most widely cited articles on devising team mental model measurements was written by Langan-Fox & Langfield-Smith (2000). Within the article, the authors reviewed the strengths and weaknesses of multiple elicitation and representation methods for measuring team mental models. The measurements within the elicitation category are: cognitive interviewing, verbal protocol analysis, content analysis, observation of task performance, card-sorting, casual mapping, pairwise rating, and ordered tree. Measurements among the representation category are: MDS, distance ratio formula, and pathfinder. In addition to the author’s review of each measurement technique, a six-phase approach for designing and developing team mental model research studies is outlined. This approach is widely used among many team mental model researchers (and this study) and can be seen in Table 3.
Phase 1: Obtain an Overview of the Research Context
- Conduct exploratory interviews
- Ask what skills and competencies are required, what are the characteristics of the team task
- Identify team mental model boundaries
- Match sample capabilities (e.g., reading level, English competency) to measurement types

Phase 2: Choose an Elicitation Method
- Develop method selection criteria (e.g., applicability, practicality, theoretical suitability)
- Select the method that best meets the criteria

Phase 3: Define the boundaries of the team mental model
- Choose boundaries based on theory, exploratory interviews

Phase 4: Generate Concept Pool and Pilot Test
- Pilot the elicitation method
- Ask participants for feedback
- Adjust method accordingly

Phase 5: Derive the Final Concept Pool
- If concept pool is researcher-generated, go to Phase 6
- Use feedback from teams to select concepts for the main study

Phase 6: Conduct Main Study
- Elicit, represent, and analyze the team mental model

Table 3. Phases for Design and Development of Team Mental Model Research (Langan-Fox & Langfield-Smith, 2000)

With so many measurement techniques, organizing and interpreting measurements in a logical manner is challenging, but a meta-level analysis by DeChurch & Mesmer-Magnus (2010b) has helped identify that most methods fall under three main methods: *elicitation, structure representation, and representation of emergence.*

The elicitation method is utilized when the researchers seek to understand the content or individual components of the team mental model (DeChurch & Mesmer-Magnus, 2010b). Some of the most common elicitation techniques are concept maps, similarity rankings, rating scales and card sorting (Mohammed, Kilmoski, & Rentsch, 2000). These types of techniques allow the researcher to better understand the content (knowledge) that is encapsulated within the model. Understanding the content of the model is only part of understanding a team mental model; it is also important to understand how the content is “modeled” or structured within the team mental model. Techniques that allow for insights into the modeling or structure of content are known as...
structure representation methods. Structure representation methods are used to gain a better understanding of how the content of the team mental model is represented within the mind (DeChurch & Mesmer-Magnus, 2010b). While there are many structure representation methods, two of the most frequently utilized techniques are similarity ratings and concept mapping. The technique of concept mapping is unique in that it falls under both elicitation and representation. Concept mapping is especially powerful because of its ability to capture both the content and structure of either an individual mental model and/or a team mental model. The method of representation of emergence is typically used to understand how individual mental models make up part of the team mental model (DeChurch & Mesmer-Magnus, 2010b). This method relates back to the development of a team mental model and the convergence work conducted by McComb (2007). It is important to understand the similarity among individual models and how they converge upon each other to ultimately represent the team mental model. One of the most popular representation of emergence techniques is pairwise comparison ratings. These ratings are then analyzed using the pathfinder algorithm to understand the overlap of a team’s mental model.

2.3.5 Team Mental Models and Collaborative Information Seeking

As noted earlier, a team mental model is developed based on the evolution of multiple different models. While the two main models are teamwork and taskwork models, it has been surmised that many other specific models help to formulate the overall team mental model (Lim & Klein, 2006). Within this perspective, the team mental model is the overarching construct but it is built on the existence of many other context specific team mental models within the overall model. To the best of my knowledge, there has never been a study that has explored if there is a team mental model specific to CIS. Work by McNeese & Reddy (2013) first conceptualized the idea of there being a team mental model specific to the context of CIS. In addition to highlighting a lack of CIS based team cognitive research, they have also suggested team cognitive methods for capturing a team mental model specific to CIS. They take the perspective that understanding a team mental model within the context of CIS is critical and helpful to understanding how teams make decisions. They also indicate that understanding the cognition of CIS (along with the interaction) is valuable to improving the process and the tools associated with it. The lack of knowledge and research pertaining to the relationship of CIS and a team mental model is a significant research gap. Building on their 2013 work, McNeese and colleagues (2014) identified
a team mental model of CIS, specifically highlighting taskwork and teamwork models within the CIS focused model. In addition, McNeese & Reddy (submitted) have also identified specific cognitive activities that take place during CIS that help to develop team cognition. Work from all of these articles is highlighted in this dissertation.

2.3.6 Summary

The large amount of work that has focused on the team mental model construct over the past decade has cemented its position in the team cognition literature. This section highlighted the many advances made in regard to the conceptualization, development, and measurement of the construct. In addition, this section also outlined the significance of many empirical studies. Yet, even though the construct is well established it has not been explored within the context of CIS. As noted, a team mental model consists of multiple models, all of which help to formulate the greater model. Exploring whether a team mental model of CIS develops has the potential to provide a greater understanding of the various models that build the overall team mental model.

2.4 Collaborative Information Seeking

This section will review work directed at collaborative information seeking.

2.4.1 Conceptualization and Definitions

Traditionally, information seeking has been studied at the individual level (Shah, 2010b). Yet, as work and organizations become more collaborative (Karsten, 1999; Reddy & Dourish, 2002) the importance of studying information seeking from a collaborative perspective has become apparent. The collaborative perspective of studying information seeking is referred to as collaborative information seeking (CIS). CIS is an interdisciplinary research domain that spans multiple fields, such as Information Science (IS), Human Computer Interaction (HCI), and Computer Supported Cooperative Work (CSCW). Within CIS, two main emphasis of the research have developed- social and technical. Research focusing on the social aspects of the CIS has generally sought to understand how CIS occurs in multiple contexts. Whereas, technical CIS
research aims to develop features, systems, and tools specific to aiding humans during CIS activities. Most CIS research focused on understanding the social aspects of CIS is studied using an interactional approach, as opposed to a cognitive one. Cognitive approaches, while minimal, are found more in the technical stream.

In this dissertation, I use the term CIS yet there are many related and often interchangeable terms that also refer to the concept of CIS. Shah (2010b) has identified the following terms and research focuses as being strongly related to CIS: collaborative information retrieval (CIR) (Fidel et al., 2000), collaborative search (Morris, 2013), social searching (Evans & Chi, 2008), collaborative exploratory search (Pickens & Golovchinsky, 2007), co-browsing (Gerosa, Giordani, & Ronchetti, 2004), and collaborative information behavior (Reddy & Jansen, 2008). Even though the breadth and specificity of each of terms is different, they all incorporate aspects of CIS.

The variety of terms presents challenges in defining specifically what CIS is for two reasons. First, there is not a clear understanding of what the breadth of the definition should include. For instance, some definitions include the act of seeking, searching, and retrieving information, while some only include one of those actions. Second, definitions of CIS greatly vary depending on the community. As Foster (2006) highlights, depending on the community, certain aspects of the definition “may emphasize information handling, search and retrieval, interaction, or the seeking and retrieving of information in support of collaborative work tasks.” However, despite these challenges, there are definitions specific to CIS that are commonly cited within the literature.

The most widely acknowledged definition comes from Foster (2006) who defines CIS as “the study of the systems and practices that enable individuals to collaborate during the seeking, searching, and retrieval of information.” Similar to Foster, Poltrock & colleagues (2003) have defined CIS “as the activities that a group or team of people undertakes to identify and resolve a shared information need.” Taking a more specific and formulaic approach to CIS, Hansen & Jarvelin (2005) use the following definition of CIS: “an information access activity related to a specific problem solving activity that, implicitly or explicitly, involves human beings interacting with other human(s) directly and/or through texts (e.g., documents, notes, figures) as information sources in an work task related information seeking and retrieval process either in a specific workplace setting or in a more open community or environment.” In addition, Karunakaran & Reddy (2012) define CIS in the simplest terms: “two or more individuals working together to seek needed information in order to satisfy a goal.”
These are only a select few definitions of CIS. The convoluted nature of the many definitions results in no canonically or community wide accepted definition. For the purposes of this dissertation, Karunakaran & Reddy’s definition of CIS will be utilized. In addition to the definitional understanding of CIS, it is also important to highlight that CIS is a highly complex contextual and dynamic activity. The activity involves both static and dynamic goals that are specific to the situation and context. Also, depending on the situation and context, information may change throughout CIS. Lastly, CIS requires multiple people with many individual differences to work together using many different means to seek information.

2.4.2 Collaborative Information Seeking Models and Processes

There are many models of individual information seeking (Ellis, 1989; Kuhlthau, 1988; Leckie & Pettigrew, 1997; Wilson, 1981). However, very few models of CIS have been developed. In fact, to my knowledge, only one specific model of CIS is published (Shah, 2009). In addition to that model, there is a model specific to social search that has also been presented (Evans & Chi, 2008). Finally, a model of collaborative information behavior (CIB) has been presented that includes CIS but does not fully explain the process of CIS (Reddy & Jansen, 2008). These are the only models that have specifically sought to minimally account for the process of CIS. To better understand research regarding the CIS process, I will briefly review a model of CIS, a model of social search, and a model of CIB.

2.4.2.1 A Model of Collaborative Information Seeking

Shah (2009) developed a four-layer model of CIS. The model begins with a high level individual model of information seeking (Figure 2) and is then extended to incorporate collaboration (Figure 3). The individual model consists of the following four layers (Shah, 2009):

Layer 1- Information: This layer represents the available information to the user. This information varies and can be localized knowledge, information found on the web, etc.

Layer 2- Tools: This layer represents the tools and techniques used to access the information found in layer 1. Often this layer is represented via a search engine.
Layer 3- Users: This layer incorporates the user utilizing the tools in layer 2 to find the information in layer 1.

Layer 4- Results: Finally, in this layer, the user accumulates information that they find to be important and representative of solving their problem. An example of this corresponding to web search might be the user bookmarking the pages he or she feels are valuable.

Figure 2. Four-Layer Model of Information Seeking (Shah, 2009)

Extending the notion of the four-layer individual model, a model incorporating collaboration was established. Currently, this model is conceptual with very little empirical basis to confirm it. The collaborative model operates under the assumption that two people are collaboratively searching for information. During that search, collaboration occurs across the different layers. Specifically, collaboration occurs (1) while formulating an information request, (2) while obtaining results, and (3) while organizing and using the results (Shah, 2009).
2.4.2.2 A Model of Social Search

Evans & Chi (2008) developed a comprehensive model of social search incorporating what users do before, during, and after a collaborative search. As noted earlier, social search is very similar to CIS. As this model is very detailed, I will only present a high level description. Below, I outline the three phases of the collaborative search process highlighting the specific processes within each (Evans & Chi, 2008):

Before Searching- This stage is motivated by the users understanding their need for information and then refining their search requirements based on that need.

Context Framing: During this process, users seek to understand the “need” for information. Specifically, this process allows the user to understand the motivations for the information and the need. The need for information may be rooted in an external request or self-initiated.

Requirement Refinement: Once the information needs are realized and defined, search requirements are then refined. This allows users to change what and how they will search for information.
During Search: This stage is where traditional information seeking activities take place, meaning the user is interacting with a search engine and their collaborators. Collaborators might initiate three different types of search within this stage: transactional, navigational, and informational.

Transactional Search: This type of search is conducted when users find a website that will allow them to complete a transaction by asking for specific information. An example of this type of search is entering two locations and asking for the directions between the two.

Navigational Search: This type of search describes when users “navigate” through the web to find specific information. An example of this would be starting a search on Google, finding a website, then searching that website for the needed information.

Informational Search: This search is the least formal of all the searches. During this type of search collaborators will search for information assumed to be present, but otherwise unknown. Often collaborators rely on foraging and sensemaking techniques to search for information this way.

After Search: This stage explains the process of an “end product” being obtained after the actual search.

Organizing Information: Explains how collaborators utilize the information found “during search” and organize it to make sense for the end product.

Distributing Information: Once collaborators have found information, they must then share it with each other depending on the structure of the collaboration. This process explains how people share information to develop the common goal of an end product.

2.4.2.3 A Model of Collaborative Information Behaviors

Reddy & Jansen presented a model of CIB in 2008, where they explain the information landscape on two axes: behavioral and context. The behavioral axis encompasses a range of information seeking to information searching. The context axis is oriented to the range of individual information behavior to collaborative information behavior. The researchers make the claim that there is an interactional effect between behavior and context. More specifically, the searching or
seeking that takes place at an individual level will be different than searching or seeking taking place at a collaborative level. For example, the researchers explain that information behavior consisting of collaboration and information seeking will be complex. Whereas, information behavior at only the individual level and consisting of information seeking will be simple. Overall, Reddy & Jansen (2008) make the argument that interplay exists across both axes. Depending on the complexity of the problem, the number of people working together, and the type of interaction, the switch from individual to collaborative information behaviors will occur.

Overall, very few models of CIS or related areas have been developed. Within this research study, how people approach CIS will be explored. Through this, hopefully more knowledge is developed pertaining to the approach and process of CIS.

2.4.3 Collaborative Information Seeking: Empirical Results

As noted earlier, CIS research has been examined from two perspectives and focuses, social and technical (Karunakaran & Reddy, 2012; Reddy & Jansen, 2008). The social stream investigates how CIS is structured, processed, and takes place within multiple contexts. The technical stream, while it has some of the same interests as the social stream, investigates the development, testing, and implementation of tools and systems with the potential ability to support and enhance CIS activities.

Social Stream

In order to fully understand CIS, it must be investigated within multiple contexts. In response, the social aspects of CIS have been studied within the contexts of education, military, and medicine (and others to a smaller degree). Each of the CIS related contexts are reviewed below.

Education

The context of education has been a fixture within CIS research for many years. The importance and relationship of CIS and learning is a focal point within the literature. Specifically, many researchers have explored the impact that CIS has on the educational experience in multiple contexts. As education has become more team oriented, interest in CIS has flourished. Below are examples of work conducted in this context.
Sonnenwald and colleagues (2004) explored the relationship of situational awareness and CIS among physicists seeking successful academic collaboration. The study explored the types of information and knowledge that users need to share to support the development of situational awareness among collaborators. In addition, technologies enabling collaborators to share information were also explored. For this work, both ethnographic methods and an experimental design were implemented. The researchers found many types of “awareness” information must be present for successful collaboration to take place. Awareness information, which is shared amongst the team, allows team members the availability to update their overall understanding of the team’s progress. Contextual, task and process, and socio-emotional awareness were specifically identified as needed to maintain situational awareness.

Work by Hyldegard (2006; 2009) extended the individually focused Information Search Process (ISP) (Kuhlthau, 1991) model to encompass collaborative information seeking. The goal of the study was to explore the differences between how individual and groups of students seek information. And, specifically, if the ISP model would accurately explain group’s behaviors and attributes of CIS. The researcher found that the ISP model was not accurate in explaining group’s CIS, which led to her calling for the ISP model to be extended to support group collaboration. A group’s contextual and social factors significantly change the process of collaborating to find information. Unlike a group, the individual does not always have to consider certain contextual and social factors found within group work. The final conclusion put forth is that groups shouldn’t and cannot be modeled from an individual level and that the effect of group work on information seeking practices is significant.

Work conducted by Poltrock and colleagues (2003) has indicated that information seeking activities within design teams are often similar across teams. In their study, two separate and different design teams (software and hardware) were studied and the researchers found that the information sought and the methods used to retrieve it were similar between the teams. Implications from this study show that while many of the methods used to find information are similar across teams, there are also many ways in which information seeking may take place (individually and different types of teams). Due to this, the authors call for technologies to be developed that support many types of information seeking during teamwork.

Recent work by Reynolds and colleagues (2013) has focused on the collaborative information seeking activities of 18 middle school aged teams during game design learning. During their study, they found that students self-organized their teamwork in multiple ways
according to individual work preferences. In addition, they found multiple ways in which students seek out information specific help from their peers.

Among CIS practices, Talja (2002) explored the role of information sharing within CIS. Qualitative methods were employed to understand and explain how academic scholars share information among each other within the information seeking process. The results of the study indicate that there are four types of information sharing taking place within CIS: strategic (consensus building to maximize efficiency), paradigmatic (novel approach within or across domains to sharing information), directive (two-way exchange of information), and social (relationship or community building information sharing).

Finally, work conducted by Spence and colleagues (2005) surveyed academic researchers on their CIS practices. This study found that a lack of expertise is the main reason why researchers collaborate when seeking information. Academics also indicated that they preferred to collaboratively seek information by using traditional means of communication (face-to-face, phone, email). Finally, the researchers indicate that CIS is often more useful than individual information seeking.

Military

The importance of information and teams within the military and the command and control contexts makes CIS a fundamental activity that all teams partake in. Below are studies that have specifically focused on CIS in the military context. There are two main studies within the military domain that have greatly impacted the CIS community.

Prekop (2002) investigated CIS behaviors in the Australian Defense Forces command and control unit. Specifically, the researcher qualitatively analyzed how command and control workers collaboratively worked together during information seeking activities. This study focused on three specific aspects of CIS: information seeking roles, information seeking patterns, and the contexts with which those roles and patterns are found. Through analysis, multiple roles within collaborative information seeking were found: information gatherer, information verifier, information referrer, and information indexer. Patterns of CIS that were identified were: information seeking by recommendation, direct questioning, and advertising information paths. Finally, two different contexts of work were found. First, the CIS context was identified, which occupies the knowledge, skills, and known information within the group. Second, an organizational context was identified that encapsulates where CIS is occurring.
Work by Sonnenwald & Pierce (2000) also investigated collaborative information behaviors that occur in the command and control context. In this study, the researchers collected data during simulated battle exercises and interviewed experienced workers. Analysis from this data resulted in three themes relevant to collaborative information behaviors. *Interwoven situational awareness* was found at an individual and inter and intra group level. This awareness helped to facilitate work at all levels. *Dense social networks* were identified, which helped to increase communication relevant to the work and context. Lastly, a theme of *contested collaboration* was present where team members will collaborate but also work to advance their own interests.

**Medical**

Similar to the education and military contexts, much of the medical context is grounded in the teams working together to interpret and handle information. Due to the increased importance of teamwork and information within this context, many researchers have focused on it as their primary context to study CIS.

One of the first studies to explore CIS within the medical context was conducted by Reddy & Dourish (2002). In this study, they used field study methods to investigate information seeking activities during the work of healthcare providers in the intensive care unit. Within this study, the significance of temporality and the role that work rhythms play during CIS is highlighted. Rhythms found and understood within the team provide team members with information about each other, allowing them to plan their information searches. Therefore, if the team understands the work rhythms, they are able to both plan for seeking information and understand what information is needed. The authors of this study indicate that the role of rhythms within the medical team allowed for members to collaborate and seek information in a “just in time” manner.

Spence & Reddy (2007) conducted a field study of CIS within the medical domain with the aim to understand why and how patient care team members collaborate to find information. The researchers found that the unit secretary took on the responsibilities and role of a “technological gatekeeper”- someone who connects an organization to the external world. Yet, in addition, the unit secretary also took on an active and important role in the information seeking process. Due to the nature of the unit secretary taking on so many important roles, Spence and Reddy termed a new type of gatekeeper, an “active gatekeeper”-someone who is a conduit for many people, a boundary spanner, and takes a lead role to connect information seekers.
Extending upon the previous work, Reddy & Spence (2008) conducted an ethnographic field study to understand CIS among a multidisciplinary patient care team. Specifically, the study sought to identify the information needs of the teams, and situations that “trigger” CIS activities. The authors identified seven team information needs: details about the individual patient, policy and procedural, action plan the team implements, unable to correlate to other categories, continued data gathering, learning or training, pharmaceutical issues. In addition to the information needs, three triggers of CIS activities were found: lack of expertise, lack of immediately accessible information, and complex information needs.

In more recent years, research by Paul and Reddy (2010) has focused on understanding the role of sensemaking during CIS. This research employed an ethnographic study of the CIS practices of healthcare providers within the emergency department. There are varied perspectives on what sensemaking is (Dervin, 1992; Weick, 1995), but for the purposes of this study sensemaking was “making sense of the information found collaboratively”, i.e., collaborative sensemaking. The findings of this study indicate that collaborative sensemaking is a very important part of the CIS process. The study found three occurrences for collaborative sensemaking: ambiguity of information, role-based distribution of information, and lack of expertise. Finally, the study presents three characteristics of collaborative sensemaking: prioritization of information, sensemaking trajectories, and activity awareness.

Work by Hertzum (2010) studied the adoption of electronic medical records (EMR) over five years in Danish hospitals and identified multiple CIS breakdowns. Specifically, 82% of medical incident reports related to EMRs were related to CIS breakdowns. Breakdowns during CIS were specific to collaborative grounding, records and not oral communication, and that the record itself creates multiple problems in regard to CIS.

Recently published work by Spence & Reddy (2012) investigated the CIS activities of IT teams in two separate hospitals. Their work highlights the importance of context within the overall activity of CIS, specifically identifying four contextual factors of CIS: individual, team, organizational, and technological. Overall, these factors impact the activity of CIS and the processes directly associated with it.

**Technical Stream**

Many researchers have sought to develop tools to support the activities of CIS. Some of the most predominant created over the years are presented below.
Coinciding with the beginnings of CIS research during the mid to late 1990s, Twidale and Nichols (1996; 1998) developed one of the first and most influential CIS support systems called *Ariadne*. This system was the first to specifically acknowledge the need for collaboration during the search and retrieval process. Up to this time, almost all information systems were designed with a single user in mind, seeking information individually. *Ariadne* included affordances allowing for collaborative browsing among group members, leading to collaborative information seeking, retrieval, and sharing being conducted within the system. The premise and groundwork that led to the design implementation of *Ariadne* were grounded in a series of studies investigating information behavior within conventional and digital libraries (Nichols & Twidale, 1998). Based on these studies, it was clear that groups of people needed technological support to help during their search for information. In addition to collaborative browsing, *Ariadne* also incorporated functionalities allowing users to share search information and visualize their search.

*Babble* was developed by Erikson and colleagues (1999) during the same time period as *Ariadne*. The main goal of this system was to create and maintain awareness among all users during the CIS process. Continuing the growth of CIS technologies during this time period, Ackerman and McDonald (2000) created *Café ConstructionKit* and *Collaborative Refinery*. *Café ConstructionKit* provided tools allowing for enhanced communication flows among multiple people. Similar to *Café Construction Kit*, *Collaborative Refinery* provided mechanisms for enhancing informal information during communication flows.

Using the previous CIS systems as a foundation, a new wave of CIS systems and tools were created starting in the mid-2000s. In 2005, Krishnappa (2005) developed a CIS tool named *MUSE* (*Multi-User Search Engine*) that supported synchronous, remote collaborative information seeking between two people. Similarly, Morris & Horvitz (2007) introduced *SearchTogether*, a web search tool aimed at enhancing collaboration. *SearchTogether* is a tool affording users to synchronously or asynchronously collaborate during Internet searches. The focus of this tool was three-fold: (1) to support awareness among searchers, (2) manage division of labor, and (3) account for persistence of information throughout the search process. Paul & Morris (2009) developed *CoSense*, a CIS system aimed at supporting sensemaking during collaborative web searches. By utilizing search visualizations and creating a visible timeline of searches, the functionalities of *CoSense* increase and support sensemaking.

*Cerchiamo* is a collaborative exploratory search tool created by Golovchinsky and colleagues (2008). The system allows teams of searchers to explore document collections in a synchronous manner. While each team member is searching for information, *Cerchiamo*
algorithmically mediates search activity by reordering search results and suggesting search terms based on the team’s actions. The mediation provided by the search system allows for higher productivity and efficiency.

One of the best known CIS systems developed in recent years is Coagmento (Shah, 2010a). Coagmento is one of the more advanced CIS tools, affording much functionality. It is a system built on client server architecture that allows groups of people to work together to find information within their web browsers. The system is a plug-in, and when downloaded it provides a toolbar and sidebar within a web browser. The main functionalities of the system are that it captures the process of CIS by affording the ability to collect bookmarks, snippets of information, and the final report, while also keeping track of the processes (search, share, interactions) inherently associated with CIS. The system is multi-leveled in that it captures information that the groups are finding, but also the set of processes utilized to find the information. This multi-level functionality is very useful for CIS but also for researchers to learn about the interactions groups of people utilize during the activity itself.

2.4.4 Individual Information Seeking and Cognition

In this section, I outline work investigating the role of cognition during individual information seeking. Through this work, we can see the importance of an individual’s cognition during the information seeking process, highlighting the need for understanding team-based cognition during the CIS process.

While there is a little current research examining the role of cognition in CIS, there has been significantly more work on cognition in individual information seeking (Wilson, 1997). Cognition has played an important role in understanding the individual information seeking process. There are four often-cited information seeking models: Wilson’s Model of Information Seeking (1981), Kuhlthau’s Information Search Process (1988), Ellis’ Model of Information Seeking Behaviors (1989), and Dervin’s Theory of Sense-making (1983). All these models explicitly mention the importance of cognition during the information seeking process. They also present cognitive aspects of individual information seeking.

Wilson (1981) specifically identified the importance of cognition in his explanation of “information needs.” Information seeking is dependent on the premise that there is an information need. This information need is then used to satiate three basic human needs: physiological,
affective, and cognitive (Wilson, 1981). Similarly, Kuhlthau (1988) outlined the importance of affective cognition during the information seeking process. The foundation of Kuhlthau’s information search process (ISP) model derives from Kelly’s (1963) personality construct theory that emphasizes the importance of human affection in constructing meaning of knowledge and/or information. Using this as motivation, Kuhlthau created a six-stage ISP model that sought to include and capture the affection and thought that impacts information seeking.

While less explicitly mentioned in Ellis’ model of information seeking behaviors (1989), cognition is also a fundamental characteristic within the model. Within the model, six general characteristics of information seeking are outlined—starting, chaining, browsing, differentiating, monitoring, and extracting. Each of these characteristics is descriptive of the decision-making process that occurs during the information seeking process. Cognition is a fundamental aspect of these characteristics. Finally, Dervin’s theory of sensemaking (1983) is not specific to information seeking but has been applied to many information seeking activities. Sensemaking is often viewed as a cognitively grounded process that helps humans bring meaning to a situation or experience by constructing knowledge from information (Weick, Sutcliffe, & Obstfeld, 2005; Klein, Moon, Hoffman, 2006).

These models have provided a foundation for understanding cognition during information seeking. They have also led to specific research investigating the relationship between cognition and information seeking. As highlighted by Marchionini (1989; 1995), cognitive science has the ability to aid and guide information seeking research. One research area within cognitive science that has been studied within the context of information seeking are mental models. Marchionini (1989) outlined the importance of considering that information seekers might have multiple mental models in regard to search systems and the information seeking process. Researchers have noted that mental models of information seeking often vary significantly in content and are constructed through a variety of means but are critical in helping to better design information systems (Matusiak, 2006; Zhang, 2008).

Researchers have also investigated different cognitive styles and their subsequent impact on the process of information seeking (Bellardo, 1985; Kim, 2001; Ford, et al., 2002). Cognitive styles are often used to refer to the different ways individuals organize, categorize, and process information (Riding & Rayner, 1998). These studies have found that different cognitive styles impact the information seeking process, and subsequent performance (Kim, 2001). Information seeking research has also utilized cognitively oriented frameworks: the utilization of cognitive
frames (Ingwersen & Jarvelin, 2005), and uncertainty orientation (Kuhlthau, 1993; Sorrentino & Short, 1986).

Clearly, cognition plays an important role in individual information seeking and has been a focus of much research. Some of the most influential models of individual information seeking highlight the cognitive aspects (outlined above). However, there has been less clarity on the role of team cognition in collaborative information seeking.

2.4.5 Social and Technical Aspects of CIS: Cognition is Missing

Both the social and technical perspectives have been influential in describing what takes place in terms of interaction between collaborators during CIS activities. As we develop a better understanding of the interactional aspects of CIS, we must also start to examine the cognitive aspects of CIS. In particular, we need to understand CIS from a team cognitive perspective. Understanding team cognition within CIS has the potential to further our understanding of why and how CIS occurs.

While researchers acknowledge cognition as being influential and important (Shah & González-Ibáñez, 2011), it has not been the primary focus of CIS research. Why is this the case? First, CIS research is still relatively new within the broader field of information seeking. Consequently, there has been a great deal of focus on laying the foundations of the field and much of that focus has been on understanding how users collaborate with each other and the role that technology can play in supporting that collaboration during CIS activities (Kelly & Payne, 2014). Furthermore, the growth of CIS tools has led to focusing on issues of usability and usefulness (Morris & Horovitz, 2007; Capra, et al., 2012).

The cognitive perspective of CIS has not been explored or utilized to the extent that it should. If the research community is to fully develop a conceptual understanding of CIS, then social, technical, and cognitive perspectives must be considered.

A recent review of the CIS literature by Shah (2010b) indicates that most CIS research focuses on social and technical perspectives. Cognitive work is hardly mentioned within the review. In addition to Shah’s review, this dissertation’s literature search also produced minimal results of cognitive research on CIS. Even less (almost non-existent) research is found when exploring the relationship of team cognition and CIS. Often, when cognition is investigated within CIS it is looked at from an individual level. Researchers explore the individual cognition
that has taken place during a CIS activity and then attempt to understand the impact individual cognition has on the greater collaborative collective.

During the development of the CIS system Coagmento, individual cognitive walkthroughs were conducted to understand how users understood and worked with the system from a cognitive perspective (Shah, Marchionini, & Kelly, 2009). Expanding upon Coagmento, during experimentation researchers found that users cognitive load during CIS is not more than an individual users load during information seeking (Shah & González-Ibáñez, 2011). Looking at cognition from a socio-emotional perspective, researchers propose a model of studying group’s affective relevance during CIS (González-Ibáñez & Shah, 2010). A cognitive work analysis was conducted on design researchers at Microsoft to further understand their motives for collaborative information retrieval (CIR). The study found that designers attempted CIR when they were new to the team, when information was ambiguous, and when needed information was not documented (Fidel et al., 2004).

Team cognition and CIS have very rarely been investigated together. In fact, the only research study that has come close to investigating them was work by Paul & Reddy (2010) who explored the notion of sensemaking during CIS. Sensemaking traditionally is a cognitive process that allows humans to “understand” their environment. In recent years, this process has been extended to the team cognition level, giving way to the concept of collaborative sensemaking. This research viewed sensemaking as an important aspect of CIS within the medical domain, and sought to conceptually understand how the two are related. This is the only study of significance that has taken a team cognitive perspective and utilized it within CIS. While a few others have suggested the importance of team cognition within CIS, no one has taken the initiative to empirically explore the two together.

Overall, there is very little team cognition research within the CIS community. In comparison to the rest of the background, this section is sparse. This is not due to a lack of searching for relevant literature; rather, the sparseness accurately represents the lack of CIS and team cognitive research.

2.4.6 Summary

CIS is a relatively new but growing field. This section reviewed the conceptualization of CIS, the development of CIS models, the empirical work that has been presented within the social and
technical stream, the importance of cognition within individual information seeking, and the relationship between team cognition and CIS. While there is a wealth of research within CIS, significant gaps persist. First, little is known about how people approach CIS and the specific process of CIS from a step-by-step perspective, leading to a lack of CIS models. In addition, while the social and technical streams of CIS research produce many important findings, little work has been done from a cognitive or team cognitive perspective. To fully understand CIS, researchers must consider social, technical, and cognitive perspectives.

2.5 Chapter Summary

This background covers many different research communities, yet they all are related to each other. CIS is fundamental to the team decision-making process, but its importance is often implicitly assumed. The team mental model construct has proven to be a critical component to the team decision-making process, but has not been explored within CIS. Finally, very few models have been produced that help understand how teams approach CIS. In addition, CIS has a rich history of both social and technical research but little cognitive research.

This background highlights the following significant research gaps, leading to the development of the research questions investigated in this dissertation:

1. While information seeking is often acknowledged as a critical part of the decision-making process, the concept of CIS is rarely viewed as being important to team decision-making.
2. Many models have been found to make up an overall team mental model, but the concept of a team mental model within the context of CIS has never been explored.
3. CIS lacks the development of models to help the community better understand how teams approach the activity. In addition, CIS has been explored from social and technical perspectives, yet very little work has focused on the cognitive perspective, with almost none focusing on team cognition.

I now turn our attention in the following chapters to the studies examining these issues.
Chapter 3

Study 1- Co-located: Design & Methodology

This chapter provides an overview of study 1’s design and research methodology. The following sections describe the rationale for choosing the methods, an overview of the procedures for pilot and main study teams, a description of data collection and analysis techniques, and the methods employed to assure validity and reliability.

3.1 Research Site and Equipment

All of the studies were conducted in the User Science and Engineering Lab located in 314 IST. This is an experimental lab divided into two areas. The first area houses a modular experimental space containing six physically isolated computer terminals. The second area, utilized for this study, is an open meeting space located in the back of the lab. This area is larger than the experimental space and contains a large conference table in middle of the room, surrounded by whiteboards and other desks. Before participants entered the lab, all whiteboards and desks were cleared. Once participants arrived, they were seated at the large table, where three laptops were aligned in a horizontal manner. To ensure that web searching was not influenced, previous history and website data were erased before each study session.

3.2 Research Approach: Qualitative Methods

Qualitative and quantitative research methods have many different strengths and weaknesses. In the past, I have successfully utilized both methods. For this research study, I utilized qualitative methods for the following reasons (Mason, 2002; Patton, 1980):

- The open-ended and exploratory nature of this research best allows for qualitative methods. The goal of this study is to begin to understand the motivations, nature, and characteristics of CIS approaches and team cognition during CIS activities.
Consequently, I do not have any a-priori hypotheses about the nature and characteristics of the approaches or team cognition that could be tested through quantitative methods. Therefore, qualitative methods allow me to identify the general themes in the research and then iteratively refine these themes to develop theoretical constructs.

- I am not studying a large population or dataset, variables that would be useful to employ quantitative methods. Rather, I am examining small teams to understand their cognitive activities and social interaction. Using qualitative methods, such as interviewing, I am able to explore cognition and interaction issues that are specific to each team.
- Qualitative methods allow for an in-depth and thick description of the phenomena being studied. This rich description allows for an understanding of the implicit nature of the participant’s work, which they are often unable to articulate.

### 3.3 Study Procedure

Below, I describe the procedures for both the pilot study and main research study.

#### 3.3.1 Pilot Study

The goals and objectives of the pilot study were four-fold. First, I wanted to ensure that the research procedure adequately captured the data. Second, I wanted to test whether the study could be completed within the allocated time period. Third, I used the pilots for concept generation. Concept generation is a procedure that the individuals and teams conducted to produce concepts that would later be used by participants in the main research studies. Finally, it was important to get feedback from the participants on each part of the study’s procedure. This allowed participants to indicate areas of the study that were unclear and ways to improve the overall study.
3.3.2 Participants

Participants for the pilot studies were recruited from summer and fall undergraduate classes in the College of Information Sciences and Technology. A total of 12 participants completed the pilot studies- 3 two-person teams (dyads) and 2 three-person teams (triads). The majority of the participants were freshman to juniors. The large majority of the participants were IST majors (67%), with three other majors also represented: Eberly College of the Sciences- 17%, College of Liberal Arts- 8%, DUS- 8%. Participants reported that they had worked on an average of 10 student teams, and were comfortable working in teams (Table 4). Upon completion of the study, each participant was paid $30.00.

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<td>College of Liberal Arts</td>
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<tr>
<td>DUS</td>
<td>8%</td>
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Table 4. Pilot Study Demographics

3.3.3 Task and Procedure

The pilot study procedure was the same for dyad and triad teams. Each study lasted approximately 2 hours. Participants were brought to the back of the lab and asked to take a seat at each of the laptops. First, participants were introduced to the study and asked to sign an informed consent. Then, a short demographic survey was given to each participant (Appendix A). The researchers then explained that the participants would be working in teams to complete three CIS tasks. The CIS tasks were developed and adapted from tasks that had been utilized for CIS lab research by Shah & González-Ibáñez (2010). The content and scope of the tasks were designed to ensure that that they were familiar enough for the participants to understand but, at the same time, general enough that the teams would have to search for the needed information to complete the
tasks. The tasks were time limited to ensure that the study could be completed in a reasonable time period. Once the tasks were presented, a brief explanation of CIS was provided. Following this explanation, each participant was presented with the first CIS task. Participants were advised that they could use any resource available to them, such as the computers, their previous knowledge, and their teammates. Participants were given 15 minutes to complete the first task. The first task was:

“The National Cancer Institute has hired your team to identify the top 5 causes of pancreatic cancer. It will be up to your team to decide what those top 5 causes are. However, you must also provide some reasons (including substantial facts and evidence) why your team thinks these are the leading causes of pancreatic cancer. You may present your findings in whatever way you think is best, whether it is bullet points or a formal paper. You may utilize any website that you find useful as was your individual knowledge of the subject.”

Once time had expired, or if the team completed the task before time expired, they were given the second task, lasting 10 minutes:

“In addition to reporting the top 5 causes, the National Cancer Institute would now like you to indicate at least 3 lifestyle choices that have been found to prevent pancreatic cancer. Please add this information to the document from task 1. You may utilize any website that you find useful as well as your individual knowledge of the subject.”

When the team completed task 2, they were given the final task, lasting 5 minutes:

“As a last request, the National Cancer Institute would like you to discuss different technologies that are helping with early detection of cancer. Please add this information to the document from task 1. You may utilize any website that you find useful as well as your individual knowledge of the subject.”

All three tasks were audio and video recorded. When the team completed the final task, the researchers proceeded to the next part of the study. Following the tasks, interviews were conducted with each participant to gather feedback. These were short interviews aimed at capturing if the participants understood the tasks and felt
they could adequately complete them. The interviews were audio recorded so the feedback could be logged and stored for further review.

After the interviews, participants completed the process of concept generation. This process is adapted from work presented by Langan-Fox & Langfield-Smith (2000), who provide techniques, methods, and analytic approaches for team mental model research. More specifically, they outline 6 phases specific to method design for mental model research. For this research, *Phase 4: Generate Concept Pool and Pilot Test* and *Phase 5: Derive the Final Concept Pool* were followed to generate concepts for the concept mapping portion of both the pilot and main research studies. The next steps of the pilot study are closely adapted to the phases shown in Figure 4.

![Figure 4. Concept Pool Generation from Langan-Fox & Langfield-Smith (2000)](image)

Participants were asked to individually complete the first portion of concept generation. Each participant was provided his or her own whiteboard. The concepts that each participant generated were written on the whiteboard. A sheet of paper was given to each participant with high-level prompts relating back to the CIS tasks they had just completed (Appendix B). The prompts were as follows: *The Task Itself, Team Interactions, Resources Used, Information Seeking, and Information Sharing.* Based on these prompts, participants were then asked to generate as many concepts as they could for each prompt. Fifteen minutes were given for this initial individual concept generation session. Following concept generation, each participant ranked the generated concepts based on their perceived importance (Figure 5). A scale of 1-10 was used with 1 being least important and 10 being most important. Participants were given 5 minutes to write their importance ranking next to each concept on the whiteboard. Once each participant finished ranking concepts, the team reconvened.
The team then systematically reviewed each participant’s concepts and their importance ranking. The goal of having the team review each participant’s concepts and importance ranking was to have the team reach a consensus on which concepts were important. During this review period, any concept that was individually rated a 5 or below was excluded and defined as not important. The team spent 15 minutes reviewing concepts. Next, the team spent an additional 15 minutes combining concepts that were synonyms or viewed as being the same, resulting in having only 1 concept represent the same conceptual idea. Once the concept pool was reduced, the team identified the 15-20 most important remaining concepts. The entire process of reducing the concept pool and eliminating concepts was audio recorded.

![Concept Generation and Importance Ranking](image)

Figure 5. Concept Generation and Importance Ranking

Once the concept generation portion of the study was completed, researchers introduced the team to concept mapping. The researchers explained what a concept map is and how to produce one. To better explain a concept map, the researchers provided a tutorial on concept mapping using the focus question: “How do you choose a college major?” This concept map topic was chosen due to its saliency to the participants. The researchers surmised that it would be easy for the participants to grasp due to their relevancy with the topic. During the tutorial, the researchers walked the participants through the process of concept mapping, using input and content generated from the participants.

Next, after the participants indicated an understanding of concept mapping, participants individually produced a declarative concept map with the focus question being: “How did you collaboratively find information as a team during the tasks?” Similar to concept generation,
participants had their own whiteboard to produce their concept map. The concepts generated earlier in the study were used for this concept map. Individuals were provided 20 minutes to develop their individual declarative concept map (Figure 6).

Finally, once participants finished concept mapping, they were interviewed about the process of concept mapping. These interviews focused on ensuring that the participants accurately understood how to concept map and that the researchers properly explained it. A list of all the interview questions can be found in the Appendix, along with the complete pilot study/concept generation research protocol (Appendix D).

Figure 6. Concept map produced during piloting

3.3.4 Pilot Study Feedback

A majority of the pilot teams feedback was positive regarding the CIS tasks, explanation of research concepts, and procedures. The most important feedback related to the CIS tasks and the amount of time associated with each task. Specifically, multiple teams indicated that the amount of time for task 1 (15 minutes) was adequate but the time for task 2 (10 minutes) was too much and there was not enough time for task 3 (5 minutes). In response to this concern, I changed the allotted time for each task in the research study to: task 1- 15 minutes, task 2- 5 minutes, and task 3- 10 minutes. The feedback given about the task’s times makes sense because task 1 and 2 are directly related to each other, meaning that the teams were utilizing information found in task 1 to help them quickly finish task 2.
I viewed the pilot studies as successful for three reasons. First, the research design was confirmed as being able to successfully capture the appropriate data within the confines of the study’s time. Second, participants provided feedback that allowed for timing adjustments during certain procedures. The change in the task’s times did not change the overall research design, rather better allowed the participants to complete the required tasks. Finally, participants provided feedback regarding the process of generating concepts and developing individual declarative concept maps. This feedback allowed for minor changes in how the researchers explained concept mapping during the research study. Overall, participants indicated that they felt the pilot study was valuable, and that the only significant aspect of the design that they would change would be the CIS task’s times.

3.3.5 Pilot Study Concept Generation

One of the most important outcomes of the pilot studies was the generation of a “parking lot” of concepts. This grouping of concepts was critical to participants completing concept mapping during the main research study. Due to the time constraints of the main research study, rather than spending extra time developing each of their own concepts, participants need concepts that they could pull from to create their own concept maps. To understand what concepts were most important across all teams and create a “parking lot” of concepts, the researchers analyzed the aforementioned concepts that each team generated during piloting. This analysis is adapted from the aforementioned work by Langan-Fox & Langfield-Smith. Two researchers simultaneously and systematically analyzed the concepts that were generated most frequently across all teams. The researchers completed this analysis together because there had to be discussions on related/synonyms of concepts across all teams. Using the concepts each team chose as being most important, a total of 87 concepts were analyzed between the 2 researchers. After the researchers completed the analysis, a total of 22 concepts were chosen based on frequency as being most important across all pilot teams. These concepts were used as the “parking lot” for participant’s concept mapping during the main research study. These concepts can be found in the appendix (Appendix C).
3.3.6 Main Research Study

This section reviews the main research study. The goals of this study were to begin to answer the research questions stated in the introduction.

3.3.7 Participants

For this study, participants were recruited from fall and spring undergraduate classes within the College of Information Sciences and Technology. A total of 28 undergrad participants completed the study, resulting in 6 teams of 3 people (triads) and 5 teams of 2 people (dyads) (Table 5). Most of the participants were juniors. Similar to the pilots, a large majority of participants were IST majors (64%) with 6 other majors being represented. Participants also reported working on an average of 8 student teams, and were comfortable working within teams (Table 5). Upon completing the study, each participant was paid a total of $30.00.

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<td>36%</td>
</tr>
<tr>
<td>Major</td>
<td></td>
</tr>
<tr>
<td>College of IST</td>
<td>64%</td>
</tr>
<tr>
<td>Other Majors</td>
<td>36%</td>
</tr>
<tr>
<td>Average # Teams Worked On</td>
<td>8</td>
</tr>
<tr>
<td>Average Comfort Level Working in Teams</td>
<td>4.32 of 5</td>
</tr>
</tbody>
</table>

Table 5. Study Demographics

3.3.8 Task and Procedure

Similar to the pilot study, this study lasted approximately 2 hours. Participants were asked to sit at the laptops and complete an informed consent form. Once they finished the form, they then individually filled out a demographic survey. Once they completed the survey, the researchers explained the study to the participants. Unlike the pilot studies, the researchers described both CIS and team mental models in depth. Before moving forward with the study, the researchers made sure that each individual participant understood both concepts. Ensuring that participants
fully understood the concepts was important to the success of the study. If participants did not understand one or both of the concepts, they wouldn’t be able to draw concept maps or answer questions about team cognition/team mental models. Once the researchers felt that each participant understood the concepts they proceeded with the CIS tasks. The CIS tasks portion of the study is the same as the pilots. The tasks in this study were the same as the tasks in the pilot study (Section 3.3.3). As previously noted, the only change in the CIS tasks was the amount of time given to complete each. The tasks were audio and video recorded. After the teams completed the tasks or 30 minutes expired, the team members were separated to conduct the next part of the study.

Concept maps and the process of developing them were explained. Similar to the pilot study, 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 concept map, and then provided feedback on the map. In addition, the researchers also explained that there are two types of concept maps: declarative and procedural, and that the participants would be producing both. Once the participants were comfortable with concept mapping process, the researchers explained that one or two (depending on team size) of the participants would be producing an individual declarative concept map while the other would be interviewed about the CIS tasks.

Participants produced an individual declarative concept map with the focus question being: How would you explain how you view collaborative information seeking? Participants were placed at their own whiteboard and given the “parking lot” or concept pool that was produced during the pilot studies. Each participant was explicitly told that he or she 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). Twenty minutes were provided to complete the individual declarative concept map. Photographs were taken of all the declarative concept maps (Figure 7). Gathering individual concept maps allows for understanding the individual’s cognitive structure, as well as the ability to aggregate the individual maps to a team level.
While the other team participant(s) were developing concept maps, the remaining participant was interviewed about the CIS task and issues of team cognition. These were semi-structured cognitive interviews that utilized verbal probing techniques. Verbal probing takes place when the participant answers a question. Once the interviewee answers, the interviewer asks for more specific information relevant to the question or the specific answer, essentially “probing” further into the response. Willis (1999) provides specific examples of verbal probes (Figure 8).

<table>
<thead>
<tr>
<th>Comprehension/ Interpretation probe:</th>
<th>What does the term &quot;outpatient&quot; mean to you?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraphrasing?:</td>
<td>Can you repeat the question I just asked in your own words?</td>
</tr>
<tr>
<td>Confidence judgment:</td>
<td>How sure are you that your health insurance covers drug and alcohol treatment?</td>
</tr>
<tr>
<td>Recall probe:</td>
<td>How do you remember that you went to the doctor five times in the past 12 months?</td>
</tr>
<tr>
<td>Specific probe:</td>
<td>Why do you think that cancer is the most serious health problem?</td>
</tr>
<tr>
<td>General probes:</td>
<td>How did you arrive at that answer? Was that easy or hard to answer? I noticed that you hesitated - tell me what you were thinking?</td>
</tr>
</tbody>
</table>

Figure 8. Verbal Probing Techniques from Willis (1999)
In addition to verbal probing, techniques from the critical decision-making method were adapted for use in these interviews (Klein, Calderwood, & Macgregor, 1989). Specifically, participants were asked to think retrospectively back to the CIS tasks and attempt to explain what they were thinking at a certain point in time during the task. The content of the interviews were aimed at understanding: (1) how the team approached CIS, and (2) understanding if and how team cognition, more specifically team mental models, developed during the CIS tasks (Interview Guide- Appendix F). Like the declarative concept maps, 20 minutes were allotted for this part of the study. When 20 minutes expired, the participants switched research activities – the participants who were concept mapping were then interviewed and the interviewee concept mapped. This allowed every research participant to produce both a declarative map and be interviewed.

Once all participants produced declarative concept maps and were interviewed, 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? Researchers explained that the team should map the entire CIS process from beginning to end, noting where and when they perceived team cognition to have played a role. Thirty minutes were provided to complete the procedural map. Unlike the individual declarative concept maps, a “parking lot” or concept pool was not provided during team procedural concept mapping. I took this approach because there was increased time and the availability of two or three participants being able to generate concepts. The team procedural concept mapping was audio and video recorded. Photographs of the procedural concept maps were also taken (Figure 9).
3.4 Data Collection and Analysis

The research study procedure allowed for the collection of many different types of data (Table 6). In this section, I outline the specific types of data that were collected, the reasoning for their collection, and the analytical technique used to understand the data. Findings of the analyses will be reported on in the next chapter.

<table>
<thead>
<tr>
<th>Data Collection Method</th>
<th>Number of Participants</th>
<th>Data Collection Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIS Task Video</td>
<td>28</td>
<td>11 Teams</td>
</tr>
<tr>
<td>Individual Cognitive Interviews</td>
<td>28</td>
<td>28 Interviews</td>
</tr>
<tr>
<td>Individual Declarative Concept Maps</td>
<td>28</td>
<td>28 Concept Maps</td>
</tr>
<tr>
<td>Team Procedural Concept Map</td>
<td>28</td>
<td>11 Concept Maps</td>
</tr>
<tr>
<td>Team Procedural Video</td>
<td>28</td>
<td>11 Teams</td>
</tr>
</tbody>
</table>

Table 6. Data Collection
3.4.1 Collaborative Information Seeking Tasks Video

Videos of the CIS tasks were important in understanding both cognition and interaction. These videos act as observations of the CIS tasks. Observations are important for a number of reasons: 1) obtaining information on the practices and processes of work, (2) capturing non-routine events and unanticipated issues that arise during work, and (3) exploring surrounding activities that impact work (Denzin & Lincoln, 1994). Also, in team cognition research, observations play an important role in capturing continuous concurrent cognition (as opposed to retrospective) (Cooke et al., 2000). The videos also allow for a better understanding of the set of interactions that occurred during the CIS tasks. Learning about the interactions that occur during the task will bring forth insights into cognition.

Analysis:

Due to the large volume of data gathered within this study, I focused the majority of my analysis for this study on the cognitive interviews and concept maps. I used the themes identified within the cognitive interviews as a basis for observing the video recordings. My goal was to note if the themes found in the thematic analysis of the cognitive interviews were also visible during the team’s CIS activities. This process included watching the videos and specifically noting instances that either confirmed or contradicted the themes found in the cognitive interviews.

3.4.2 Individual Cognitive Interviews

Cognitive interviews are important to understanding both the interaction and cognition that occurred during the CIS tasks. The goal of a cognitive interview is to learn about the cognitive processes of human behavior and their associated interaction. These interviews are an approach to improving memory and retrieving cognition specific to an exact context or time period (Fisher and Geiselman, 1992). During a cognitive interview, the interviewer asks the interviewee to retrospectively describe what they were thinking during a specific point in time. This often results in the participant revisiting the context and explaining their individual cognition and in some cases team cognition. In addition to describing their cognition, participants often explain interactions that are closely linked to the cognition. As previously noted, in this study, cognitive interviews were paired with verbal protocol techniques and the critical decision method. Utilizing these methods allows for a greater understanding of the thought process associated with a team’s
CIS approach. In addition, participants discussing cognition at an individual and team level allows the researcher to identify if and how team cognition develops (specifically a team mental model).

**Analysis:**

The interviews were analyzed and coded using thematic analysis. More specifically, I followed Braun & Clarke’s (2006) canonical 6-phase methodology to successfully conduct thematic analysis. This process (Table 7) depends on the researchers becoming familiar with the data, systematically identifying codes and themes, and then defining and naming the common themes found across the data. I selected this analytical approach because it is widely considered one of, if not the most, effective means to analyzing qualitative interview data.

Since this research is focused on teams, the analysis of the interviews needed to go beyond only the individual. I completed the analytical process at three different units of analysis: individual, individual teams, and all teams. The process of analyzing all three of these is as follows:

- The analysis needs to be focused and oriented to the research questions.
- Each individual interview within the team was transcribed, coded, and thematically analyzed. This stage utilized all 6 phases of thematic analysis.
- The themes from each individual interview within that team were collated and then analyzed to develop overall team themes based on the individual themes. Phases of thematic analysis that were applied at this stage were phases 4, 5, and 6.
- The team themes from each team were collated, and then analyzed across all teams to develop overall study themes. Phases of thematic analysis that were applied at this stage were phases 4, 5, and 6.
- Documents containing the themes for individuals, teams, and across all team were created.
<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Familiarizing ourselves with the data</td>
<td>Transcribed the notes taken during the interview and read through the transcriptions to ensure a general understanding of the interviews.</td>
</tr>
<tr>
<td>(2) Generating of initial codes</td>
<td>Labeled segments of data in a systematic way across all of the interviews.</td>
</tr>
<tr>
<td>(3) Searching for themes</td>
<td>Reviewed individual codes and identified preliminary themes.</td>
</tr>
<tr>
<td>(4) Reviewing themes</td>
<td>Reviewed preliminary themes to ensure that they made sense across the entire data set.</td>
</tr>
<tr>
<td>(5) Defining and naming themes</td>
<td>Continuously refined each theme, identified a specific name for each theme, and defined the boundaries of the theme.</td>
</tr>
<tr>
<td>(6) Producing the report</td>
<td>Presented themes with interesting examples from the data that illustrate the individual themes.</td>
</tr>
</tbody>
</table>

Table 7. Braun & Clarke’s (2006) six-phase approach to thematic analysis

### 3.4.3 Individual Declarative Concept Map

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 allow 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 team processes, team cognition, and team mental models related to a specific context. Concept mapping captures data that allows for a greater understanding of this studies objectives. Specifically, concept maps have been utilized many times to understand mental models and team mental models (DeChurch & Mesmer-Magnus, 2010; Johnson, 2005; 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.

Constructing a concept map consists of many attributes:
• **Concepts** - Concepts can also be called nodes, and are defined as events or objects. The concept is usually labeled by one word but can also consist of a few words.

• **Linking words or phrases** - Linkages refer to the word or words on a linking line that specify the relationship between two or more concepts.

• **Propositions** - Statements about an object or an event that are constructed when two or more concepts are linked together to form a meaningful relationship.

• **Hierarchy** - A concept map may be hierarchical. If a hierarchy is used, general concepts are usually at the top with more specific concepts trending downward.

• **Cross-links** - Relationships between concepts that are in different segments or domains of the map. Usually linkages are between two concepts that are spatially close. Cross-links are often linked between two concepts that are not close to each other.

A concept map must 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. Content for the map may be given to the concept mapper, or the mapper may be asked to produce it. If content is given to the mapper, it can range from concepts, linkages, and hierarchical structures, to a variation of all three. For this study, a list of concepts, known as a “parking lot”, was given to the participants (Novak & Cañas, 2007).

Within this study, concept maps were used to capture the cognitive structure and content associated with CIS. Maps aimed at both declarative and procedural knowledge were collected. Understanding both declarative and procedural knowledge will help understand how people think about CIS and better explain the cognitive and interactional processes of CIS.

The 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, within this study, these maps allow for participants to describe how 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. This knowledge is represented at the individual level, but when individual maps are aggregated or analyzed together, knowledge at the team level is described. Aggregated individual concept maps are also a method to identify attributes of team mental models. Concepts and
relationships that are found throughout many individual maps are viewed as information important to the team mental model.

**Analysis:**

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 along with other measurements (Cañas, Bunch, & Reiska, 2010). This analysis depends primarily on counting the concepts, propositions, linking phrases, and branch counts within the map. Then, dependent on the frequency counts of each aspect of the map, a taxonomy score is derived (1-5) indicating the value and strength of the map. This analysis is helpful in understanding and assessing the map itself, but also helps with assessing the content within the map. Specifically, it allows for the analysis of the most central concepts within the map to be indentified. The centrality of a concept is defined by the amount of linking phrases attached to the concept. The most central concepts not only indicate perceived importance, but also identify how participants cognitively orient them within the entire map. The more central a concept, the more cognitive significance the participant has assigned to the concept.

After the concept maps were photographed and saved, I used CmapTools, from the Institute for Human and Machine Cognition, to translate the maps into a digital format. With an extension of CmapTools, CMap-analysis, the counts of concepts and propositions in each map were reported (Cañas et. al., 2010). To better understand the content of the concepts centrality, I extended the analysis to across all teams. In addition, in this analysis, I added the component of frequency. Comparing the most frequent and central concepts has the potential to help us understand the overall importance of the concepts. By exporting each list of concepts from CmapTools, each participant’s concepts were added to a Microsoft Excel spreadsheet. Then, all concepts from the teams were combined and counted for frequency. Once the concepts were counted for frequency, they were then sorted from high to low.

After analyzing for frequency, CmapTools was again used to count for centrality. Centrality was defined to be the sum of the number of links going into and out of a given concept. 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.
3.4.4 Team Procedural Concept Map

The team procedural concept map is important to understanding both the approach teams take to 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 process of CIS. Teams describe how they thought about this process by identifying specific concepts that occurred throughout the CIS task, some specific to team cognition.

Analysis

The team procedural concept maps were analyzed qualitatively using a method first introduced by Zaff & colleagues (1993). This method was later adapted by Brewer (2005), which I used for the analysis of the team’s concept maps. 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.

Transcription of the concepts maps was completed utilizing the CMaps software. The concept maps were transcribed using the software to replicate exactly what was drawn on the white boards – the content of the concepts and propositions were not changed and the spatial proximity was not altered. Once the maps were transcribed they were reviewed and verified using transcriptions of the discussion that took place during the concept mapping period. 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 verifying that the map accurately represents what the team meant to describe. While the concept maps were verified using this data, the maps were only edited if an omission or error was apparent. The goal was to keep the maps as close to their original content as possible.

The goal of this analysis was 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, the 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 (Figure 10). A thematic color-coding method conducted by Brewer (2005) was adapted for this study. Yellow was used
for resources that the team used during CIS. Red identifies concepts that are directly related to the CIS task. Blue represents critical decision-making areas during CIS. Purple identifies concepts specific to information. Pink was used to code concepts focused on the individual team member. Light blue was used for team oriented understanding or cognition. Orange was used for concepts that relate to the process of searching or researching. Dark green was used for concepts aimed at presenting information or the final document. Finally, lime green was used to represent collaboration and communication concepts. Concepts that were left white represent obscure concepts that do not fall within any of the themes.

Figure 10. Color Coding Guide

The process of coding the maps is iterative and requires constant review of the color-coded themes. Once the coding is completed, interpretation of the maps may begin. Color-coding of the maps provides two major benefits in interpreting the maps: (1) the color codes make it easier to identify the overall content of the map through being able to identify “clusters” of content and the relationships between the codes, and (2) the spatial relationships within the map are made clearer due to coding. Figures 11 and 12 show the difference between the original black and white concept map and the color-coded map.
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, unions, and clusters). The goal of interpreting a concept map should be to summarize the information throughout the map in a way that develops themes. A methodology for interpreting concept maps was outlined by Zaff & colleagues (1993), in which they highlight the importance of identifying “kernels.” A kernel is a cluster of different concepts that are connected or relate back to one important concept. While kernels are simply key concepts and clusters of concepts, they are often defined by these characteristics: (1) they have a large number of connected concepts, (2) they are often bounded by a parent concept that results in multiple
layers of connected concepts, (3) they are invariant across maps, and (4) represented by declarative words (Zaff et al., 1993). 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. Referring back to the previously color-coded concept map, the concepts of individual insight, discussion, and developing an answer and their linked concepts are all considered to be kernels. These concepts are connected to multiple other concepts and the overall concept map is mostly bound by these three concepts.

In addition to identifying kernels, relationships between important concepts and clusters of concepts can be indentified within 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 goals of the analysis of 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, I analyzed the maps for kernels (key concepts/clusters of concepts), the overall process of CIS based on connected concepts and their relationships across the start to finish timeline, and the relationships among concepts that led to themes. Each concept map was analyzed using this method and then analyzed across all maps to develop overall themes. So, the analysis for each team concept map resulted in findings relevant to: (1) the CIS process or approach, (2) themes within the map, and (3) important concepts or kernels.

3.4.5 Team Procedural Video

Similar to the CIS task video, the team procedural video allows for the gathering of observations and insights into the process of the concept mapping process.

Analysis

A review of the video taken during the team procedural concept mapping was completed. Specifically, I watched the video during the editing/reviewing of the team procedural concept maps to ensure that the information represented on the maps was representative of what the team actually meant.
3.5 Validity and Reliability

Validity and reliability of research are critical to evaluating the trustworthiness and integrity of the findings. Regarding validity, both internal and external validity are needed. The following describes efforts to increase validity and reliability within this study.

**Internal Validity:** One of the most impactful ways to increase the internal validity of a research study is to ensure that the findings are credible. To assure that my findings are credible, I performed data triangulation. Triangulation is the process of collecting data on the same research topic from multiple sources using multiple methods (Lincoln & Guba, 1985a). Within this study, many different data sources were collected: interview transcripts, video observations, individual concept maps, and team concept maps. An example of triangulation in this study was done to understand how teams approach CIS. To confirm team’s CIS approaches I used data from the CIS video observations, the individual interviews, and the team procedural concept maps. These sources and data collection methods were used in conjunction with each other to provide and ensure that the data collected was accurate.

**External Validity:** I collected data to provide a thick description of the nuances of the context and the assumptions of the research study (Erlandson et al., 1993). Providing the details of both the data collected and the analysis allows an individual to check its appropriateness in other contexts. In addition, this study was developed and has been grounded within the literature of other studies that are examining similar research phenomena.

**Reliability:** The reliability of findings is judged by the data being consistent and the findings being dependable and trustworthy (Lincoln & Guba, 1985b). To ensure that the data is consistent I closely analyzed it and compared/corroborated it with other similar research studies (Campbell, 1997). Trustworthiness of the research is achieved by being transparent and revealing the entire research process. I have included every step of the research procedure, also identifying feedback that was received during the pilot studies and incorporated in the research study. Research materials for the study are also included in the Appendix. Furthermore, numerous examples, photographs, and quotations from the data support the findings and analysis.
3.6 Chapter Summary

In this chapter, I outlined the tasks and procedures for both the pilot studies and the main research study. I then highlighted the data collected and the analytical technique that is used for each data in the main research study. Finally, I concluded by reviewing techniques to ensure validity and reliability within this dissertation. In the next chapter, I present findings from study 1.
Chapter 4

Study 1- Findings: Understanding CIS Approaches and The Development of Team Cognition in a Co-located Environment

In this chapter, I present findings from Study 1, which focused on understanding how teams approach CIS and develop team cognition within a co-located setting. More specifically, I outline the following findings:

- Four approaches of collaborative information seeking
- Awareness within teams
- Individual cognitive acclimation period
- Triggers of CIS and team cognition
- Shared understanding of information importance
- The development of a team mental model
- The analysis and interpretation of individual declarative and team procedural concept maps

4.1 Approaches of Collaborative Information Seeking

These approaches were identified during cognitive interviews where participants explained how they approached and collaboratively sought information. In addition, the approaches were also triangulated from team concept mapping data and video data. Through analysis, I identified four different CIS approaches: *Individual to Team Variation 1*, *Individual to Team Variation 2*, *Team to Individual*, and *Team* (Table 8). It is important to note that while I have identified four approaches, there are probably a number of different approaches to CIS. I briefly explain each of the approaches identified in this study and then provide a visualization of the approach. Specific features highlighted within the approaches will later be discussed within the team cognitive activities section.
<table>
<thead>
<tr>
<th>Approach</th>
<th># Of Teams That Utilized The Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual to Team Variation 1</td>
<td>5</td>
</tr>
<tr>
<td>Individual to Team Variation 2</td>
<td>2</td>
</tr>
<tr>
<td>Team to Individual</td>
<td>3</td>
</tr>
<tr>
<td>Team</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 8. Approaches Utilized by Teams

### 4.1.1 Individual to Team Variation 1 Approach

The *individual to team variation 1* approach was the most frequently used CIS approach in the study with 5 teams utilizing it - Teams 6, 8, 10, 12, & 16 (Figure 13). This approach began with the individual team member. At the beginning of this approach, each team member individually thought about the CIS task. Individuals indicated that they began with individual focus because they needed to first understand the task on their own before contributing to the rest of the team. After the team member understood the task, they then individually searched for background information relevant to the task. Once a team member felt comfortable with their own understanding of the task and gathered enough background knowledge, they initiated team interaction by communicating with other team members. On average, the individual thought period only lasted 30 seconds to 2 minutes, making it a very short part of the overall CIS process. During this time period, participants indicated that a team mental model had not yet started to develop; rather, individuals had their own individual mental models of information seeking.

After a team member initiates contact with the rest of the team, the team has a discussion. This discussion is aimed at ensuring that everyone understands the task and their team goals. If everyone is on the same page, the team discusses a course of action to search, share, and track information. In this approach, team members decided to divide up the task and search for information individually. Dividing the task varied depending on the team but most teams assigned each team member a specific part of the task. Also, during this initial team discussion a leader may or may not emerge. Most of the teams utilizing this approach did have leaders, often the person who first initiated team interaction. During team discussion, the leader often helped to
divide the task up and figure out an approach for searching, sharing, and tracking information. This initial team discussion is thought to be where the team mental model first starts to develop.

Once the initial team discussion has ended, team members then individually searched for information. Once a team member identified a piece of information that they deemed as being important for the overall team’s goals, they shared it. The finding and sharing of information is thought to be the trigger that initiates CIS. After team members have individually searched, they reconvene and decide what information is important to completing the task. Information importance is dependent on how frequent information appears across multiple sources, and the overlap of information that is found by all team members. Once information is deemed important, the team then completes one last individual search focused on gathering more important information. Finally, the team comes back together and decides what information should be included in their final answer or report, and then prepares their document. It is very important to understand that while team members are completing individual searches they are still working together as a team. There is continuous communication of shared information, leading to many discussions outside of the identified team discussions within this approach. During this period of collaboration, the team mental model may weaken or grow based on the effectiveness of the teamwork.
Figure 13. Individual to Team Variation 1
4.1.2 Individual to Team Variation 2 Approach

The *individual to team variation* 2 approach was only utilized by 2 teams - Teams 9 & 13 (Figure 14). This approach is very similar to variation 1. The difference between the approaches occurs after individual team members have finished understanding the task and gathering adequate background knowledge. In variation 1, the team members come together and have a discussion orienting themselves as a team. In variation 2, this initial team discussion does not happen. Rather, the individual team members began with individual information seeking. So, instead of discussing the task and goals with the team, they attempted to answer the question on their own without the consultation of the team. The lack of an initial team discussion in this approach resulted in it being the least collaborative of the four CIS approaches.

When collaboration did occur, it happened much later in the approach. After individual each individual has searched, and once a team member believed they had enough information relevant to the task, they then initiated the initial team discussion. This initial team discussion is much different than the discussion in variation 1. At this point in the approach, team members have already gathered a large amount of information. The goal of this discussion was to share what information had been found and identify an overlap of information within the team. During this team discussion, a leader emerged within one of the teams utilizing this process. Once the team discussion ends, team members reverted back to individual searching. The only difference between the rest of this approach and the rest of variation 1 is that the remaining steps within variation 2 are shorter because the team has already found a great deal of information. In regards to the development of a team mental model, the only difference between variation 1 and 2 is that the model starts developing later in this approach. This could possibly affect the development of the team mental model because of the shorter time that the team members worked together and communicated with each other.
Figure 14. Individual To Team Variation 2
4.1.3  Team to Individual Approach

Unlike the previous two approaches, the *team to individual* approach began with the team, not the individual. This was the second most frequently used approach with 3 teams utilizing it—Teams 7, 11, & 15 (Figure 15). This approach began with the team having a discussion at the onset of teamwork. The team discussion helps the team to orient itself to understand the task and understand the goals of the team. During this discussion the team decided how to individually break up the task, allowing for individual searching. This discussion also afforded the opportunity for a leader to emerge at the beginning of the task, something that often occurred during this approach. Once the initial team discussion has concluded, team members then started individually searching. During this individual search, team members shared information. Once the team finished individually searching, they came back together to discuss their findings and determine what is important among their found information. The team then completed another individual search specific to the information being deemed as important. Essentially, the later part of this approach is the same as the later parts of the individual to team approaches. The team discusses information together, then individually searches, then comes back together as a team and produces their final document.

Overall, this approach is significantly different than the previous two approaches because it begins as a team effort and then moves towards an individual search. This is completely opposite to the individual to team approaches. Since, the team collaborated from the onset; this allowed the team mental model to start developing from the beginning.
Figure 15. Team to Individual
4.1.4 Team Approach

The last approach was the most collaborative, but also the least utilized with only 1 team (Team 14) using it (Figure 16). Similar to the team to individual approach, this approach began with an initial team discussion aimed at orienting the team’s goals. In the previous approaches, the initial team discussion resulted in the team deciding how to divide up the task. However, during this approach, the team never divided up the task. Rather, once they discussed the task and what information to search for they moved to an individual search with constant communication. The individual search was still conducted on separate computers, but it was much different than the individual searching outlined in the previous approaches. In the previous approaches, individual searching consisted of each team member searching on their own and sharing important information with the rest of the team. In contrast, individual searching in this approach consisted of team members continuously communicating and explaining to each other what they are searching for and what they are finding. The individual searching process lasted for a short time period, until each team member felt familiar enough with their found information to transition into a team search.

Team search consisted of the team members moving to one computer and searching together. One person operated the computer and followed the suggestions of their other team members. The start of team search was based on the information that individual members found during their individual search. This type of search allowed the team to understand found information together. Once the team has found adequate information during the team search, they then had a discussion to determine what found information is important. Finally, the team has another discussion aimed at deciding how to prepare the final document. In regards to the team mental model, it starts developing from the onset, and it is assumed that it has the ability to be stronger than the other approaches due to shared searching and the subsequent shared understanding. The team who utilized this CIS approach indicated that they felt they had developed a strong team mental model of CIS.
Figure 16. Team
4.2 Role of Collaboration in CIS Approaches

When does Collaboration Occur?
While there are similarities and differences among the different approaches, the most significant difference between the approaches is when collaboration occurs. Team members indicated that collaboration was not something that randomly occurred. Rather, in these approaches, collaboration occurred either at the start of the tasks, or later in the tasks. In the Team to Individual and Team approaches, collaboration started immediately after the team received the tasks. On the other hand, in the Individual to Team approaches, collaboration only occurred after the individual thought and individual searching stage.

Teams who immediately approached the tasks from the team’s perspective utilized the Team to Individual and Team approaches. One team member described her initial thought process:

“My first thought was how we were gonna work together as a team to... divide, like jobs for the, to find our goal. And then how we were gonna work together so that we maximize our time, didn’t go over, and how we were gonna share the information so we both were on the same page.” (Team 14, #2)

Teams who first approached the task from an individual perspective utilized the Individual to Team approaches. Each of these approaches included an individual thought period, used to help the individual think about the tasks. A participant explained the importance of the individual thought period: “I think it was first based on every individual understanding what the general task was. And once every individual had this, they knew what we were doing, then, we all combined into a group.” (Team 16, #2) This individual thought process resulted in collaboration occurring later in these approaches.

How Collaboration Occurs
In all of the approaches, collaboration is initiated by a team discussion. Based on the initial team discussion, teams utilize one of two different approaches: dividing the task and communicating with each other during the individual search process or conducting a team search. Teams overwhelmingly (10/11) choose to divide the task among individual team members. A participant described the decision to divide up the work for individual search:
“We tried to... break up the research and first we just kinda narrowed down a list of 5. And then we each broke off and got statistics from 1 or 2 of those things, and did the research separately and then just brought it together.” (Team 8, #1)

The other means of collaboration was through team search. Team search consisted of the team members moving to a single computer and searching together. One person operated the computer and followed the suggestions of their other team members. This type of search allowed the team to understand together the information that was being found. The participants from the team that utilized this approach explained team search:

“At the beginning she was doing the searching. But then, we ended up just looking off of my computer, and then, she wrote down. And then we kind of switched, and she did a little bit of research and I wrote stuff down.” (Team 14, #2)

“And then we pulled up like 5 different webpages and read through them together.” (Team 14, #1)

Yet, for the vast majority of teams, collaboration during the search process focused on communication between individual searchers.

**How Much Collaboration Occurs?**

Collaboration occurred in all four approaches, but the amount of collaboration varied based on the approach. The most collaborative approaches were the Team to Individual and Team approaches. Because collaboration was part of these approaches from the start, it was woven into the entire procedure.

On the other hand, collaboration occurred later in the Individual to Team and Individual approaches. Therefore, the collaboration, while present, was not as integral to the work of the teams that utilized these approaches. Participants explained the nature of working individually and often coming back to work with the team, something that was frequent in both of these approaches:

“We went and did our individual research, and then we were throwing ideas off of each other, we kinda determined, okay, this is important, this isn’t.” (Team 12, #1)
“Individually we’ll look up stuff, and then, after that, after we found something good, we would come back and share it, what we had.” (Team 16, #1)

There was less communication amongst team members in these approaches. Overall, the least collaborative approach was Team to Individual Variation 2. Because collaboration occurred the latest in this approach, team members did not share information or communicate as much as in the other approaches.

4.3 CIS Team Cognition Activities

Multiple team cognitive activities were identified and observed during CIS. Below, I describe of these activities.

4.3.1 Awareness within Teams

Through analysis, I identified CIS related team cognitive activities. Many of these activities were associated with developing awareness within the team. Awareness is often linked as a central feature of team cognition (Fiore & Salas, 2004). Awareness is defined as “knowledge created through interaction between an agent and its environment” (Gutwin & Greenberg, 2004), which results in team members “knowing what is going on” (Endsley, 1995). In addition, Rentsch & Woehr (2004) have described how awareness of team members’ knowledge and the overlap of overall team knowledge help to conceptualize team cognition.

In this study, I identified three types of awareness activities - search, information, and social awareness – that affected team cognition (Table 9). Below, each is detailed.

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Table 9. Types of Awareness Activities
Search Awareness

During the CIS tasks, the main challenge revolved around searching for information. While different teams used different search approaches, all of them utilized techniques to enhance their team awareness during the search process.

Keeping Track of Searches

Many teams actively kept track of searches performed individually and within the team (Teams 6, 9, 11, 12, 14, 16). Often, team members would keep track of their own individual searches and then share their searches with their team member(s). However, not all of the teams individually tracked their searches and then shared them. Instead, in some teams, a team member would formally keep track of the entire team’s searches using a list (Team 6, 11, 14). The assignment of a team member to keep a list of searches for the entire team usually happened without any pre-planning on the team’s part:

“And then, as we went, it developed into… a semi organized structure of okay, has someone already checked this website? Keep a list of the websites. And, one guy wasn’t… picked by us, but he just kinda came out on top and already started writing things down, more detailed than myself or the other person. And so he ended up taking the lead on keeping the notes.” (Team 6, #1)

Regardless if the team individually shared searches or one team member tracked their searches, keeping track of and sharing searches among the team occurred mainly through explicit verbal communication:

“I think, at some point we had to tell each other what we are looking at, because we don’t want to research the same stuff. ‘Cause we are trying to find as much information as possible. So we told each other like what were searching and what we have found.” (Team 12, #2)

While most teams relied on verbally sharing their searches, some teams utilized different ways to track searches. A team member explained the utilization of visual search tracking:

“I was in the middle, I checked to make sure—I kinda looked over each one (of my team members), to make sure that none of us were on the same website, just because that’s almost a waste a time.” (Team 9, #3)
Another participant explained this activity: “I kind of, would look over, see what website she was on, and try to go on a different one, to get different information.” (Team 16, #1) Visual tracking was observed in all teams, either indirectly (as highlighted in the quote) or directly through team members showing each other their computer screens.

Not only did teams keep track of actual searches, some also kept track of their sources (Teams 9, 11, 14, 15). As one team member explained:

“I think it goes back to the third search, when we decided that we were going to start keeping track of the sources. Not only, which ones came out the most often, but which sources we went to, so we could speed up our search time, and we wouldn’t have duplicate, we wouldn’t have team members going to duplicate sites.” (Team 9, #2)

As this quote highlights, teams were keeping track of sources for two reasons: to track how often the source showed up in searches and to avoid overlap of sources. One of the primary reasons for maintaining search awareness is the desire to avoid search overlap within the team, especially in time-limited activities. This issue was raised in many of the participant interviews. Consequently, to ensure that the team was avoiding search overlap they utilized various mechanisms to keep track of searches and sources within the team.

**Checking-In**

Many teams decided to have individual team members search for information using different queries and then share their findings with the rest of the team (Teams 6, 8, 9, 10, 12, 16). These teams utilized a variety of methods to help each other maintain awareness of their searches. Even though communication was limited in these teams, they often still informally communicated the progress that was being made within the team. A team self-identified this process as check-ins:

“Um... well... there was check-ins. Like I would ask what are we trying to accomplish now? Has this step been, passed or completed (searching)? So that would set up what we’re doing as a team.” (Team 6, #1)

While this was the only team to explicitly call this activity a “check-in”, similar activities such as question/asking and intermediate updates were observed in all of the teams that individually searched for information and then shared information among the team.
Searching Together

One of the most common techniques for maintaining search awareness was for team members to search for information together (Teams 7, 11, 13, 14, 15, 16). Instead of relying primarily on individual searching, team members would search for information together. While this process included individual searching at certain points during the CIS process, these teams spent a majority of their time searching together. One team member explained the process of searching together: “And then we pulled up like 5 different webpages and read through them together.” (Team 14, #1) Another team described how their team searched together: “We ended up just looking off of my computer, and then, she wrote down (information). And then we kind of switched, and she did a little bit of research and I wrote stuff down.” (Team 7, #1) Finally, a team member in a team that began working individually explained why they ended up searching together:

“I remember we... we just went off to search separately and then, we ended up on the same webpage, ‘cause we looked at each other’s screens and shared information, we were on the same webpage, so we just did it together.” (Team 16, #1)

The ability to search together led these teams to increase their awareness of what was being searched without having to explicitly track the search, or explain the process through check-ins.

Information Awareness

Similar to how teams utilized awareness techniques for searching, they also used techniques to help raise the awareness level specific to information being found within the team.

Directing and Finding Information

While team members developed methods to keep track of searches, they also employed techniques for helping team members find specific information. A participant described how she helped her team member find information by giving specific directions:

“And if I found information that was really important, that she didn’t have, or didn’t have previous knowledge on, then I said hey, Google search this—like pull up a new tab and Google search this. And... say okay, I Googled this specifically, it’s the second link down, click on that
Participants mentioned throughout the interviews and the observations indicated that team members often helped each other find specific information either through direction or guidance. Many participants mentioned that a chat system would have been helpful, as they could easily lead team members to information that was being found by simply copying and pasting links.

Presenting Information

Two teams in the study mapped out information at both the individual and team level (Team 10, 12). A team member explained individually mapping out information: “You know, I noticed that I was making little maps of different things, as how they were related.” (Team 10, #1) The same participant further explained this in relation to teamwork: “Yeah, I mean we were, we were trying to just map out the basic concepts and then from those concepts identify which ones were more important.” (Team 10, #1) The observations also highlighted that other teams utilized similar mapping techniques.

In addition to mapping information, all of the teams developed information lists to present their information. This list was made individually and shared among the team or the team would jointly work together and create the list. One team member described utilizing a bullet list for presenting information: “And we kinda ultimately made our bullet list, and then off a bullet list then, make sub bullets to support the facts that we found.” (Team 12, #1) These lists allowed the team to not only keep track of information, but also easily identify what information had already been found within the team. Since this list was shared in the team, it provided each team member with the awareness of what other team members had found.

Comparing Information

Every team compared information that was found during the CIS process. This technique was the most common way to both understand the information and ensure that team members were aware of the information being found. Teams primarily used the information lists to aid in comparing information. A team member described the process of comparing information:
“I guess, whatever we saw, we just talked about it aloud, and we would see what everyone else said “oh yeah I saw that too as well, maybe we should write that down. So we just compared.” (Team 11, #3)

Another participant explained comparing information: “And then once I understood myself that she knew what the task was, then we kinda branched off, and then did our own things, and compared notes as we went.” (Team 12, #1) Comparing information was the primary approach that team members used to communicate what had been found.

Social Awareness
A third type of awareness was social awareness. There were multiple instances throughout the study of team members observing and taking note of other team members’ behaviors. For example, team members would actively watch what other members were doing during the CIS tasks. Team members would turn their attention to observe what team members were doing on their computer or what they were writing down on paper. This type of awareness resulted in two types of activities: following and changing. First, team members would often follow what the other team members(s) were doing in regards to the search. During an interview, one participant even realized that they were replicating their search based on the rest of the team: “I could tell that some of the other two guys were, you know, went right into it. So I kinda went along with them, in terms of their strategy of attacking the task.” (Team 10, #3) Participants tried to remain actively aware of what their team members were doing.

In addition to team members following and replicating other’s behaviors, some even changed their actions based on the awareness of how others were acting during the CIS task. A team member best described this:

“The kid to my left was slow at sharing information. He was focused more on, at first he was focused on more reading in depth and trying to get the whole article before he spit anything out. The kid to my right was just, soon as he got an article he just spit it out. And he also took notes for what other people spit out. And once the kid to my left realized that we weren’t really analyzing this, we were just, here’s what we found, he got up to speed and was moving at the same pace.” (Team 6, #2)

These activities highlight the impact that social awareness has on team members during the CIS process. Teams utilized social awareness as a mechanism to guide how they
collaboratively sought information. Whether these activities help or hinder the development of team cognition is still unclear. For instance, if a team member replicates an experienced or efficient team members’ activities, then it could help the development of team cognition. On the other hand, the opposite could also be true - replicating the activities of an ineffective team member could be detrimental to the development of team cognition.

### 4.3.2 Individual Cognitive Period of Acclimation before Collaboration

As described in the background, team cognition depends on both individual cognition and emerging new team-level cognition. In this study, participants described how their individual cognition was important to developing overall team cognition. Often, team members indicated that they would individually acclimate themselves before collaborating with other team members. This individual period of acclimation only lasted for the first few minutes of CIS. Team members used this time period to cognitively understand the given task, perceive their social orientation within the team, and understand their overall role within the team. Consequently, this time period was important to developing team cognition. Many participants explained that team cognition could not start developing until team members individually understood the task. A participant explained the individual cognitive acclimation period:

“I think it was first based on, you know, every individual understanding what the general task was. And once every individual had this, like, they knew what we were doing, then, we all combined into a group. So it wasn’t like, you know, what is each individual gonna do to help the group. But as long as they understood, yeah, what they were trying to do, when we combined as a group to, to get to that goal.” (Team 16, #2)

Another team member stated:

“I feel at least initially, people were trying to figure out what the problem was, how to aim themselves with the group and individually for their own research. I think we tried to develop an idea of what it was. From that idea we kind of, came up with a couple ideas for the research.” (Team 10, #1)
Both participants highlight two important aspects of the individual cognitive acclimation period- (1) individual cognition focused on acclimating to the *task*, and (2) individual cognition focused on acclimating to the *team*. Team members indicated that it was important to not only understand the task, but also understand how they fit into the overall team dynamics. A team member described the critical first few moments of working in the team: “Well, I wanted to see how the group would like first form. In other words, who would probably take on the leader role because usually that happens in the first few seconds of a group.” (Team 10, #2)

The combination of individual and team cognitive activities taking place during this period is important because team members are cognitively multi-tasking between individual- and team-oriented cognition. Team cognition requires both individual and team cognition. The individual cognition that is taking place impacts the emerging team-level cognition. Although the data only points to a specific point in time (at the beginning of CIS) where team members cognitively orient themselves at an individual and team level, I suspect that switching between individual and team cognition occurs often throughout CIS.

4.3.3 Triggers of Collaborative Information Seeking and Team Cognition: Finding and Sharing

Team members indicated a relationship between the start of CIS and the development of team cognition. Specifically, there is a particular instance that initiates CIS, which then also starts the further development of team cognition. The CIS initiation also results in a switch from team members thinking individually about the task to thinking about it from a team perspective. This switch is “triggered” by a series of activities occurring during the CIS process that initiates the change from individual information seeking to CIS. Once the CIS process begins, team members start to think from a team perspective. Finding and sharing information were identified as the main triggers that start CIS and shift the thought process from individual to team, allowing for further development of team cognition.

Once an individual finds information relevant to the collaborative task, they start thinking about the task as a team and orienting their work towards CIS. As one team member described: “I feel as though, like when we started to find information is when we really started to come together as a team, 'cause we knew that we were making a lot a progress with it then.” (Team 9, #2) This switch only needs to be triggered by one team member finding and sharing information.
In addition to finding information, many team members specifically indicated sharing information as a critical trigger. Participants explained the chain reaction that occurred once a team member found and shared information:

“I guess what started it (CIS) was that once... we all just did it separate at first, and then, once one person found what they thought was the first one (cause of cancer), we wrote that down. And then that’s when it kind of worked as a group, ‘cause we said, yeah, we saw that as well. And then took it from three. Said well what else, what else is everyone seeing as a group.” (Team 11, #3)

Another participant indicated:

“But then as soon as there, you know, information started flowing, and there was a lot, there was more ideas on what was going on, then that’s when it was more of a group, a group effort. We kind of all started—well, when we first read it, you’re thinking about it individually, and you’re searching individually, but then, as soon as someone finds any reasonable information, that might be used in your task, then all of a sudden it turns into... a group where you’re trying to combine your information with his information and his information with your information.” (Team 9, #3)

Sharing information within the team allows team members to understand what others find. This leads to an understanding of the information available to the team through team members communicating, comparing, and contrasting information found by individual team members. This communication allows individual members to focus their objectives and goals towards the team due to the ability to understood what the team is searching and finding.

It’s also important to note that information needs to benefit the team or the common goal that the team is working towards in order for it to be considered valuable enough to share with the rest of the team. A team member explains the thought process of identifying information worthy of sharing with the team: “Finding something interesting. Finding something that would benefit the group or the common task, or whatever, whatever we were trying to get to.” (Team 9, #1) Another participant also explains how information must be deemed important to share with the rest of the team: “You think that’s important enough to stop whatever they’re doing, to, make, say hey guys, this could, this could help us all out.” (Team 8, #1) The initiation of CIS and team level cognition will not occur unless the information that is being found is deemed important enough to
share. If information is shared and it is viewed as not important to the common goal of the team, then it is perceived as distracting and counter-productive to CIS and developing team cognition.

4.3.4 Shared Understanding of Information Importance

Throughout the CIS tasks, teams found a wealth of relevant information. Yet, not all of the information found was perceived as being relevant or important to completing the CIS tasks. In order to make sense of all of the information, teams developed approaches to help them determine what information was actually important to correctly answering the CIS tasks. Information importance was mainly determined through discussion within the team, but two factors were largely critical in determining information’s importance. Teams deemed information to be important if it was found frequently throughout multiple websites, and if the source of the information was perceived as credible. Both methods of determining information importance (frequency and credibility) help to develop team cognition. Over time, teams developed a shared understanding of information importance based on these two criteria.

4.3.4.1 Information Importance: Frequency

Every team within this study indicated that information was important if it was found multiple times throughout different websites. Participants explained taking note of information that was reoccurring, overlapping, and frequent on multiple websites. Based on the number of times teams saw information, they assigned a level of importance to the information. If a team only viewed a piece of information once, they would discard it. In contrast, if a team saw the same information 10 different times, they might identify it as being important. A participant explained the role of frequency within information importance:

“I think we determined that (importance of information) by evaluating what kept coming up in our research. The more we saw a certain term or a phrase or… piece of information, the more we kind of said, you know, oh, this might be important. Since none of us really had background information on the topic, you know the more we saw something, the more credible, the more credibility we attributed to that piece of information.” (Team 10, #3)
This quote highlights why frequency was often the main metric for determining importance. Since most of the participants lacked previous knowledge on the topic of pancreatic cancer they had to rely solely on the Internet to find information. The lack of knowledge led teams to only rely on the metric of seeing information over and over again on multiple sites to identify if it was critical or important to the CIS task. The common assumption that participants made, whether right or wrong, was if information shows up often on multiple sources, it must be correct or important.

4.3.4.2 Information Importance: Credibility

In addition to using frequency as a method for identifying important information, teams also evaluated the source the information was found from. For example, one participant explained judging the difference of the importance of information found between Wikipedia and WebMD: “Importance was determined based off where we found it. Like Wikipedia verse Web MD. Web MD obviously has a, a little step, a step above.” (Team 9, #1) Similarly, another participant described avoiding using sources deemed as having little credibility: “I mean I didn’t use like... Wiki or, like Ask Jeeves, or things like that. I just stuck to Google, and, the most populated obviously come to the top, so I figured, they’re probably know—some of the better ones.” (Team 12, #1) Finally, in addition to judging websites based on brand name credibility, some teams judged websites based on how it looked: “It was determined what was a good website or not based on how, I know we’d probably judge it based on how it looks .org versus .com, versus .net makes a difference.” (Team 6, #1) Most teams felt very confident in their ability to judge if a website was credible, and subsequently if they should trust the information found on the site.

4.4 Development of a Team Mental Model

Through analysis, a majority of teams described the development of a self-identified team mental model (TMM) during CIS. The following findings focus on the development of the TMM during CIS, taskwork and teamwork models within the overall TMM, and attributes that positively affected the development of the TMM.
4.4.1 A Team Mental Model During CIS

Of the eleven teams that participated in the main study, nine teams stated that they developed a TMM within the context of CIS. These teams were quick to state that a TMM developed, but many were unable to articulate how the TMM developed, often identifying that the model “just kinda came out that way” (Team 6, #1). However, some participants were able to provide insight into the development of the model. These participants explained that the overall TMM was a combination of each team members’ own individual mental model. Specifically, even though each team member might have a different individual mental model, it was bounded within the goals of information seeking and sharing within the overall TMM. As one participant explained:

“The model was at least generally consistent among all 3 people. Because we had our ideas that we were sharing. So, I mean people may have had the different mental models, but the overall goal was still apparent in terms of the actual problem, solving the problem.” (Team 10, #1)

As team members worked together, they shared components of their individual mental models with each other. As they became more collaborative, individual mental models changed to more closely match the overall TMM. This change was prompted by individual team members learning about each other’s mental models and then orienting their own particular model to better fit the overall TMM. A team member described the process of sharing individual mental models to create a team model:

“But the initial mental models were created independently, and then when we came back together and kind of generalized for an overall just broad, high level concept, we had a unified model, at least to continue to branch out and go okay how are we gonna address the problem.” (Team 8, #1)

Similarly, a different participant described the changing of individual mental models based on the influence of other team members’ models to create the broader TMM:

“Everyone has assumptions, and then when they do the research, their assumptions may change. So they have the initial mental model that just immediately when they’re given the task, they would look at and go okay this is how I’m gonna address the problem, and how I’m gonna like look at the concepts. But when they start getting other influence from other members saying oh, well this is a huge causation because of this, well that may change their whole layout of the
mental model.” (Team 10, #1)

The TMM within the context of CIS developed by individual team members sharing their mental models with each other. These individual models changed and were integrated with each other based on the CIS goals of the team and the influences of other team members’ mental models. This process of development is very similar to McComb’s (2007) conceptual framework that explains the process of mental model convergence during team decision-making.

4.4.2 Taskwork and Teamwork Models

Many researchers have found that a TMM consists of multiple models (Mathieu et al., 2000; Lim & Klein, 2006). For example, a TMM grounded by the context of CIS is only one of many context or activity specific TMMs that ultimately make up the “overall” TMM. As highlighted in the background, TMMs generally consist of both a teamwork and taskwork model. Participants also referred to their CIS grounded TMMs in terms of teamwork and taskwork models. All teams (9 of the 9 teams who identified a TMM) identified and discussed the TMM in terms of a taskwork model.

Team members explained that they developed a taskwork model that allowed them to find, keep track of, and share information. One team member explained how the taskwork model allowed the team to find information:

“Once we had established some basic information, since we were pretty much clueless going into it, once we had some basic information, I think we were feeding off of each other’s... using the document (to track) the information that we found, and we could kinda sense you know, alright, he’s trying to form this link between these two things. I think it was more of a... yeah, I think there was definitely some feeling, some sensing where what each other were go—was going with... with the information.” (Team 10, #3)

Similarly, another participant explained that the team developed a common model of how to find information:

“We definitely got to the common state of... you know, we were all... seeking the common goal of whatever was written on the paper (the tasks), whether it be the... reasons why pancreatic cancer,
or that sort a thing. And we all had a common mental model of how to go about doing that. You know, you just shout out what you found on some website. And through the mental model, we all knew kind of, you know, this was what was expected and how we were gonna continue going on.” (Team 11, #2)

While the taskwork model developed in all of the teams who identified a TMM, the granularity of the task model varied throughout teams. It ranged from simply understanding which team member would write down what, to team members identifying systematic methods for CIS.

In addition to the taskwork model, a more complicated teamwork model developed in some teams (3 of the 9 teams who identified a TMM). The teamwork model was only present in teams that possessed the ability to assume, predict, and expect each other’s understanding. The teamwork model required more time to develop than the taskwork model. A majority of teams never advanced to the point of having a teamwork model because they were never able to work seamlessly together and anticipate what each other was doing. The taskwork model was simpler to develop because it was easier to explicitly communicate how the team was going to search for information. These tasks then became systematic and predictable over time. The teamwork model required that the teammates “understand” each other, a much more difficult process. Some teams did reach this level of understanding within the TMM. As one participant explained, her team reached the level of anticipating what each other would say: “The way we worked together. And then we kind of, were anticipating what the other one was saying. We were on the same page the whole time, and stuff like that, so.” (Team 14, #2) Another team member explained that his team reached such a level of understanding amongst each other that minimal communication was needed to accomplish the task: “It kinda, kinda became like second nature. Once we got the second task, we all started doing our research and, we didn’t really need to talk about the task.” (Team 9, #2) The participants’ comments reflect and highlight the level of sophistication that is required to establish a level of team understanding that allows for prediction and anticipation.
4.4.3 Attributes Supporting TMM Development Within the Context of CIS

While participants indicated many different attributes helping to contribute to developing a TMM during CIS, a few were repeatedly mentioned. These attributes were leadership, previous team experience, and understanding the team’s goal.

4.4.3.1 Leadership

Most participants described leadership within the team as a necessary attribute to developing an effective TMM. Yet, they were also adamant that it must be the correct type of leadership. Many participants explained that a leader must promote equal responsibility and delegation and not be “power hungry.” Effective leadership helped to develop the TMM in multiple ways. A participant highlighted how a leader can initiate teamwork from the beginning of the CIS:

“I think having a leader is something that causes you to step back, and instead of you know, diving right into doing the project, you know, getting a mental model, you know, getting used to working together would be the first step I think. A leader would make sure that that would happen. Versus all the individuals trying to dive right into their task and then, there’s not a specific person that everybody’s looking for in order to get this common understanding and process of how to do what they’re doing.” (Team 11, #2)

Similarly, another participant explained that a leader helps to develop common ground within the team:

“I think it, it helped (leadership in regard to the team mental model). If one person kind of takes a leadership role in the very beginning, and establishes, alright, let’s do this; this is our common goal, this is how we can work to achieve it, this is what we have to do, then, everything is laid out, everyone’s on the same page, you don’t really, like you don’t waste any time, it’s more efficient, but then I feel like you should... divide up the responsibility, or it can... hurt the model.” (Team 14, #2)

In addition, participants also described how leaders help to mediate conflict within the team:
“Uh the team leader is able to facilitate ideas evenly. Like if, if 2 people are conflicting within a
group, the team leader can act as like a mediator, and is able to make sure everyone’s ideas get,
get like passed along. And... I think that helps with getting everyone on the same page, which
helps build the team mental model.” (Team 10, #3)

Leadership was evident in many of the teams. Yet, for the leadership to be beneficial to
both CIS and the development of TMM, it needs to be the correct type of leadership.

4.4.3.2 Previous Team Experience

When asked specifically if previous team experience helped to develop a TMM during the CIS
tasks, almost all of the participants strongly indicated that it did. Participants explained that
increased previous team experience led them to better understand the expectations of teamwork
and how to better work in teams. One team member explained that experience helps working in
teams, and subsequently developing a TMM:

“Oh sure. I’m all about the more you experience something, the more you practice something, the
better you get at it. And the more experience I had with teams is, helped me, you know, kinda
read people better, and... you know, see what works and doesn’t works, and, work in terms of
working together, getting other people to work together. So, I think it definitely helped; my prior
experience (in regards to developing a TMM).” (Team 10, #3)

Another participant pointed out that team experience led to the development of team
expectations:

“100% (in response to if experience helps develop a team mental model). It’s just like any other
thing, the more experience and practice that you have with it, the better you are at it, the better
you can become, the more things you can learn from it. I think someone that, for instance, myself,
already having previous knowledge, you kinda know what to expect and... kinda know what to get
out of things.” (Team 12, #1)

In this study, experience allowed team members to make assumptions, anticipate, and
develop expectations in regard to the team’s CIS process. Similar team expectations laid the basis
for TMM development. A team composed of individuals with previous team experience allows
them to start with a general shared understanding of what to expect during CIS, quickening the development of a TMM.

### 4.4.3.3 Common Understanding of Goal(s)

In addition to leadership and team experience, participants often indicated that the development of a TMM was dependent on the entire team having a common understanding of their CIS goals. Teams not only had to decide what their goal was, but also develop a common understanding of that goal. A participant explained the importance of a common understanding of the goal and its relation to finding information:

“I think just having that common understanding of what the, what the goal was (helped develop the team mental model). Not only what the goal was, but, once we had the, the information, once we had the means to get to that goal. We were all on the same page, since we all had the, had similar information, and we were starting to sense patterns with the information, I think that definitely helped.” (Team 8, #3)

Once a common understanding of the goal was reached among all team members, they were able to start collaborating and searching for information. Most teams directly identified their goal at the beginning of the task, leading some participants to indicate that the first step in developing a TMM is reaching a common understanding of the goal. One team member articulated this first step:

“If you don’t know what you’re trying to do, you’re not going to have a common understanding. I think that’s definitely the first thing that you need to do in order to create a mental model is to understand, you know, how you’re gonna get, or what you’re gonna do and how.” (Team 11, #3)

Understanding the common goal at the onset of teamwork allowed for the quicker development of shared understanding, leading to TMM development.
4.4.4 Time and the Team Mental Model

4.4.4.1 Team Mental Model Starts Developing Early

Most team members explained that a TMM during CIS started developing very early on within the tasks. As early is highly subjective, I define it to be less than 10 minutes. A complete TMM might not have been in tact in under 10 minutes, rather it was beginning to formulate. One participant described the model as “starting right away” (Team 16, #1), while another further articulated the model developing early:

“I think it happened early. I think all we just needed was the background information about the topic, and then moving forward once that was established. I think we were pretty much on the same page in terms of breaking it all down and finding links and what have you.” (Team 13, #2)

Similarly, another team member described how quickly the model was initiated: “Well, definitely with us 10 minutes or below. We knew what we were doin’ within the first 5 minute period.” (Team 9, #1) The interesting question is why did so many participants feel that the model started from the onset of the task? In response, participants indicated a few reasons for the early development. Specifically, team members explained that the task itself played a role in developing the TMM early on in the tasks. Multiple participants explained that the task was specific enough in what it was asking for that it allowed them to immediately develop team goals and begin searching. In addition, a few team members also indicated that the first task required the most communication (of all tasks), resulting in the early development of the TMM. One participant was asked directly why the team mental model started developing early on and pointed out the need for communication in the first task as being a significant reason:

“I think it’s because the first task was, find 5 main causes, but, like the last one was like find technologies to, for the early detection of cancer. But, I think the third one actually can be done without much communication. I think the first task requires more communication than the third one, helping to start the mental model from the beginning.” (Team 12, #2)

In addition to the task, participants identified the time constraints associated with the task as expediting the process of developing the TMM. A participant explained the effects that the time constraints had on early development:
“Well we all know we had a certain amount a time to get it done, so, we... we knew that we had to first understand the problem. So once we started doing that, we realized, okay it’s been about 2 minutes without talking. We have I think 15 minutes for the first one. So we started sharing ideas. So I think that the issue that led to the model is just the time.” (Team 9, #2)

4.4.4.2 More Time Allows for a Stronger Team Mental Model

Because the CIS tasks were relatively short (30 minutes), many participants stated that more available time would strengthen their TMM. Team members were aware that the more time they spent working with their team, the stronger their TMM became: “Through, from Task 1 to 3, we definitely became more organized in how we did things, and by the third one, we were very quickly able to work—I don’t even we spoke at the beginning of that one.” (Team 8, #1) Even though teams felt they still developed TMMs during the short amount of time, it is clear that they felt more time would help develop the model. A participant explained the difference between developing a TMM within a short amount of time, as compared to a long amount of time:

“I feel like having less time would push you to have a model quicker. I feel like team members feel obligated to have some sort of general understanding as a group before they move forward with finite stuff. But if you were given more time, you could develop a more, like a clearer mental model, so that everyone is exactly on the same page. Cause there was, obviously discrepancies between the end results for all 3 of us, but we did have a generalization that worked.” (Team 10, #1)

Another team member simply described: “I think with more time, you can develop a better model.” (Team 15, #1) The longer team members spent collaborating with each other, the more they understood each other and the shared goals they were trying to accomplish. Working together for longer time periods also allows for the team to learn and identify work patterns within the team. This then leads to the potential ability to predict each other’s work. All of these associations are representative of a TMM.
4.5 Interpreting the Concept Maps

Below I present the findings for both the individual declarative and team procedural concept maps. As outlined in the previous chapter (pg. 64), the individual declarative concept maps were analyzed using quantitative content analysis (Henno & Reiska, 2008), and the team procedural maps were qualitatively analyzed using a methodology developed by Zaff & colleagues (1993).

4.5.1 Individual Declarative Concept Maps

Below (Table 10), I present the first part of the quantitative content analysis on the maps. The table outlines each specific map’s associated content, and most importantly the most central concepts along with the amount of associated links. The analysis shows 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, showing that the most central concepts vary widely depending on the individual map. The variation of the most central concepts within the map is interesting because it identifies that at an individual level there are significant variations in the perception and importance of CIS related concepts. This means that designing and planning for CIS related activities can be challenging, knowing that there are significant differences among individual’s perceptions of CIS.
<table>
<thead>
<tr>
<th>Title</th>
<th>Concept Count</th>
<th>Proposition Count</th>
<th>Linking Phrase Count</th>
<th>Branch Point Count</th>
<th>Taxonomy Score</th>
<th>Three Most Central Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team6Sub1</td>
<td>25</td>
<td>24</td>
<td>16</td>
<td>6</td>
<td>4</td>
<td>Computer=4, Team-Related Areas=3, Prior Knowledge=2</td>
</tr>
<tr>
<td>Team6Sub2</td>
<td>24</td>
<td>26</td>
<td>12</td>
<td>10</td>
<td>5</td>
<td>Collaboration=3, Member=3, Internet=3</td>
</tr>
<tr>
<td>Team6Sub3</td>
<td>15</td>
<td>17</td>
<td>14</td>
<td>7</td>
<td>5</td>
<td>Team Leader=4, All Members Engaged=4, CIS=3</td>
</tr>
<tr>
<td>Team7Sub1</td>
<td>13</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>Source Credibility=2, Share Information=2, Tasks=2</td>
</tr>
<tr>
<td>Team7Sub2</td>
<td>25</td>
<td>32</td>
<td>30</td>
<td>10</td>
<td>2</td>
<td>Sharing Information=5, Ideas/Knowledge=4, Collaboration=4</td>
</tr>
<tr>
<td>Team8Sub1</td>
<td>21</td>
<td>26</td>
<td>26</td>
<td>5</td>
<td>4</td>
<td>Verbal Communication=6, Team Leader=4, CIS=4</td>
</tr>
<tr>
<td>Team8Sub2</td>
<td>24</td>
<td>29</td>
<td>29</td>
<td>7</td>
<td>2</td>
<td>All members engaged=9, Research=7, Internet=5</td>
</tr>
<tr>
<td>Team8Sub3</td>
<td>23</td>
<td>24</td>
<td>21</td>
<td>6</td>
<td>2</td>
<td>Communications=6, Sharing Information=3, Dissagreement=3</td>
</tr>
<tr>
<td>Team9Sub1</td>
<td>19</td>
<td>22</td>
<td>21</td>
<td>7</td>
<td>5</td>
<td>Collaboration=6, Research=4, Sharing Information=4</td>
</tr>
<tr>
<td>Team9Sub2</td>
<td>24</td>
<td>30</td>
<td>26</td>
<td>9</td>
<td>5</td>
<td>Members=7, Personal Experience=5, Joint Understanding of Task=5</td>
</tr>
<tr>
<td>Team9Sub3</td>
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<td>23</td>
<td>21</td>
<td>7</td>
<td>2</td>
<td>Leader=5, Sharing Information=4, Collaborative Information Seeking=4</td>
</tr>
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<td>Team10Sub1</td>
<td>25</td>
<td>27</td>
<td>27</td>
<td>7</td>
<td>2</td>
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<td>Team10Sub2</td>
<td>14</td>
<td>14</td>
<td>13</td>
<td>3</td>
<td>5</td>
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</tr>
<tr>
<td>Team10Sub3</td>
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<td>21</td>
<td>21</td>
<td>5</td>
<td>5</td>
<td>Communicate=4, Internet=4, End Goal=4</td>
</tr>
<tr>
<td>Team11Sub1</td>
<td>25</td>
<td>30</td>
<td>27</td>
<td>4</td>
<td>5</td>
<td>Common Goal=7, Methods=5, Group Members=5</td>
</tr>
<tr>
<td>Team11Sub2</td>
<td>24</td>
<td>26</td>
<td>24</td>
<td>6</td>
<td>2</td>
<td>Sharing Info=4, Delegating Responsibilities=4, Team Members=3</td>
</tr>
<tr>
<td>Team11Sub3</td>
<td>18</td>
<td>25</td>
<td>20</td>
<td>7</td>
<td>4</td>
<td>Group Members=10, Research=4, Team Leader=3</td>
</tr>
<tr>
<td>Team12Sub1</td>
<td>26</td>
<td>42</td>
<td>42</td>
<td>10</td>
<td>2</td>
<td>Groups=9, Communication=6, Individuals=6</td>
</tr>
<tr>
<td>Team12Sub2</td>
<td>22</td>
<td>28</td>
<td>26</td>
<td>7</td>
<td>2</td>
<td>Internet=5, All Members Engaged=4, Delegating Responsibility=4</td>
</tr>
<tr>
<td>Team13Sub2</td>
<td>28</td>
<td>29</td>
<td>27</td>
<td>6</td>
<td>5</td>
<td>Teamwork=7, CIS=5, Share Information=3</td>
</tr>
<tr>
<td>Team13Sub3</td>
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<td>38</td>
<td>37</td>
<td>10</td>
<td>5</td>
<td>Communication=8, Leaders=7, Tasks=7</td>
</tr>
<tr>
<td>Average</td>
<td>21</td>
<td>24</td>
<td>24</td>
<td>7</td>
<td>3.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 10. Quantitative Analysis of Declarative Concept Maps
Table 11 presents the top 15 most frequent concepts after removing the focus concept, “collaborative information seeking.” This analysis is focused specifically on the most frequent concepts used across all of the individual declarative concept maps. The concepts of research, internet, end goal, prior knowledge, and agreement were the top five most frequently used concepts. There is once again a wide range of concepts that were most frequently used.

<table>
<thead>
<tr>
<th>Concepts (Sorted)</th>
<th>Frequency (# of times concept used across all teams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
<td>24</td>
</tr>
<tr>
<td>Internet</td>
<td>22</td>
</tr>
<tr>
<td>End Goal</td>
<td>21</td>
</tr>
<tr>
<td>Prior Knowledge</td>
<td>20</td>
</tr>
<tr>
<td>Agreement</td>
<td>17</td>
</tr>
<tr>
<td>Collaboration</td>
<td>17</td>
</tr>
<tr>
<td>Verbal Communication</td>
<td>17</td>
</tr>
<tr>
<td>Email</td>
<td>16</td>
</tr>
<tr>
<td>Team Leader</td>
<td>16</td>
</tr>
<tr>
<td>Computer</td>
<td>15</td>
</tr>
<tr>
<td>Joint Understanding of Task</td>
<td>16</td>
</tr>
<tr>
<td>Personal Insight</td>
<td>15</td>
</tr>
<tr>
<td>Sharing Information</td>
<td>15</td>
</tr>
<tr>
<td>Individual Generation of Ideas</td>
<td>14</td>
</tr>
<tr>
<td>Online Messaging</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 11. Frequency of Concepts Across All Teams

Table 12, shows the top fifteen concepts sorted for centrality. The top five most central concepts across all individual declarative maps were research, sharing information, end goal, internet, and collaboration.
When the analysis of the most frequently used concepts and most central concepts are compared, there are some interesting similarities and differences that become apparent. First, research is viewed as the most frequent and central concept across all of the maps. This is not necessarily surprising considering the activity of CIS 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 across both the centrality and frequency metric. For the most part, many of the concepts are jointly viewed as being important to centrality and frequency. Moving towards the differences between the two metrics, we can see 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). Also, computer based technologies, such as the concepts of Internet, Computer, Email and Online Messaging are more prevalent within the most frequently used concepts than they are in the most central. This could show that the participants perceive these technologies as being more critical and important to CIS.
than they actually are. Finally, an interesting theme across both metrics of centrality and frequency is how low concepts related to collaboration and communication fall on the tables. One would suspect that the role of such concepts would be viewed as being of high importance. While they are present in the analysis, they are not as high as other concepts.

4.5.2 Team Procedural Concept Maps

To decrease repetition, I present the analysis for one of the team’s procedural concept maps (Team 8 - other teams can be found in Appendix I). The analysis is separated into three main focuses: (1) the overall CIS process, (2) themes, and (3) important concepts and kernels. I then outline the themes that were found across all maps. For more information on the analytical process, please refer back to section 3.4.4.

4.5.2.1 Team 8 Procedural Concept Map Analysis and Interpretation

Figure 17. Team 8 Procedural Concept Map
**CIS Process:**
The overall CIS process within this map starts with individuals conducting a search and then collaborating to seek information and address the CIS task. Specifically the collaboration leads to decisions that are based on team understanding. The process of collaborating and making decisions based on the collaborative results is iterative throughout the entire map.

**Themes:**
One of the main themes of this map is the divergence from utilizing individual work to team focused work. The team begins with individual research. Eventually, the team extends their individual research collaborative work. The collaborative work then leads to shared knowledge. This is an important microcosm and theme of the entire map. Another important theme within this map is the close relationship that collaborative concepts have with team understanding and decision making concepts. Throughout the entire map, there is often a linkage from a collaborative activity to the development of team understanding or a decision being made. More specifically, there is a cluster at the bottom of the map that revolves around collaborative activities, team understanding, and decision-making. All three of these activities are directly related to each other and lead to the completion of CIS. The theme within the map indicates that team collaboration helps to develop a team understanding, which is then utilized to make decisions. In the bottom right corner we can see this theme through the connection of multiple concepts- *group discussion* used *shared knowledge* used to *answer prompt*. Group discussion is the main facilitator in helping teams collaboratively seek information through developing a shared understanding of how to do it. This process then leads to action and decisions being made.

**Important Concepts and Kernels:**
This concept map produces quite a few important concepts and kernels, most directly related to collaboration and team understanding.

*Group Discussion*- This concept is directly linked to the concepts of *team leader, shared knowledge, and joint understanding*. In addition, it is the parent to multiple levels of different concepts (example: *group discussion-shared knowledge-revise and add to prior knowledge-better and faster results*). The concepts overall importance is linked to decision making and developing team understanding.
Understanding Teamwork Knowledge & Skills - This concept has multiple concepts coming in and out of it, along with multiple layers of concepts extending from it. Similar to group discussion, the concept is often linked to decision-making and collaborative aspects of CIS.

Increase Group Comfort - This concept has multiple connections in and out of it and connects to concepts in different parts of the map (known as crosslinks) signifying greater importance. Much like the previous two kernels, this kernel also is specific to collaboration, decision-making, and team understanding.

More Discussion - This concept is directly related to the previous 3 kernels in terms of its overall meaning.

Individual Research - This is the first concept on the map and while it does not have as many connections as the other kernels, it initiates much of the overall CIS process. If this concept were not there, then much of the overall process would not exist.

**4.5.2.2 Findings Across All 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. Much like the individual analysis of the team procedural maps, the aspects that were analyzed across all maps were the CIS approach, themes, and key concepts and kernels. The findings across all maps are presented below.

**CIS Approach:**

There were 3 main CIS approaches identified and used in the maps. Each team procedural concept map aligned with either the Individual to Team, Team to Individual, or Team approach. When compared to the approaches identified in the interviews and observations, these approaches are closely linked to each other and represent the same overall process. When each team’s identified CIS approach is directly compared to the findings between the interviews/observations and the team procedural concept map, we can see that they match up very closely with only one
team (Team 10) having conflicting approaches. This not only bolsters the overall CIS approaches, it provides further validity for the analysis conducted on the interviews/observations. The only difference between the identified CIS approaches in the interviews/observations and the team procedural concept maps is that the difference between individual to team variation 1 and 2 was not apparent in the concept maps.

When detailing the content of each approach, the concept maps actually made it clear and simple to identify what occurred during each. 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 either occurs in concert with each team member or they will work together individually and constantly share 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. An interesting note about the Team to Individual approach was that teams often did not explicitly identify themselves as moving away from collaboration in the concept maps. Yet, when they are analyzed from beginning to end, it is clear that less collaboration occurs during the end of the CIS approach than in the beginning. Finally, the Team approach is very unique because it is constant collaboration. When analyzing the concept maps, this map was very different than any other map because it was highly unstructured and mainly consisted only of collaborative and decision-making concepts.

<table>
<thead>
<tr>
<th>Team #</th>
<th>Approach Identified Through Interviews and Observations</th>
<th>Align with Approach Identified in Procedural Concept Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team 6</td>
<td>Individual to Team V1</td>
<td>Yes</td>
</tr>
<tr>
<td>Team 7</td>
<td>Team to Individual</td>
<td>Yes</td>
</tr>
<tr>
<td>Team 8</td>
<td>Individual to Team V1</td>
<td>Yes</td>
</tr>
<tr>
<td>Team 9</td>
<td>Individual to Team V2</td>
<td>Yes- variation not apparent</td>
</tr>
<tr>
<td>Team 10</td>
<td>Individual to Team V1</td>
<td>No</td>
</tr>
<tr>
<td>Team 11</td>
<td>Team to Individual</td>
<td>Yes</td>
</tr>
<tr>
<td>Team 12</td>
<td>Individual to Team V1</td>
<td>Yes</td>
</tr>
<tr>
<td>Team 13</td>
<td>Individual to Team V2</td>
<td>Yes- variation not apparent</td>
</tr>
<tr>
<td>Team 14</td>
<td>Team</td>
<td>Yes</td>
</tr>
<tr>
<td>Team 15</td>
<td>Team to Individual</td>
<td>Unclear</td>
</tr>
<tr>
<td>Team 16</td>
<td>Individual to Team V1</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 13. Approaches Identified Through Interviews/Observations & Team Procedural Concept Maps
Themes:

Strong Relationship Among Collaboration and Decision-Making

The strongest theme identified within the maps is the importance between the collaborative concepts and decision-making concepts. In almost every map, team members continually 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 method that team made decisions was through collaboration. Various collaborative concepts show that they afford the ability for a variety of decisions to be made. Without collaboration, it would seem that most teams would not be able to make CIS decisions. In addition, the overall importance of the collaborative and decision-making concepts must be noted as well. In all of the maps, these two categories of concepts were used often, showing the importance that teams assigned to both collaboration and decision-making. The associated importance makes sense because CIS is part of the larger team decision-making process, and the activity of CIS is grounded in collaboration. So, when pairing team decision-making and CIS, one would expect teams to value decision-making and collaborative concepts.

Structured and Iterative Nature of CIS Depending on Approach

The team procedural concepts maps did an excellent job of showing 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 off of the previous tasks information and 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 Work & The Transition Between the Two

There is integration of individual cognition and work within the larger collaborative process. Throughout the maps, one can see that there are points in time where individual team members are 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, and 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 are below. I will only provide a baseline level of detail on each, as they are outlined in the Appendix with many other concepts.

*Collaborate:* 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.

*Communication:* Much like collaboration, communication is closely linked to many other concepts, used frequently, and often centrally located in the map.

*Discussion:* Like collaboration and communication, discussion is closely linked to many other concepts, used frequently, and often centrally located in the map.

*Research:* The concept of research is used many times throughout the maps. The concept itself is incredibly important to the activity of information seeking, just as collaboration is important to the collaborative aspect of CIS.

### 4.6 Chapter Summary

In this chapter, I outlined four approaches to CIS along with a description of the role of collaboration within each of them. Within those approaches, team cognitive activities that affect
both the actual process and the development of a team mental model were described. Based on
the different CIS approaches and team cognitive activities, a self-identified team mental model in
the context of CIS was presented. Finally, the individual declarative and team procedural concept
maps were analyzed and presented. In the next chapter, I describe the impact of these findings.
Chapter 5

Study 1 Discussion

In this chapter, I expand on the preceding chapter’s findings and how they relate to each other to further explain their implications. In particular, I discuss (a) the development of team cognition during CIS, (b) the implications the different CIS approaches have on CIS (c) design implications to better aid CIS and develop team cognition, and (d) methods for measuring team cognition during CIS.

5.1 The Development of Team Cognition during CIS

Through this study, I have started to gain insight into the development of team cognition during CIS. The findings begin to identify aspects of team cognition development during CIS through multiple awareness activities. In addition, the individual cognitive acclimation period aligns with previous literature that explains how the development of team cognition starts with individual cognition (McComb, 2007). Finally, the development of team cognition depends not only on cognitive activities but also interplay between cognition and interaction. Below, I discuss these issues in greater detail.

5.1.1 Awareness as a Mechanism for Developing Team Cognition

As mentioned in the previous chapter, awareness is often noted as a central component of team cognition (Fiore & Salas, 2004; Rentsch & Woehr, 2004). The various awareness activities found in this study lead to teams sharing knowledge and understanding their tasks and teamwork. This in turn leads to the development of team level cognition. Since the teams were composed of participants who did not know each other, they had little awareness of each other’s abilities and knowledge. Consequently, to address this lack of awareness, participants developed awareness mechanisms that allowed them to keep track of other teams members’ activities. The awareness gained through each of these activities allowed team members to generate team awareness.
Awareness at this level directly helps team members understand multiple aspects of the team and the team’s work.

One of the most common aspects of team cognition within the literature is team knowledge. Team knowledge is an aspect of team cognition that is often studied through the construct of a team mental model (Cooke et al., 2003; Mohammed, Ferzandi, & Hamilton, 2010). The team mental model construct was introduced by Cannon-Bowers, Salas, & Converse in 1990 with a purpose to further understand the deep cognitive processes of teams within dynamic situations and account for the differences in performance across teams. As noted in the background, team mental models are often separated into two different team knowledge models: teamwork and taskwork (Lim & Klein, 2006). Taskwork models capture the task related goals of the team, as well as the processes that are related to achieve those goals. Teamwork models subsume interpersonal communication and interactions, along with the knowledge and skills of teammates. Often, aspects of the taskwork and teamwork models overlap with one another—communication being an example. Teams in this study exhibited awareness activities that help to develop both teamwork and taskwork based team cognition. While each of the awareness activities consisted of different types of work (comparing information, keeping track of searches, tracking social behaviors, etc.) they were all directed at teamwork or taskwork cognition.

The various awareness activities highlight how teamwork and taskwork knowledge develops during CIS. Each awareness activity directly helps the team to acquire or develop teamwork and/or taskwork knowledge. Consequently, the teamwork and taskwork knowledge is then used to build team cognition. Therefore, the awareness activities in this study are mechanisms for developing team cognition through the development of teamwork and taskwork knowledge.

For example, the Search awareness activity of Keeping Track of Searches helps to develop taskwork knowledge. In this activity team members keep track of searches at both an individual and team level. At a team level, the team tracks all searches conducted by all team members. Through tracking, team members were able to become aware of what searches team members were conducting. The shared information of knowing what searches were conducted allows the team to develop a shared understanding of information pertaining to searches throughout the team. This shared understanding develops through the awareness mechanism and allows for taskwork knowledge to be acquired. Taskwork knowledge is developed through a shared understanding of the information being tracked, found, and compared. Through the shared
understanding of taskwork knowledge, team cognition is being built and growing as more searches are shared and more knowledge is acquired.

Specific to teamwork knowledge, the Social awareness activities have the potential to help develop team cognition through developing a shared understanding of how team members are working, through observing each team members’ work. Teamwork knowledge is developed through the knowledge of how team members are working together via interaction and communication during the process of CIS.

Throughout all of the awareness activities, I identified awareness aiding in developing a shared understanding of task and teamwork knowledge. The shared understanding of this knowledge is directly helping to build team cognition. For team cognition to develop, taskwork and teamwork knowledge is needed. Consequently, it is extremely important that teams develop this knowledge during CIS. This study highlights development of how this knowledge may occur through awareness. Realizing the importance of awareness’s role in developing team cognition is relevant to CIS researchers. The design of CIS systems must include features that allow for the development of individual and team awareness. Awareness has the capabilities to develop team cognition, which has the potential to directly impact team performance.

5.1.2 Individual to Team Cognition during CIS

In addition to awareness activities helping to develop team cognition, the individual cognitive acclimatization period is also viewed as critical to the development of team cognition. Researchers describe the development of team cognition as a process starting with individual cognition and evolving to team cognition. McComb (2007) labeled this the mental model convergence process-how team members converge their individual mental models to formulate a team mental model. The process of mental model convergence starts at the onset of team members’ interactions and is continuous through the task. The observations and collection of information about each team members’ activities leads individuals to evolve from their individual mental models to a team mental model. This requires a cognitive shift in focus from individual to team (McComb, 2007). According to McComb et al. (2010), the process of mental model convergence occurs in three distinct phases: orientation, differentiation, and integration. Team members must:

1. Orient themselves to their unique domain,
2. create their own view of the situation, which may or may not be similar to their fellow team member’s views,
3. allow their individual perspective to evolve into a team view.

Once each team member has progressed through these three phases and the team has a shared understanding of the team mental model, the convergence point has been reached and the team mental model develops and continues to develop throughout teamwork.

This study identified team cognition developing in a similar process. All three phases of McComb’s process were reflected in this study. The various awareness mechanisms allow team members to observe and collect information about each other’s activities. These mechanisms were critical in allowing the team members to integrate their individual cognition with their team members. Team members also highlighted the importance of the individual cognitive acclimation period to the development of team cognition. This individual cognitive period aligns very closely to the first 2 phases of McComb’s process and leads to phase 3. Interestingly, I found the entire process (individual to team focus) occurs quickly (1-2 minutes). Often, after 1-2 minutes, a team member starts developing team cognition by finding and sharing information with the rest of the team.

The individual cognitive acclimation period highlights some interesting insights into how CIS should be viewed. For instance, knowing the importance of this individual time period indicates that team members should not be forced to collaborate too early. If CIS processes and systems are designed solely for the ability to collaborate, with little affordance for individual cognition, the result may be counterproductive to the development of team cognition. CIS processes and systems must afford aspects of individual and team cognition to fully develop team cognition.

5.1.3 Interaction and Cognition as Developing Team Cognition

Cognition and interaction are often studied independently but they share a close relationship (Kreijns, Kirschner, & Jochems, 2003; Van den Bossche, 2006). Social interaction is defined as “two or more autonomous agents co-regulating their coupling with the effect that their autonomy is not destroyed and their relational dynamics acquire an autonomy of their own” (De Jaegher, Di Paolo, & Gallagher, 2010). Interaction is the communication, observations, and personal
actions that we participate in on a daily basis. Using knowledge elicitation methods, strong links between cognition and interaction became apparent in this study. Specifically, I identified a strong relationship among cognition and interaction that results in interplay between the two, directly helping to develop team cognition.

CIS is a human behavior consisting of both interaction and cognition; therefore one of the overarching goals of this study was to understand both the cognition and interaction that occurs during CIS. Yet, since most previous research focuses on understanding CIS through interaction, this study leaned more towards understanding the (team) cognitive aspects of CIS. Therefore, the focus of the research questions and the methodologies used were oriented more towards team cognition than interaction. Still, the study was designed to capture both team interaction and cognition in an attempt to understand how each affects one another and gain more insight into the interplay between the two.

To better understand the interplay between cognition and interaction during CIS activities, I will outline how each affects one another within the CIS approach Individual to Team Variation 1.

1. The individual team member takes a short period of time to cognitively acclimate themselves to the task. This period of time has a direct affect on the interaction that takes place during the team’s first interaction together as a team. The individual thought that occurs will help to shape the team’s initial interaction. The individual cognition being formulated is what the individual will bring forth within the first team discussion. This first step is an example of interaction being dependent on cognition.

2. Once the team actually starts interacting during team discussion, the interaction then affects individual and team cognition. While the team is interacting, participants are individually orienting their cognition to the team. In addition, the team’s interaction allows for team cognition to start developing. If there weren’t any team interaction it would be very hard for the team to start developing team cognition. The communication that takes place during the interaction is what allows the team to start sharing ideas and creating a common goal, also allowing for the development of team cognition. If communication did not occur, team members wouldn’t be able to understand what each other were thinking, disallowing for team cognition. This step shows that the cognition is dependent on the interaction.
3. Next, after a team discussion, the team members individually search for information. During this step, cognition takes the forefront, allowing for team members to further develop their individual cognition. Similar to the first step, cognition that is developed here will focus the interaction that takes places within the next step. Next, the team will have another team discussion. During this step, the interaction that happens here will further develop the team’s cognition. **This interplay of interaction then cognition, or cognition then interaction continues throughout the rest of the process.**

This process highlights how CIS consists of interplay between interaction and cognition. Both interaction and cognition are equally important to CIS activities being successfully completed.

The interplay between cognition and interaction is also visible in the many awareness activities. For example, the Search awareness activity of Keeping Track of Searches incorporates aspects of both cognition and interaction. The action of Keeping Track of Searches occurs through interaction among team members. As participants search for information, they are developing cognition specific to their searching. In order to share their searches with the rest of the team and contribute to the team they must also verbally communicate with each other. Therefore, the interaction (verbally communicating searches) is dependent on cognition (identifying specific searches). The communication of the searches cannot happen before team members understand what to search. Once the team members communicate their searches, they become aware of what has been searched and adjust their own searching in an attempt to avoid overlap. This exemplifies how cognition (adapting searches) is dependent on interaction (learning what has been searched from the other team members). I found this type of interplay throughout the study.

This interplay between cognition and interaction is one of the building blocks of team cognition. Without this interplay, information could not be shared among the team members, which would pose problems to the development of team cognition. The communication that occurs during the CIS tasks is essential to developing team cognition because it allows for information sharing. In addition, the communication also allows team members to refine their individual cognition to be better aligned with team-based cognition.

This perspective on team cognition aligns with Cooke & colleagues (2013) recent theory of Interactive Team Cognition, postulating that team cognition is an activity that occurs through interaction. Consequently, to examine team cognition, we must not only focus on the cognitive
activities of team members but also understand the various types of interactions that take place between team members. By capturing both the cognitive and interactional aspects of CIS, we provide the potential to understand a more detailed picture of how team cognition develops during CIS activities.

5.2 Understanding the CIS Approaches

I identified findings on how people collaborate to search for information using data from 11 different teams engaged in CIS tasks. The study found that CIS varied depending on the team, resulting in four different approaches of CIS. In addition, the study also identified the importance of collaboration during all four approaches. These findings provide valuable insights in furthering our understanding of CIS and providing multiple implications for CIS. More specifically, what does the effect of multiple approaches of CIS mean for the field of CIS. Building on that, the knowledge of CIS approaches consisting of both individual and collaborative work is important to consider. Lastly, it is critical to understand why the different approaches emerged during the study. Each of these points will be further explained below.

5.2.1 What does this Mean For Collaborative Information Seeking?

So, what do these different variations, approaches, and behaviors of CIS really mean? Simply, CIS should not be categorized in a “one size fits all” manner. CIS can take many forms. There is often the notion to plan, design, and anticipate the actions of the masses, resulting in a “one size fits all” perspective. While there is value in this perspective, it doesn’t account for the individual and team differences that occur throughout human behavior. Through this study, we can see that CIS has many differences based on both the individual and the team. CIS is not a clear-cut process that allows for it to be viewed in a singular manner. Not only have I identified four different approaches to CIS, but also multiple variations as to how collaboration takes place within each approach. Yet, I have not identified all of the approaches of CIS, as there could potentially be many more. The process of CIS is dependent on so many characteristics, each with the ability to significantly change the overall approach. In this study alone, I identified multiple ways collaboration changes just by one characteristic changing. Take for example, something as
simple as when a team starts collaborating; this characteristic changed how the team collaborated, how much collaboration occurred, and whether a leader emerged.

My work is not the first to outline the differences and variations within collaborative seeking. Recent findings by Morris (2008, 2013), and Capra et al. (2010) have identified and explained multiple specific behaviors found during collaborative web search (e.g. sharing screens, taking notes, bookmarking). While my findings are focused on four different CIS specific approaches, I also identified similar behaviors during the approaches. My work also adds to Evans & Chi’s (2008) model of social search. Their model is broad, accounting for multiple variations and characteristics. The addition of my findings to their model further helps to highlight the many variations of collaborative seeking. Understanding the complexities of CIS makes it harder to plan, aid, and design for the multiple approaches of CIS. As researchers, we need to be careful that we don’t restrict or bias users to use one approach or the other. An approach that is successful for one team might lead to failure for the other. Finally, the design of CIS systems must avoid thinking about CIS in a “one size fits all” manner.

5.2.2 Collaborative Information Seeking: Balancing Collaborative and Individual Work

CIS is conceptualized as team members working together to search for needed information towards a shared goal (Morris & Teevan, 2009). The scope and aim of collaboration varies widely depending on the perspective (Wood & Gray, 1991). Yet, within the CIS community, collaboration is usually limited to characteristics of control, communication, and awareness (Shah, 2010b). Of these characteristics, communication is often highlighted through numerous collaborative behaviors (e.g. sharing screens, social media, sharing notes and bookmarks) (Morris 2008, 2013; Capra et al., 2010). Communication is critical to the collaborative aspects of CIS. Communication may or may not be synchronous and continuous during CIS. Within the literature, CIS systems have focused on both synchronous and asynchronous communication (Morris & Horovitz, 2007; Shah, 2010a).

Yet, due to the relevance and preponderance of synchronous communication, quite a bit of CIS research utilizes the viewpoint of a group of users constantly interacting with each, sharing information, and communicating about what they have found. Consequently, the design of many collaborative information seeking and retrieval tools focus on features that support this view of a continual collaborative mode of interaction (Amershi & Morris, 2008). However, this study’s
findings show that CIS is much more than constant continuous communication. Instead, CIS has an ebb and flow between individual and collaborative searching. So, CIS is much more a set of activities (rather than a concrete and constant set action) that vary based on at least four approaches to CIS; each approach contains different degrees of balance and flow.

At the core of these approaches is the balance between collaborative activities and individual activities, allowing the team to accomplish the information tasks. This means that CIS is not purely collaborative, like its name suggests. Rather, each of the four approaches consists of both collaborative and individual activities, with team members moving between the two types of activities as they progressed towards accomplishing the information task. Depending on the approach, the balance varied between the collaborative and individual work aspects of these approaches. For instance, the team approach has more a collaborative focus than the individual to team variation 2 approach. Some approaches were weighted more to collaborative and some were more individualistic. However, each approach clearly contained elements of both collaborative and individual work.

Another striking feature of these approaches was the flow between the collaborative and individual activities. As the four approaches highlight, there was a constant movement between these different types of activities. Reddy and Jansen (2008) describe specific triggers for transitioning from individual to collaborative information behavior. The findings highlighted in my research show that a single trigger does not occur. Instead, the trigger process happens multiple times during the completion of an information task. This flow, and series of triggers, between collaboration and individual work varies within the approach in regards to timing and frequency. In addition, the flow is influenced by team leadership and team expertise of the individual members.

The realization that CIS does not consist solely of constant collaborative work but also has an inherent individual component is important for how researchers and system designers conceptualize CIS. The individual activities influence the collaborative activities and vice versa. This insight has profound effects on how searching systems that support CIS are designed.
5.2.3 Team Factors that Affect the Different Approaches

One question that the findings raised was “what led to the four different CIS approaches?” Regardless of the approach, I identified two contextual factors that influenced a particular team’s approach – leadership and team member experience.

5.2.3.1 Leadership

Leadership has long been a focal point of effective teamwork (Campbell, 1956) and can be defined as “a process whereby an individual influences a group of individuals to achieve a common goal” (Northouse, 2012). In the study, participants identified leadership as an important aspect of the CIS process. Regardless of the approach, a majority of teams utilized leaders or some form of leadership during the completion of the CIS tasks.

Leaders played an integral role in determining how CIS would begin, thus determining what approach the team utilized. Although all the teams had leaders, teams in which the team discussion occurred at the onset of the task (i.e. Team to Individual and Team) had leaders emerge earlier. These leaders were usually more in control of team activities. For instance, during the activity of team discussion, leaders often helped dictate and develop the approach through defining roles and identifying goals. Furthermore, team leaders also specified how the collaboration within the teams would take place. For example, leaders often divided the CIS tasks and developed an approach for searching, sharing, and tracking information among team members.

The influence of leadership on CIS is significant because it has the ability to influence the team in two ways: (1) determining the particular approach for the team, and (2) developing the specific collaborative activities. Researchers have previously described the strong impact that team leadership has on a teams’ effectiveness (Zaccaro, Rittman, & Marks, 2002). Therefore, it is useful to understand the type of leadership within a team in order to better support team CIS activities.
5.2.4 Team Experience

Team experience was the second contextual factor identified as being influential to the development of the different CIS approaches. Team experience is often characterized by expert and novice team members. Team members who are experts have a high level of teamwork experience, resulting in a better understanding of new information (Rentsch, Heffner, & Duffy, 1994). Similar to the leadership issue, I asked participants about the impact of team experience, and a majority indicated that it significantly influenced CIS.

Participants indicated that experience was one of the main factors in determining when collaboration occurred, thus playing a role in determining the approach that was utilized. Teams with high a level of team experience often started the team discussion at the onset of the CIS task and maintained a more collaborative atmosphere through the task. Therefore, most teams with high levels of team experience utilized the Team to Individual or Team approaches. Participants also stated that higher levels of team experience led to more collaborative activities taking place. Due to having a higher comfort level working in teams, team members explained that they knew what to expect in certain situations and how to respond to teamwork, which resulted in increased collaboration.

Understanding how team experience impacts CIS approaches is important as we consider how to plan and design for CIS. Researchers have highlighted that high levels of team experience often lead to increased team effectiveness (Rentsch & Klimoski, 2001). Therefore, we must consider the impact of teams varied levels of experience during CIS activities. Since not all teams will have high levels of team experience, we need to also consider how to best support these teams during CIS tasks. For example, developing features that initiate question asking has the ability to spur collaboration among the team, which might be something that is needed in teams with little experience.

5.3 Design Recommendations

As outlined in the background, multiple systems exist to aid and enhance teams during CIS. These systems rely heavily on the implementation of design requirements that are thought to help the collaborative search process. Some of the most widely discussed design requirements for collaborative search systems are: awareness, communication, visualization, integration, and
This study identified multiple ways people collaboratively search for information. As previously noted, this means that CIS is not "one size fits all." Consequently, systems aimed at aiding users during CIS should not be configured in a "one size fits all" manner. Specifically, CIS systems should allow for adaption based on the four previously outlined CIS approaches. In all of the approaches, individual information processing and team collaboration occur with different ebbs and flows. And in three of the four approaches, collaboration is not constant throughout CIS. These findings have a direct impact on CIS design. First, the system should be able to account for adaption between individual work and teamwork. Each type of work entails similarities and differences, meaning that the system should work towards aiding each. In addition, CIS systems need to account for transitioning between individual to teamwork and vice versa. The collaborative features of the system have the potential to "smooth" the transition from one to another. Finally, CIS systems must understand the ebb and flow of communication and work, allowing users to not be distracted and constantly orienting them to working with the team.

Customizing and designing systems to be configured to multiple contexts and approaches is difficult, yet it is something that is needed. In addition to the aforementioned recommendations, design recommendations in this community must also consider the effects of cognition and team cognition. Below I outline important contextual factors that must be considered during CIS design. These factors are aimed at improving CIS and developing team cognition within this context (RQ 4):

**Awareness:** As highlighted in this chapter and the previous chapter, awareness is one of the most prevalent ways in which team cognition develops. In addition, awareness is continually discussed as being one of the most important features of team cognition (Gutwin & Greenberg, 2004). The design of a CIS system must account for and help develop awareness among the team. Developing team awareness allows each team member to understand what individual team members are doing, then resulting in an overall understanding of what the team is doing. Over time, team understanding eventually develops into a shared understanding. Specific to CIS, systems must help users understand what other team members are searching for and finding. Possessing the awareness of what each team member is searching and finding allows for team members to truly understand the CIS process, as well as understand the content being found. This understanding can only be accomplished if awareness is present throughout the team. Therefore, designing for team awareness must accomplish two things: establishing and maintaining
awareness. Establishing initial awareness is not enough to fully develop team cognition. Team cognition grows over time; therefore the system must continually support the maintenance of awareness as the team continues to collaboratively seek information.

*Communication:* Like awareness, communication is integral to the CIS process and to developing team cognition. Simply, CIS and effective levels of team cognition do not develop if the team lacks communication. Communication allows for the sharing of individual cognition throughout the team. The communicating and sharing of each team members’ individual cognition is what leads to team cognition. Therefore, in order to support the development of team cognition during CIS there must be effective means for communication. Even in a co-located team, normal dialogue might need to be aided by additional communication means. In this study, teams often conducted individual searches with minimal communication. A system that has the capabilities to maintain communication during individual searching might help develop team cognition. Significant gaps in communication potentially hurt team cognition, so CIS systems must aid in continuous communication throughout the entire team.

*Visualization:* Within the human computer interaction community, there is a long history of the benefits and challenges associated with visualizations. Often visualizations are implemented in order to simplify information. Specific to CIS, systems need to present visualizations related to information searching and found information. During the CIS process, each team member finds a great deal of information from many different websites. Tracking what information has been found and where it was found can be a daunting task for the team. Yet, understanding as a team what information has been found and where it came from is critical to developing a shared understanding of information. If a system could develop a visualization of found information and its sources, it would greatly help the team develop a shared understanding of collaboratively found information. In addition to visualizations helping the team understand information, they also have the ability to increase team awareness.

*Individual and Team Processing:* A CIS system must allow for individual and team-level cognitive processing. In the findings, it was apparent within many of the approaches that team members went back and forth between focused individual and team cognition. As a system is designed, it must account for the ability to let the team member understand and process information at an individual level, while still enhancing team cognition. A CIS system should not
inundate and force team cognition upon the user. A constant barrage and focus on team cognition will not allow for the development of individual cognition. If individual level cognition is stifled, then team cognition will not be developed since its foundation is all team members’ individual cognition. Yet, managing individual and team cognition within the system is a very tricky design feature because the system cannot necessarily predict when a team member is switching from individual cognition to team and back. It is possible that the system can possess the affordance to allow users to indicate when they are thinking and working individually and when they are working with the team. While this might help team members focus their cognition on the individual or team, it could be another barrier to streamlined, uninterrupted cognition because they will have to remember to turn the affordance on and off.

*Cognitive Load:* System design, no matter the context, should always account for cognitive load. Even more importantly, systems that are aimed at multiple users or teams must pay closer attention to cognitive load. A team inherently brings forth a greater deal of cognitive load due to added information and cognition that each team member brings to the table. This increased cognitive load makes developing team cognition hard enough, yet many systems bring forth too many affordances that increase the cognitive load. Individuals have a limit to how much information they can cognitively process at a time. Therefore, a system should not stretch one’s cognition even more so than it already is from the teamwork. It’s important to think about how to improve CIS systems and design new affordances, but these improvements must not overload the individual and the team. If the system is significantly adding to the cognitive load, then the individual team members will have trouble processing information, which will lead to team cognition not being developed. The saying, “less is more” can be true in regard to designing for team cognition during CIS.

### 5.4 Methods for Measuring Team Cognition during CIS

Below, I describe five methods that are potentially useful for measuring team cognition during CIS. Of the five methods, two are specifically used within this study (qualitative methods and concept mapping). While these methods are neither new nor innovative, they provide a repository of methods to consider when studying team cognition and CIS. This list is also not all-inclusive
but I see these knowledge elicitation methods as potentially being very effective for capturing team cognition, and specifically team mental models, during CIS activities.

*Paired Comparison Testing:* This method is often regarded as one of the most popular team cognition methods. Participants are given pairs of statements in which they rate the degree of similarity between them. The similarity ratings are then configured using computer algorithms (examples: Pathfinder, Multidimensional Scaling). Once the ratings are available, the mean similarity rating of the team (all participants) can be compared with individual similarity ratings. This comparison helps to further understand the relationship of individual and team mental models. Paired ratings would be given in regard to both the taskwork and teamwork team mental models. In the context of CIS, statements regarding the CIS task would simply be given as highlighted in the example below.

*Teamwork Paired Comparison Ratings:*
1. Sharing information openly with all team members.
2. Trusting all team members.

These statements are directly related to the teamwork mental model. If one were actually using these paired comparison statements, they would give both of the statements to the participants along with directions to rate them on a scale of 1-5 dependent on how related the statements are. The goal of these statements is to understand the relationship between sharing information and trust. Once the comparison rating is derived from aggregating all team members’ ratings, the researcher will then be able to understand how the team views trust and information within their team mental model.

*Concept Mapping:* As utilized in this study, concept mapping can be instrumental in understanding team cognition during CIS. For more information on the concept mapping process, revisit Chapter 3 (pg. 62). Similar to this study, in the context of CIS, participants within a team are given a traditional CIS task, asked to work through it, and then produce a concept map based on the task. The concept map includes concepts directly related to the CIS task and propositions connecting them. The concept map also affords the ability to be collected in a variety of ways: individual, team, or a combination of both. The value of this method from a team cognitive
perspective is that the participants are essentially mapping out their team mental model in relation to the CIS activity.

Qualitative Methods - Observation and Cognitive Interviewing: Traditionally measurement and analysis of team cognition is conducted through quantitative means. While quantitative measurement is very valuable, qualitative measurements must also be considered to provide more depth. Observation is often overlooked within cognitive research circles because it is looked at as method primarily focused on capturing interaction and not cognition. A significant amount of cognition can be learned from observation if it is paired with other more traditional measurements. There is great value in understanding if what is actually carried out matches up with the cognitive intent. This method is most valuable when one is seeking to understand if actions (carrying out a CIS task) match up with thoughts (CIS contextual team mental model). Cognitive interviewing is also a valuable qualitative technique. This is a specific approach to interviewing where a researcher directly interviews a participant regarding their cognition during an activity. Probing is done in such a way that requires the participant to describe to the researcher the activity and what they were thinking at certain points in time. This interviewing approach demands the participant cognitively recall and revisit what they were experiencing.

Card Sorting: Known as a highly psychological method, card sorting is a well-known team cognition measurement. Participants are given cards with critical components of a situation on them, and the participant must then sort those cards into groupings based on how they view them as being related. Once the groupings of cards are sorted, the participant is then asked to name each grouping. This allows for the researchers to understand both the content and cognitive structure of the mental model. The individual mental model card groupings are then measured throughout all members to see which groupings are most similar and accurate, thus providing the team mental model groupings. Much like concept mapping, card sorting can be aligned directly to a CIS task. In this context, the cards would simply be named after the critical components within the CIS task. An example of card sorting within the context of CIS follows.

Teamwork Cards:
These cards would be given to each member of the team and they would then be asked to separate them into groupings based on concept similarity. So, hypothetically, the participant grouped cards 1, 2, 7, 9 in one group and 3, 4, 5, 6, 8, 10 into another group. Now that the following cards have been sorted into groups the participant must name the groupings. For this example, the participant names the first group information sharing and the second group information seeking. The results across all team members will then be aggregated and analyzed to understand the structure and content of the team mental model.

**Analytical Methods:** Verbal protocol analysis (VPA) is one of the most widely used analytical methods for measuring team cognition. While VPA is a method for capturing cognition, it is also a way to analyze the data. For this measurement, traditionally the researcher asks the subject to think aloud while they are performing a task. This works well for an individual, but when a team is present it can be more complicated. One can’t expect each member of the team to think aloud while they are also communicating with their teammates. An approach to get around this problem is to not even ask them to think aloud, rather just let them communicate normally with their team. Cooke et al. (2004) have made the argument that because team members are in a team they are already thinking aloud to a degree. If members of the team didn’t think aloud, then teammates wouldn’t understand what each is thinking and no ideas or solutions would be developed.

VPA is mainly used within the Human Factors community as a way to make cognitive inferences from content found during discourse (Walker, 2005). As previously mentioned, the “content” is a written transcript derived from participant’s verbal communication during a task. The content can then be further coded by words, sentences, and themes. The coded content is then categorized based on a pre-defined categorization theme. Researchers link that a participant’s “think aloud” is directly related to their cognition. As the participant continues to think aloud, the researcher is then able to derive how they cognitively develop their thoughts and outcomes. During team research, inference can be made about how each member of the team thought and verbalized their cognition to the rest of the team. Analyzing each team member’s spoken thoughts allows for an understanding of how a team mental model is developed.

In addition to VPA, content analysis is also frequently used as a way to capture and analyze team cognition. Content analysis is used in many ways for many different types of datasets. For the purposes of team cognition, similar to VPA, there will need to be a written transcription of the team’s spoken word. Once the transcription is in place traditional content analysis coding can begin.
In regards to the context of CIS, analytical methods can prove to be very useful and easily implemented into current CIS research studies. Since many CIS studies consist of a team undertaking a CIS bounded task, the research design just needs to ensure that verbal communication is captured during the task. Once communication is transcribed, coding can begin via VPA or content analysis.

5.5 Study 1 Limitations

A potential limitation of this study is the utilization of both dyads and triads. Initially, I decided to use both team sizes because they are team sizes commonly used in many domains and contexts (Salas et al., 1992). I anticipated that there would be differences in CIS and the development of team cognition in the different team sizes based on the impact that team diversity has on team outcomes (Horwitz & Horwitz, 2007). However, I did not find any differences between team sizes through analysis. In addition, it would be beneficial to conduct this research with a larger number of teams conducting naturalistic CIS tasks but this is logistically difficult to carry out. However, I believe that by observing all of the CIS tasks, conducting individual interviews, and gathering both individual and team concept maps, I was able to capture detailed data to provide meaningful insight into understanding CIS approaches and the role of team cognition during CIS.

5.6 Chapter Summary

In this chapter, I first discussed how team cognition develops during CIS. Specifically, team cognition develops through three different identified means: (1) the creation of multiple awareness mechanisms, (2) the transference of individual to team cognition, and (3) the interplay of interaction and cognition during CIS. Next, I outlined the impact that the approaches have the field of CIS. In particular, I explained what the approaches mean for CIS, the importance of understanding that CIS is a combination of individual and collaborative work, and the reasoning for why multiple approaches exist within this study. I then highlighted potential design recommendations that will aid CIS and the development of team cognition during CIS. Finally, I concluded by reviewing multiple methods to measure and capture team cognition during CIS. In
the next chapter, I introduce study 2 with a focus on the study’s motivation and research design/methodology.
Chapter 6

Study 2- Distributed: Study Design & Methodology

The second study I conducted built upon the first study. In this study, I focused on how teams approach CIS in a distributed medium and if/how team cognition develops in this medium. While CIS often takes place in a co-located setting (the first study), the changing technological landscape has led to CIS work also taking place in distributed settings (often using CIS systems). Researchers have realized that CIS often occurs in distributed environments, resulting in multiple CIS systems being developed to aid CIS activities in this setting (i.e. SearchTogether (Morris & Horvitz, 2007), Cerchiamo (Golovchinsky et al., 2008), Coagmento (Shah, 2010a)). In addition, researchers have also realized that a distributed setting affects team cognition (Fiore et al., 2003; McComb et al., 2010).

Taking into account the high preponderance of distributed CIS work and the affect the environment has on team cognition, it was evident that the two research areas needed to be studied together. To my knowledge, a study has never focused on the context of CIS work in a distributed setting while also focusing on the development of team cognition. For this reason, and my interest in understanding the affects that a distributed setting has on CIS approaches and team cognition (RQs 1,2,3), I designed and organized a second study to focus on these issues. In this study, I maintained many of the same procedures found in study 1 while including the CIS system Coagmento. This system constricted participants to only communicate and seek information in a distributed manner. In this chapter, I provide background on CIS taking place in different settings, background on the development of team cognition in distributed settings, an introduction to the Coagmento system, the research design of study 2, and an overview of the data collection and analysis protocols.

6.1 CIS in Different Settings

Collaboration may occur in many ways and in many different contexts. Yet, throughout all collaborative efforts there are two aspects that often define and ground collaboration: time
Aspects of time and location mainly stem from computer mediated communication (CMC) work. Collaboration has traditionally occurred in co-located synchronous settings, but as technology grows, distributed a/synchronous collaboration is becoming more apparent (Shah 2010b). Co-located teamwork refers to team members working together within the same physical proximity, often resulting in face-to-face interaction (McNeese et al., 2008). For example, a traditional sports team, like football, is viewed as being co-located. A distributed team implies that team members are not together within the same constraints of a physical environment (van der Kleij et al., 2006). Distributed teams may be geographically, culturally, and remotely dispersed and work through a variety of CMC systems. The aspect of time is directly related to location. Often, the location that work takes place precedes the type of communication that takes place. The location itself puts constraints on how work takes place, either in a synchronous or asynchronous manner. Synchronous work entails real time work with immediate simultaneous feedback (Johnson, 2006). In contrast, asynchronous work is characterized by a delay in time and team members not simultaneously working together (Johnson, 2006).

An abundance of CMC research has explored the impact that each of these aspects has on a team’s collaboration and subsequent performance. Due to the large volume of work within the CMC community, a variety of different findings are apparent. Depending on the context, the affordances of time and location might help or hurt collaboration and performance. Yet, across all contexts of time and location, problems directly linked to CMC within the distributed setting are mostly apparent. Specifically, findings from a meta-level review indicate that distributed CMC lowers group effectiveness, increases the amount of time needed to complete tasks, and lowers team member satisfaction (Baltes et al., 2002).
While time and location have been acknowledged and discussed as being important to CIS, there is a lack of research specifically exploring the impact of each during CIS activities. Some work has specifically focused on the effect that different locations (distributed/co-located) have on CIS. Specifically, González-Ibáñez, Haseki, & Shah (2012) designed a study comparing CIS within four different time-space settings: co-located, remotely located with text chat, remotely located with audio chat, and asynchronous. They found that users who participated in the co-located environment often exhibited similar search behaviors of their team members, resulting in overlapping searches. Importantly, user’s search behaviors in the distributed condition were often independent of their team members, resulting in more diverse search results across the team. This research clearly identifies that the setting CIS occurs in has the impact to change the way teams conduct CIS. In another study conducted by Shah & González-Ibáñez (2011), they explored CIS in four different conditions: single users, pairs of users at the same computer in a co-located environment, pairs of users at different computers and co-located, and pairs of user in a distributed setting. Their findings highlight that no matter the setting (co-located or distributed), users were able to find more information if they were using different computers as compared to one. In addition, they artificially combined the results from the single users to form dyads, and found that they were able to find more information than any of the real teams. Work has also been conducted within the CIS community that investigates the affect of culture on CIS taking place within CMC. Cho & Lee (2008) investigated the process of CIS within different cultures using CMC and found that depending on the culture, the flow of information varies and can be greatly constrained. Within the area of collaborative web search, a type of CIS, researchers have also identified the usage and needs for both co-located and distributed searching (Morris & Horvitz, 2007; Morris, 2008; 2013).

Moving forward, there is a significant need to further understand CIS within multiple different settings, specifically the distributed setting. While Shah and colleagues have started to work towards an understanding, more research from other researchers is needed. In addition, the research community must work towards understanding how different settings of CIS affect team cognition.
6.2 Team Cognition in Distributed Settings

In comparison to the many other focuses within the team cognitive community, there is limited work that focuses on the impact the distributed setting has on team cognition. This has led to leaders within the team cognition community calling for more focused work describing the impact distribution has on the development of team cognition (Salas, Cooke, & Rosen, 2008). Yet, even though the amount of work is limited, researchers acknowledge this issue and some work specifically focuses on it.

Due to the temporal, team configuration, and geographic complexities associated with distributed teams, the development of team cognition is complicated and often challenging (Cummings & O’Leary, 2002). Specifically, issues surrounding communication often arise within distributed teams, leading to significant team cognition problems. In a traditional team (co-located/synchronous), team members have the opportunity to communicate through verbal and nonverbal processes and observe one or many members in real time. Due to these abilities, Stagl & colleagues (2007) have referred to traditional teams as having the fundamental gift of “on-demand coordination.” Distributed teams tend to face coordination challenges because they must communicate through an external medium. Often these mediums create a level of abstraction, lessening effective communication (e.g. media richness theory) (Daft & Lengel, 1986). Having to communicate through a technologically communicated medium can lead to higher levels of ambiguity within the team (Fiore et al., 2003). More specifically, the concept of team opacity has been suggested in regard to distributed teams. Team opacity refers to the loss of team member (level) situational awareness through technology-mediated interaction (Fiore et al., 2003). This opacity or loss of awareness is due to the inability to clearly process non-direct forms of communication, such as paralinguistic attributions, nonverbal forms of communication, and sensory perceptions (touch and smell) (Stagl et al., 2007). The development of team cognition is highly dependent on communication (Cooke et al, 2013). For this reason, the communication issues outlined above can severely impact and hinder the development of team cognition.

For a team to develop a team mental model, the team must reach a mental model convergence point. This is the point in time where individuals move from thinking only in terms of their mental model to thinking from the perspective of the TMM (convergence point) (Mathieu et al., 2000; McComb, 2007). McComb et al. (2010) examined how long it took distributed and face-to-face teams to reach this convergence point, and found that it took the distributed teams longer. The reasoning for this outcome was that the distributed teams focused on only the main
points of the research task. Focusing only on the major aspects of the research task limits the team to systematically talk through all options (Siegel et al., 1986). This could result in the distributed team being half way through the task and realizing they have missed a critical point due to their broad focus. The second barrier that resulted in the distributed teams reaching the convergence point at a slower rate was that team members felt significant time pressure due to the fact that they had to type and interact through a collaborative tool. In a separate study, Bolstad & Endsley (1999) examined the effects of physical proximity on team mental models and found that teams who interacted within a close physical proximity developed team mental models faster than teams who interacted in a distributed manner using a shared display. The reasoning for this outcome is that co-located team members were afforded higher levels of communication and observation with one another than distributed team members.

Another aspect of distributed teams is their cultural diversity. Many distributed teams are now a mixture of many different cultures. The team cognition community is starting to realize the impact that culture has on team cognition within a distributed medium. Multicultural distributed teams have seen a significant influx of growth within recent years (Connaughton & Shuffler, 2007). Organizations in multiple domains have started to realize that using these teams optimizes overall resources. Yet, there are significant challenges associated with this type of team. Research has pointed to differences in how individuals from different cultures organize and collaborate toward a shared goal (Klein & McHugh, 2005). Cultural differences during teamwork will have an impact on the development of a team mental model. Each culturally different and diverse team member brings a different mental model that is bounded by the context of his or her culture (Quinones et al., 2009). Every culture has associated values, traditions, norms, and beliefs that are implicitly and explicitly engrained within an individual’s mental model. Therefore, meshing different culturally bounded individually mental models together can be complicated and be challenging to creating a team mental model. Work by McHugh, Smith, & Sieck (2008) examined the effect different cultural variations have on team mental models. Over 60 multicultural individuals were interviewed about how mental models are developed within multicultural teams. The results found that important differences exist in culturally based mental models, leading to incoherent team mental models. Specifically, differences among culturally bounded mental models dealt with different ways of divergent and convergent thinking, trust, conflict, and respect.
6.3 Study 2 Research Design

Study 2 utilized many of the same procedures as Study 1, except participants communicated and sought information through the CIS system Coagmento. In addition to the implementation of Coagmento, the second study did not utilize concept maps. While the concept maps were very useful in the first study, I felt that I gathered more than enough valuable information through the interviews. As a result, in the second study the data is focused on individual cognitive interviews and chat log data. The exclusion of the concept maps also allowed for longer and more in-depth interviews to occur during Study 2. Overall, the goals of study 2 were to better understand:

- How do teams approach CIS in a distributed setting?
- Is team cognition or a team mental model developing during CIS in the distributed medium?
- If team cognition is developing, how is this happening?

To articulate the research design, I’ll first explain the CIS system Coagmento, and then outline the formal study.

6.3.1 Coagmento: A Collaborative Information Seeking System

Coagmento (Shah, 2010a) is a widely utilized CIS system that allows for multi-session and multi-user CIS related projects. In addition, the system also provides a multitude of different functionalities specific to aiding the process of CIS. Originally developed in 2007 by Dr. Chirag Shah, the system has been refined many times to include new features and account for different platforms. In its current state, Coagmento is a plug-in that can be downloaded to Firefox or Chrome and a mobile application that can be downloaded to both Android and iOS platforms. The plug-in and application are both available to the public and free of cost. Once downloaded, users have the availability to create multiple projects. For each project, Coagmento will track and store search history, as well as any information that is added to that project’s report. As highlighted by González-Ibáñez & Shah (2011), the Coagmento system supports: information collecting and sharing, information rating, communication, collaborative reporting, and resource
Within the CIS community, Coagmento has been used numerous times to conduct research studies (González-Ibáñez et al., 2012; Shah & Marchionini, 2010).

To better understand the system, I will highlight the overall user interface (UI) and the various features that are built into it. Figure 18 shows the UI for the Coagmento system.

The interface consists of a toolbar (Figure 19), a sidebar (Figure 20), and a basic web browsing/collaborative editor space (Figure 21) allowing for many different features. An overview of each feature is provided below.
C-Space: C-Space is an area within Coagmento that acts as the home page for the entire system. Once a user activates C-Space, a page overlays the web browsing/collaborative editor space. Within this page, all the projects that have been created along with their collaborators are presented. In addition, once a project is selected, C-Space will also graphically present browsing history, bookmarks, recommendations, annotations, and snippets throughout the team.
Bookmark: This feature is utilized by users when they find a website that has useful information on it and they would like to remember the website for future reference. When the user is on a webpage and bookmark is clicked, a pop-up comes up that indicates the page will be bookmarked. In addition, within the pop-up, the user has the ability to make notes on that page or rate the page (1-5). Once a page is bookmarked, collaborators will also be able to see it.

Recommend: Once a user finds a website that they view as useful, they have the option of sending a recommendation to visit the website to their collaborators. This feature is useful if collaborators are working on the same project but not at the same time; the system sends an email to the collaborator recommending that they visit the site once they log back into Coagmento.

Annotate: If a user finds a website that they want to leave notes on, they can utilized the annotate feature. By activating this feature, users are presented with a pop-up textbox where users can add notes. A user can add unlimited annotations to a website.

Snippets: Users have the ability to “snip” information that is found on a specific webpage. The user highlights text on the webpage and then clicks snip and a popup box will show up allowing the user to also make notes about the snipped information. Once text is snipped from a webpage, collaborators will be able to see it.

Chat: The chat client present within Coagmento is a basic chat that affords the abilities found in most synchronous chat clients. If two or more collaborators are working together at the same time, the chat client is their main form of communication within Coagmento.

History: The history tab is found in the sidebar of the UI. This feature allows collaborators to view history of searches, bookmarks, and snippets. Each history item is linkable to the website, bookmark, or snippet that it represents. The history tab allows users to view only their history or view history shared among collaborators.

Notepad: The notepad tab is also located in the sidebar of the UI. This feature allows users to either make individual notes, or notes that are shared among collaborators. The notepad is not constrained to a specific website, rather it allows for notes to be taken throughout the entire CIS project.
Collaborative Editor: Users have access to a collaborative editor based on the Etherpad platform. This editor allows users to type in a document that is shared across all collaborators. Each collaborator can add to or edit the document in real-time.

6.3.2 Study of CIS and Team Cognition in a Distributed Medium

6.3.2.1 Research Site & Equipment

Similar to study 1, this study took place in the User Science and Engineering Lab located in 314 IST. As distributed teamwork is one of the main focuses of study 2, I used the modular experimental area of the lab for this study. As noted in the first study, this area houses six physically isolated computers with noise cancelling headphones. Each side of the experimental area contains 3 modules with the computers. At the front of the experimental area is a workstation where the researcher can observe activities. For this study, participants sat at the first module on right side and the last module on the left side. This setup increased distance between the two participants, also disallowing for any psychical verbal or nonverbal communication. Upon sitting at the module, participants were greeted with Google and the Coagmento UI on their computer. Before the participants arrived, researchers set up Coagmento to include a new project, also clearing any previous history or web browsing data within the system.

6.3.2.2 Participants

For this study, participants were recruited from spring undergraduate classes within the College of Information Sciences and Technology. Recruitment resulted in a total of 20 participants taking part in study 2. The 20 participants were separated into a total of 10 teams of dyads. Most participants were 21 years old or older (58%) with more females (58%) than males participating (Table 14). Similar to study 1, a wide majority of participants were also IST undergraduates (95%). Participants also reported working on an average of 10 teams throughout their academic tenure with a 4.5 (5 point likert) average comfort level working within teams. Upon completion, each participant was paid a total of $20.00.
<table>
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<tr>
<td>21+</td>
<td>58%</td>
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<tr>
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<tr>
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<td>58%</td>
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<td>42%</td>
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<td>95%</td>
</tr>
<tr>
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<td>6%</td>
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<tr>
<td>Average # Teams Worked On</td>
<td>10</td>
</tr>
<tr>
<td>Average Comfort Level Working in Teams</td>
<td>4.5 of 5</td>
</tr>
</tbody>
</table>

Table 14. Study 2 Demographics

An important decision in the research design of study 2 was to only use dyad teams, instead of both dyad and triad teams. This decision was made for multiple reasons. First, I utilized dyads and triads in study 1 because it was the first research study to ever focus on team cognition and CIS. Therefore, I felt it was important that I included the two most common team sizes utilized in team cognition research (Salas et al., 1992) to gather an understanding of both team sizes. Yet, after analyzing the data from study 1, no differences related to CIS approaches or team cognition were found. With this in mind, I felt it was best to go forward with only using dyads. Using only dyads provided the availability of more teams at one size. Using multiple team sizes stretches out the total number of teams across two team sizes. In addition, running triad teams in study 1 caused problems by one or two participants often not showing up for the study. This problem, for whatever reason, did not occur in the dyad teams. A critical lesson that I learned from study 1 is if I use different sized teams in the future, I think it is beneficial to have a larger difference between team sizes than 1 person (2 vs. 3). Yet, creating a larger difference between team sizes causes many logistical problems, specifically scheduling and payment.

6.3.2.3 Study Procedure

Before participants started participating in study 2, I piloted one team. Unlike study 1’s pilot teams, which used undergraduate students who were recruited and paid, this study used graduate students who volunteered their free time. I only piloted one team and used graduate students for
feedback because many of the procedures in study 2 and study 1 are similar. The pilot teams in study 1 were also critical to the overall study because they provided the researchers with a “parking lot” of concepts that participants used during individual concept mapping. Piloting in this study mainly focused on the utilization of the Coagmento system and instructions for how to use it. Minimal feedback was given during the pilot, resulting in no changes to the original study design.

Study 2 lasted approximately 1 hour and 10 minutes. When participants arrived at the laboratory, they were brought into the experimental area. Participants were then seated at their assigned module. Once seated, the researchers introduced the study and asked each participant to sign an informed consent form. Participants then completed a short survey aimed at understanding their demographic characteristics and teamwork experience. Next, the researchers provided a high-level description of the study outlining each step. Researchers then referred to their script to explain the concepts of CIS and team mental models. Once participants indicated that they understood the concepts, the researchers moved on to explaining the Coagmento system. Participants gathered together and watched a video explaining the features of Coagmento and how to use the system. Once the video concluded, a researcher opened Coagmento on a computer and provided a real-time tutorial on how to use the system. After participants acknowledged that they understood how to use the system, the researchers advanced to the next part of the study.

Participants were then given 3 CIS tasks and worked through them using Coagmento. These tasks were the same tasks that were used in study 1 (pg. 50). The amount of time given for each task was also the same as study 1 (task 1-15 minutes, task 2-5 minutes, task 3-10 minutes). I used the same tasks with the same time limitations as study 1 because I felt it was important that the only aspect of CIS that changed between study 1 and study 2 was the implementation of the distributed environment and Coagmento. If I changed too many aspects of the research design in study 2, then it would be very hard to accurately identify and acknowledge any similarities or differences between study 1 and study 2.

After 30 minutes concluded and the participants finished the CIS tasks, they were separated to participate in individual cognitive interviews. The cognitive interviews in this study were longer than study 1, varying from 25-35 minutes depending on the participant. Once the participants finished their cognitive interviews, they were thanked for their time and paid a total of $20.00 for completing the study. After the participants left, the research team transferred the audio recordings of the cognitive interviews on to computers and logged the team’s chat communication within Coagmento.
6.4 Data Collection & Analysis

6.4.1 Cognitive Interviews

The individual cognitive interviews were so successful in collecting meaningful data in study 1 that I decided to use them as the main data collection methodology for study 2. The scope and depth of these cognitive interviews were different from study 1. While some of the same questions from study 1 were asked, many questions were added that specifically focused on the distributed environment and the utilization of Coagmento. The interview guide can be found in Appendix H. Also similar to study 1, I utilized multiple verbal probing techniques and aspects of the critical decision making methodology.

*Analysis:* The cognitive interviews were analyzed using thematic analysis. The analysis was conducted at three different levels: individual, team, and across all teams. For more details on this analytical process, refer back to Chapter 3 (pg.61).

6.4.2 Chat Logs

The chat communication that occurred within Coagmento was logged for future analysis. Since the role of social observations is minimal in a distributed setting, the chat logs were viewed as important to understanding the communication and interaction that occurred during CIS.

*Analysis:* The chat logs were reviewed in accordance to the cognitive interviews. The goal was to use the chat log data to triangulate the findings derived from the cognitive interviews.

6.5 Chapter Summary

This chapter introduced study 2’s design and methodology. A brief literature review on the areas of CIS in different mediums and team cognition in the distributed setting were presented. Also, an overview of the CIS system Coagmento was provided. Finally, an outline of study 2’s procedures
and data collection/analysis protocols were reviewed. The next chapter will present findings from study 2.
Chapter 7

Study 2 Findings: CIS Approach and Team Cognition Development in a Distributed Environment

In this chapter, I present the findings from study 2. This study focused on examining how team members approach CIS in a distributed setting and the affect that the distributed setting had on the development of team cognition. I first explain how teams approach CIS in a distributed setting. Then, I describe the development of a team mental model specific to CIS within the distributed setting. Finally, I describe the CIS system Coagmento’s impact on both CIS and team cognition.

7.1 Approaching Collaborative Information Seeking in a Distributed Setting: More Individualistic, Less Collaborative

While teams in study 2 collaborated early and often, their overall approach to CIS focused more on individual cognition than on team cognition. All of teams followed an approach that led to CIS activities that were more individualistic and less collaborative within the distributed setting.

Unlike in study 1, participants in study 2 utilized only one approach of CIS (Figure 22). This approach was highly dependent on the individual team members’ work. All of the teams began the CIS process with individual information seeking. During this time period, team members developed their own search terms and sought information at an individual level. Team members conducted this initial individual search to provide themselves with background knowledge on the task before collaborating. The individual information seeking period varied in length from 30 seconds to 4 minutes. Once team members were comfortable with their own knowledge pertaining to the tasks, they would initiate team member collaboration through the chat feature in Coagmento. The purpose of the initial collaboration varied depending on the team.

Team members initiated and focused their initial collaboration on:

• presenting information (example: a bullet list) (Teams 6, 8, 9, 10),
• sharing their thoughts and opinions on the answering the CIS task (Teams 1, 5),
• sharing a link (Team 7), or
• sharing what each team member was currently doing and/or did before collaborating (Teams 2, 3, 4).

The team’s plans usually consisted of splitting the task up among team members, leading individual team members to search for specific information. Although team-level planning usually takes place at this point, half the teams (5 of 10) never explicitly developed a plan for approaching the task. The lack of planning during this initial collaborative period impacted how the team worked together throughout all of the CIS tasks.

Regardless of whether teams did or did not plan, all the teams reverted to individual information seeking. After initial collaborations, team members conducted CIS activities mainly through individual searching, complemented by team members communicating with each other through Coagmento’s chat to share and agree on the found information. During the task, individual team members often searched for specific information and when they found something they deemed important, they shared it with their team member. The team member either agreed or disagreed about the importance of the information and then the team moved forward in their information search. The amount of communication occurring within each team during this time period is highly dependent on the specific team. Yet, the frequency and amount of communication within most teams was surprisingly low.

When communication did occur during these tasks, it happened primarily through the chat and the shared editor features in Coagmento. The teams used the chat feature to mainly ask questions and confirm information. During the process of finding and sharing information within the teams, the teams worked extensively through the shared editor, using it as the medium to organize and add information to the team’s final document. Each team member actively added to and edited the shared document until each team member felt comfortable enough that it represented the final answer - indicating completion of the CIS tasks.
Figure 22. Distributed CIS Approach
7.1.1 The Increased Importance of Individual Work During Distributed CIS

The aforementioned CIS approach clearly illustrates the importance of individual work during distributed CIS work. While individual work is fundamental to CIS in both co-located and distributed settings, this study found that individual work is more prominent in the distributed setting and consequently more important.

CIS work in the distributed setting began with individual searching. Individual searching continues throughout the entire process of distributed CIS. Many of the approaches outlined in Study 1 indicated a back and forth between individual and team based work. In comparison, most distributed CIS work was conducted at an individual level. CIS teamwork certainly occurred in the distributed setting, but not at the levels identified in the co-located setting. Many participants highlighted the importance of individual work during distributed CIS. A team member explained the necessity for individual information seeking in the distributed setting:

“Well I, I figured, you know, since we were doing Google searches, you can’t really do that collaboratively, right. So, I kinda realized it would, it would be more of an individual task right off the bat. And then we would compare overlapping answers, and that would be our main method of collaboration.” (Team 3, #2)

As the quote highlights, the distributed medium created a barrier among team members, forcing them to individually search for information and then relying on sharing found information. A participant explained the process of sharing individual information searches within the distributed setting:

“Well, so… before we started typing in our collaborative document, we were on the chat and we… said okay, I said it seems like from my searches that there’s not really a known cause, but there’s a lot of risk factors; What are you finding? And he said okay, you know I’m pretty much finding that same thing.” (Team 4, #1)

Similarly, another participant acknowledged the role of individual information seeking within the greater CIS activity: “We would search individually, and then... either send the link or bookmark it, and say I found these things, and then we would agree or not agree, if we thought that was good to put in.” (Team 7, #1) This process of finding information individually and then sharing was identified as a pattern in all of the teams. In the distributed setting, team members
had no choice other than to rely on their own information seeking abilities. Even with the affordances of Coagmento, it was difficult for teams to search for information in a truly collaborative manner.

7.1.2 Planning How to Collaboratively Seek Information in a Distributed Setting

Through analysis of both interview and chat log data, I found that many teams did not specifically or explicitly plan how to collaboratively seek information in the distributed setting. The structure of the process of CIS was also quite varied; teams communicated and shared information sporadically throughout all three CIS tasks. Teams approached CIS from both an impromptu manner with no plan (Teams 1, 6, 7, 9, 10) to creating a specific plan for collaboration (Teams 2, 3, 4, 5, 8).

In the distributed medium, many teams approached CIS one step at a time and did not plan ahead. These teams essentially determined how to collaboratively seek information in an ad-hoc manner as they were completing the tasks. Participants in these teams often identified their CIS work as “just kind of starting” (Team 7, #1) or “I think it just kind of happened” (Team 9, #1).

This is not to imply that these teams did not plan at all but rather that there was only limited pre-planning. When planning did occur in these teams it was often on the fly and related specifically to formatting and presenting information, not the actual process of searching and retrieving information. For example, this excerpt from Team 10’s chat demonstrates the nature of many team’s CIS work:

18:11 ‹cispipient1› the site i bookmarked has some good facts about how gender, race, age, obesity, diabetes, obesity etc affect it
18:12 ‹cispicipant1› that would work
18:13 ‹cispicipant2› ok awesome i was looking at that site too
18:14 ‹cispicipant2› im thinking age, gender, smoking, chronic pancreatitis are four top ones
18:14 ‹cispicipant1› i’d agree with that
18:16 ‹cispicipant2› i bookmarked a site
18:16 ‹cispicipant1› check out what i’m doing on the etherpad thing
18:17 ‹cispicipant2› ok
18:17 ‹cispicipant1› see if you want to change up the formatting at all
18:17 ‹cispicipant2› i like the formatting

This chat excerpt took place early in the study and highlights the “on the fly” or ad hoc nature of how some team’s performed CIS in the distributed setting. The first part of the chat
shows how they are sharing information specific to the task. Early in the chat, the team did not lay out a plan for sharing information, resulting in the team randomly sharing information via a bookmark and then quickly discussing it to reach an agreement. It was never part of the formal plan that the team would use a bookmark to share the information, it just happened. The team is also discussing how to present their information. No plan was put forth at the beginning of the tasks to present information. This resulted in the team planning while they are collaborating. The “on the fly” manner of CIS work represented within this chat excerpt was found within all of the teams who lacked specific planning during the CIS tasks.

Team members who did not plan how to approach aspects of CIS often had a difficult time explaining why their team lacked a specific plan. Yet, two participants noted that the distributed medium did not adequately allow for planning. A participant from Team 1 explained this in more depth:

“I feel you made it a little more disorganized (the distributed medium). Being face to face you can sit down and say we should do this first, this first, and then or you can just different roles to different people. But in this, this instance, we just... kinda were just thrown into it without any... preplanning or thinking, and we had to really just go on the fly.” (Team 1, #1)

Similarly, another participant explained how planning would have occurred if the team was not distributed: “But if I was together with someone I think I would... have more discussion like okay, let’s do this, okay let’s do this; okay, let’s do this.” (Team 7, #1) Clearly, in some instances the distributed setting reduced the ability for communication, which then impacted the ability for teams to create plans.

However, half the teams did plan their approach to CIS (2, 3, 4, 5, 8). In all five of these teams, planning occurred during the initial collaboration period. Also, in all of these teams, planning manifested itself through splitting up the CIS tasks among team members. For example, team members divided the task up among team members and then each team member searched for information specific to that part of the task. Teams split up the task to ease the collaboration challenges and ensure that enough information was found.
7.1.3 Cognitive Orientation is Mixed Among Individual, Team, and Both; Yet, Individual Action Outweighs All

In every team, team members indicated that their cognitive focus was on their own individual work, the team and teamwork, or a combination of both. Of the twenty participants, thirteen oriented their initial cognitive focus to the individual, four to the team, and three to both the individual and team. Team members who oriented their cognition to their own individual work often mentioned reasons similar to why the individual cognitive acclimation period occurred in study 1. Specifically, these participants explained that orienting their thought to the individual allowed for: (1) individually understanding the task, and (2) understanding their role within team.

Team members who oriented themselves to the team did so with the intent of understanding how to work with their team members from the onset of collaboration. A participant explains her thoughts being focused on the team: “No, I thought, I think, I guess I would say my first thought was... how would we work on it together. Like I didn’t really think like what I was gonna contribute.” (Team 8, #2) A few team members simultaneously oriented their thoughts to both the individual and the team. Team members indicated that their initial thoughts had to encompass both aspects because the nature of the CIS tasks required both individual and team work. A team member clearly explained the need for both individual and team oriented thought during CIS:

“I think it was a little bit of both (individual and team thought). I was trying to think how... I can make it work by not being able to talk to her. ‘Cause I mean there’s a lot a things that go into... talking to someone, compared to typing it out, ‘cause it’s easier to get the point across. And I was also thinking about how we were gonna get it all together. Like if we wanted to write a paper, or... I mean, like writing in like paragraph form or bullet form. So trying to do that too.”

Similarly, another participant described the multi-focus of the individual and the team:

“That’s tough. I guess a little bit of both (individual and team thought). It was more like how we’re gonna do it as a team, but what I’m gonna do for the team, if that makes sense. Like what my part is would be for the team, and how our team would get it done.” (Team 10, #1)

Yet, even though team members oriented their initial thoughts differently, I identified that team members’ initial actions were almost all oriented towards individual activities during these tasks. The data indicated that team members, regardless of their initial cognitive orientation,
started the CIS tasks by conducting an individual search. Only 2 participants (Team 8, #2, Team 10, #1) indicated that they did not complete an individual search before collaborating with their team member. Interestingly, these team members identified themselves as cognitively orienting themselves to teamwork (Team 8, #2) and individual and teamwork (Team 10, #1). Study 1 noted that teams initially approached CIS by either individually searching or working together as team. Yet, in this study, team members’ first action was individually searching before collaborating. The distributed setting clearly affected how team members began CIS, resulting in CIS activities that were more individualistic at the onset.

7.2 Development of a Team Mental Model

A team mental model (TMM) developed in 9 of 10 teams. All the teams indicated that a TMM developed, but after further analysis I determined that team 9 did not develop a TMM. The TMMs that developed in the distributed setting were a taskwork specific model. These TMMs lacked depth of understanding team members at an interpersonal level and understanding team members’ skill sets (aspects linked to a teamwork specific model). Often, team members mentioned that the TMM could have been better or stronger, but the decreased communication (due to the distributed setting) limited the development. The lack of communication within the distributed medium is a significant reason why a strong teamwork model was not developed in any of the teams. To better understand the TMM that developed during CIS in the distributed medium, I will outline the scope and content of the TMM, aspects of CIS teamwork that help develop the model, and difficulties associated with developing the model in the distributed setting that result in a weakened overall model.

7.2.1 Scope and Content of a Team Mental Model of Distributed CIS

As previously noted, the TMMs identified in this study were oriented towards a taskwork model. Participants often mentioned that they were “on the same page” and developed a shared understanding of the task itself, how to search for information, how to share information, and how to present information within the distributed medium. The model revolved around the concept of the task itself and how to conduct CIS to answer the task questions. When directly asked whether
a TMM developed in their team, participants always focused their answer on developing a shared understanding of the task, the method of answering the task, and understanding how to address the task within Coagmento. This focus subsequently resulted in the development of a taskwork specific model. Participants never mentioned the development of a shared understanding of their team members’ knowledge, skills, attitudes, or a shared understanding of team member roles or interaction among the team- all characteristics specific to a teamwork model. The analysis of indirect questions and the chat logs also indicated that the TMM is taskwork specific.

Yet, certain aspects of a teamwork model were present within the overall TMM. While these aspects were present, they were not strong enough to develop a complete teamwork model. In order to accomplish the task, a method of team interaction (in this case, grounded in the task) had to occur, which is directly linked to a team interaction model (subsumed within the teamwork model). This raises a point that needs to further be discussed in future literature- there are benefits to differentiating a taskwork and teamwork model, yet it is very difficult to say that there are not aspects of each within each other. While delineating the difference between a taskwork and teamwork specific model can be difficult because overlap between the two, participants made it clear within the interviews that the content of the TMM focused on the task. A participant described the focus of their TMM and how that affected its development:

“So obviously at first you almost, you’re starting with a blank slate. So... I guess once we started asking each other, you know, did you see this, did you see this, and tryin’ to probe the other person you know to see if they remember any of this, or if they’ve researched, seen it as in, in the research content they looked up. And then when they approved it, or they, when agreed or in this case mostly agreed, then that’s when it started to develop. So as, as we visited more websites and we started you know asking each other you know, is this okay to be on there, you know, I also saw that. And then, sometimes they would report something, and you’d be like oh, you know, I saw that as well. So even though you didn’t like you know tell them that, I, I think that mental model was still developing...” (Team 3, #2)

As highlighted by the quote, the model focused on the task itself, not necessarily understanding each team member at an interpersonal level. This participant noted the model developed through sharing information specific to the task. While there is teamwork occurring during the development of this TMM, the teamwork itself is oriented toward completing the task and finding information directly related to the task, not about understanding specifics about team
members. The team members were focused on the task itself and not each other. Another team member explained the focus of their TMM being on finding information to complete the task:

"So I feel like our team mental model surrounded on the idea that both of us were... independently capable of bringing information to the table, and our team would then be able to synthesize really quickly because we’re bringing information that’s been prescreened basically, and then we’re able to address and review it (for the completing the task).” (Team 1, #1)

Through developing a taskwork model specific to CIS, team members were able to assume and predict how to complete the tasks as time went by, which affected how they worked together. A participant explained how the taskwork model affected how teams worked together over time:

“This, the first question we had a lot of communication because we like were just diving into it. And I feel like we were like, we want—do we wanna do bullets, do we—what do we wanna do, how, like, do we wanna have an introduction, all this just different, like formatting, stuff like that. And then by the second one, it was still pretty, I mean we still talked about it, before we made that with the second one. But like, there was still, I mean I guess not as much in the second one, but definitely by the third one, I don’t even think we, I think we messaged each other like, a few times toward the end. And, I feel like it, it was just like a general understanding of what we had to do, and like I didn’t have any questions for her. And, but we didn’t even really need to like... make sure like she was on the same page ‘cause we both knew I guess.” (Team 8, #2)

This quote highlights how the TMM helps develop a structure or plan for the team to work on the task. This limits the need for communication because the team establishes a shared understanding of the task and how to complete it.

While a majority of teams in study 1 also developed taskwork TMMs, some teams did develop teamwork models. In study 2, none of the teams developed teamwork TMMs.
7.2.2 Aspects that Help Develop a Team Mental Model in Distributed CIS

Similar to study 1, the development of the TMM was based on the sharing of individual mental models among the team. The TMM grew and developed over time as a mixture of each individual team members’ mental model was shared. A participant explained the development of the TMM:

“Yeah, so like I feel like it’s built upon, built a ca—on the basis of individual... like... individual learning models and mental models. And then... combining that to like team mental model. So, like that’s how we’re able to collaborate, we’re able to work, to work on it together, able to do it together. But at the same time still maintaining my own perception of how to get things done.” (Team 2, #1)

In addition to the development of the TMM being dependent on team members’ individual mental models, participants in study 2 were able to identify and explain that many aspects of CIS also helped to develop the TMM. Ultimately, the combination and interaction of all of these aspects built team cognition and the TMM. Because of the many identified aspects, I am going to present them all but only specifically discuss two in-depth - Awareness and Trust & Assumptions.

There were many aspects that were perceived as actively helping to develop the TMM of CIS within the distributed setting. These include:

- **Team experience within the distributed setting:** Team members noted that increased experience working in a distributed setting made it easier to overcome the limitations of setting. Consequently, this helped to better develop a TMM.

- **Communication & Sharing Information:** Team members noted that communicating within the distributed medium was critical to developing the TMM. Specifically, because the TMM is task oriented, sharing information relevant to the task was of increased importance. While many participants noted that communication was limited in the distributed medium, they were still able to communicate through the Coagmento. However, because there was a lack of face-to-face communication, it made the development of the TMM more difficult- this issue will be discussed in a later section.

- **Learning how to work with each other over time:** Participants explained that working with each other over an extended time period led to a shared understanding of the associated taskwork, allowing for the TMM to grow.
• **Awareness**: Will be discussed below.

• **Trust & Assumptions**: Will be discussed below.

• **Leadership or lack of leadership**: Participants pointed to leadership or a lack of leadership as both helping to develop the TMM. Team members noted that a leader could help to organize the team and subsequently help focus the development of the TMM. Additionally, some team members also mentioned that a lack of leadership was a positive for the development of the TMM. These participants indicated that a leader could potentially force their individual mental model on the team, resulting in the TMM not being actually representative of the entire team. Without leadership, team members explained that all team members’ individual models could better contribute to the overall TMM.

• **Coagmento**: Will be discussed in later section.

• **Structure and repetition of distributed CIS**: Many participants explained that the nature of distributed CIS led them to develop a shared understanding of how to complete the task. Communication in the distributed setting was predicated on a structure of one person communicating then another replying and this pattern repeating. This repetition allowed for team members to understand how to communicate and share information in this setting, aiding in the development of the TMM.

Of these aspects, two of the most interesting and most discussed were Awareness and Trust & Assumptions. They are outlined below.

### 7.2.2.1 Awareness

Similar to study 1, awareness was critical to developing the TMM in study 2. Awareness helped teams to complete the CIS task but also develop their TMM. A participant explained the overall need for awareness during CIS: “You really gotta look out for what everyone else is doing, and not just focus on your own research. Kinda like gotta look at where they’re going with it, and… go from there. And make sure you’re not stepping on each other’s toes.” (Team 1, #2) In study 2, awareness developed through two different types of activities: (1) the team members would actively inform each other what they were doing through the chat, or (2) the team members would become aware of their teammates actions via features in Coagmento (bookmarks, snippets,
search history, and the shared document). During an interview, one participant explained how his team incorporated the first awareness activity, continually updating each other:

“We kept on feeding each other one what was going on. Like throughout the whole task like we, I would be like I’m search, I’m doing this, he’s doing this. And, I’ll be like I’ll do this, you do that, like, updating each other and telling each other what’s going on and keeping everybody on the—keeping both up on the same page.” (Team 2, #1)

Another participant explained how the affordances of Coagmento’s features helped develop awareness:

“Since I knew he was making bookmarks and then taking snippets and things like that, I knew…where... I knew where he was looking, so I kinda (knew) what he was thinking, and what he wanted to... put on the document over time.” (Team 1, #2)

Team members often pointed out that awareness specifically helped develop their TMM. By being aware of each other’s search actions, they gained insight into how their partner was approaching the task and the type of work he or she was doing. This helped team members to direct their individual model to better align with other team members’ models, consequently developing the TMM. Awareness was extremely important in the distributed medium because team members did not have access to many of the co-located aspects of teamwork (non-verbals, physical real-time synchronous communication). These limitations impacted overall awareness, resulting in increased teamwork difficulties. Yet, through the two aforementioned practices, team members created awareness in all of the distributed teams. As a participant described, using awareness within the distributed medium helped create the TMM:

“Yeah I would say so (awareness helps develop the TMM). You now just ‘cause it allows you to, to kinda see what the other person’s looking at, and kinda gives you a better idea of the the overall status of the team, and the task at hand.” (Team 3, #2)

Another team member also explained the advantages of awareness helping to develop the TMM:

“It (awareness) definitely helped the development of the team mental model, because... you can see that one person’s doing their part of the project, and not just sitting there playing with their fingers or something. Like you know, you know they’re being productive, and then you can trust
that their part will be okay and you can just do your part without worrying about it. And then it, it’s the kind a thing with like the basketball like the blind pass like, alright you do number 1 and 2 and I’m just gonna assume you’re gonna do it the right way ‘cause I’ll do 3 and 4 the right way. (Team 10, #2).

Along with highlighting the importance of awareness to the TMM, this quote also details how awareness helped the team member make assumptions and develop trust in their team. Trust and assumptions were two aspects of CIS teamwork that were often noted as being important to developing a TMM in the distributed medium. In the next section, these aspects will be described in greater detail.

7.2.2.2 Trust & Assumptions

Without being directly asked or probed for, team members often described the need for trust and the ability to make assumptions as instrumental to developing a TMM in the distributed setting. Participants in study 1 never mentioned either of these aspects as impacting TMM development. The differences in the co-located and distributed settings clearly influenced the need for trust and assumptions. Assumptions had to be made specific to team members’ CIS activities because the distributed setting did not allow for team members to physically view what their teammates were doing during CIS. A participant explained the barriers of the distributed medium and the need for assumptions:

“And in this, you know, you’re a little bit, you know blinded, by, by you know the, the digital interface, right. So you don’t know exactly what she’s doing, but like at the same time you know, you, you kinda have to establish, you kinda make the assumption that you know the other person is doing work, or you kinda make that prediction.” (Team 3, #1)

While team members were aware of most of their team members’ actions, they had to actively work to develop this awareness through communication or processing relevant awareness information within Coagmento. The need to actively work to develop awareness within the distributed medium created a problem- team members could not work on the information seeking task and simultaneously monitor everything that their team member is doing. For this reason, assumptions about team members CIS activities were made. Participants noted numerous times
that they had to assume that their team member was correctly working on some aspect of the task. This assumption stemmed from team members lacking the cognitive bandwidth to search on their own and also actively monitor their team members’ searches. A team member described the type of assumptions that were made during distributed CIS work:

“We just kind of, I think we had a lot of assumptions that the other person knew what they were doing, and that they knew how to find reasonable data that wasn’t stuff that you had to change or it wasn’t…I can’t think of the word. It was—like it was good information, for lack of a better term.” (Team 9, #1)

In addition to needing to make assumptions in the distributed medium, team members also mentioned trust as being critical during distributed CIS. A participant explained the role of trust:

“I think not being together, there was less discussion, I guess like over the chat. So it was more of a trusting like they were just gonna... they were gonna be doing it too, but if I was together with someone I think I would... have more discussion like okay, let’s do this, okay let’s do this; okay, let’s do this.” (Team 7, #1)

When asked about TMM development, team members often brought up the importance and need for trust. Specifically, team members indicated that they must trust that their teammates were appropriately carrying out their CIS tasks. As highlighted above, increased awareness of team members’ actions significantly helped to develop trust. Consequently, the trust that was built among team members allowed for better development of a TMM. Participants articulated the role that trust played in the team mental model:

“I mean I, I assumed he was doing work, but... it’s kind of a working relationship where you just trust that your team members and your coworkers are doing what they’re supposed to be doing, and that when push comes to shove they’ll be ready to execute and deliver. It wasn’t a case of micromanaging or me asking hey, what are you doing now, it was more a case of... both of us... having a similar enough mental model that we could trust each other to just do work and just stay productive for as much of the time as possible.” (Team 1, #2)

Similarly, another participant described trust and the team mental model:
“I think we just had a lot of trust in each other that we were following the task and staying on task. Like I trusted that she was gonna do her part, and I think she trusted that I was gonna do mine. And like, I believe in her work, so I think... I think there was a good mental model there, but, I think it could have been better with a longer... study. But I think so, I think we, there’s a good mental model there with CIS.” (Team 8, #1)

Interestingly, when team members discussed trust, they did not explain it as developing over time. Rather, participants noted that due to the limitations of the distributed medium, they were forced to trust their team member from the onset of collaboration.

Decreased communication and lack of constant awareness of team members’ actions hindered the ability to develop a TMM. In order to overcome these limitations, team members made assumptions and had to trust their team members in order to develop a TMM. Without these aspects, developing a TMM in the distributed setting would have been extremely difficult.

### 7.2.3 Difficulties of Developing TMM in the Distributed Setting

Participants indicated that difficulties associated with CIS in the distributed setting complicated their ability to develop a TMM of CIS. Specifically, in some cases, the communication limitations inherent to the distributed setting negatively impacted the development of the TMM. One specific limitation of communication in the distributed setting concerned the inability to talk with team members in real time. Within Coagmento, participants were limited to synchronous chat. Because of the limitations of this chat, many participants found that it slowed down their overall communication. Consequently, the slower communication limited the overall amount of communication that took place in the distributed medium. One participant explained the inability to speak with each other and its negative impact on CIS and the TMM:

“It’s, it does, it did hurt it a little bit (TMM development in distributed medium). I felt like... like having face to face conversation, like let’s say if we were just next to each other and, didn’t have a divider, and we can actually say hey, you know. It’s ease—it’s easier to communicate verbally than it is to just, you know. And it’d also be easy to just look over and say hey, you know, I’m looking at the same thing. So, I guess it would be, communication would be easier.” (Team 6, #2)
Many participants specifically noted problems associated with having to type everything in order to communicate, resulting in slower communication:

“I think it hurt (TMM development in distributed medium). Because... it’s tough to tell... with the way we were, without being able to talk to each other. Like... just the thoughts, and I mean, I mean there’s only so much you can put into words in typing. So I think it was, I think it hurt. I think... there was... I mean... I think we could a been a better team and... like there are some things that I think she could of suggested to me, and I could, and I could suggested to her, if we were talking.” (Team 4, #2)

Another participant explained the problems associated with having to type in the chat:

“I think it would hurt it (distributed mediums impact on TMM) because I think it’s just faster to talk. I can’t type as fast as I can talk, and I could get my point across faster, and we could finish it with more accuracy and like a better product at the end. I don’t think it, it really made a huge difference because we were still communicating. I think it was must more like speed and accuracy would be increased if we were face to face, or able to talk.” (Team 10, #2)

While participants noted the development of TMMs, the distributed setting significantly slowed down the developmental process. However, although it was limited, communication still did occur in the distributed setting, which allowed for the development of the TMM. However, because communication occurred at a slower pace than face-to-face interaction, the development of the TMM took longer. Communication is one of the key components to the development of a TMM, so when it is limited, challenges occur during the TMM developmental process. Multiple team members explained the affect that the distributed setting had on how long the TMM took to develop:

“I wouldn’t say it necessarily hurt, but it definitely made it more difficult. I think that if you were face to face, it’s definitely easier face to face. But if you were to, able to have like face to face and maybe of, obviously like outside of that, it probably, it could of developed quicker I guess. But since we were just communicating on the computer, it... I mean I guess maybe it was slower, or maybe . . .” (Team 8, #2)

Another participant also explained that the distributed medium slowed down the development of the TMM:
“Uh... yeah. I mean I think being distributed did slow the development of our mental model for, it was definitely slower than if we had not been distributed. Yeah, ‘cause definitely it took a few minutes to kind of... figure out how this was gonna go. But then by the end of the first task, I kinda figured it was gonna be like, me suggesting things and him agreeing.” (Team 4, #1)

Because the distributed synchronous communication occurred slower than face-to-face, the TMM developed at a slower rate. In addition, participants also mentioned having to focus on multiple aspects of CIS within the distributed condition, such as communication, information sharing, and awareness. This could overload their cognitive abilities and have a negative affect on the TMM. Although the TMM did develop in the distributed setting, it took longer because of the challenges associated with that setting.

7.3 Coagmento’s Impact: CIS and Team Cognition

Participants viewed the Coagmento system as being useful, noting that many of the affordances built within the system were helpful to completing CIS. While the effect of the distributed medium hindered the development of team cognition, participants often acknowledged that Coagmento helped them overcome many associated problems. Still, team members often failed to continually use or permanently adopt many of Coagmento’s features throughout the study. They also mentioned some issues with the system itself. Below, I outline how participants perceived the system, issues with feature adoption, and the system’s impact on team cognition.

7.3.1 Overall Perception of Coagmento

Participants generally indicated that the Coagmento system was a good CIS system and helped to complete CIS work. A participant explained the overall value of Coagmento:

“I mean... I, I think that... I think obviously being, being able to speak to the other person would a been helpful. I think... like on this platform which is, is a... is a pretty... I guess just a, there’s just a lot of, a lot of functionality reached on this one. It was a good platform.” (Team 3, #2)
Even though many participants noted value in Coagmento, there were problems that stemmed from the system itself, the study’s constraints, and the context. Many of the problems associated with Coagmento were specific to the study’s setting and design, rather than the system itself. Specifically, many participants noted that more time would have better allowed them to fully utilize the system:

“But I could see how it could have a good impact. Like... if it wasn’t under, if like I just get really stressed out about like time constraints, I’ve said this like 50 times. But... if I had time to go back and like look, I could see what she was searching, and I could modify my searches based upon what she was doing. Like her history, like what websites she was looking at, and stuff like that. But I think the interface could be a very good tool, I just don’t think we used it as effectively as we could have.” (Team 8, #1)

Participants also noted that in addition to using the system for short projects, it would be valuable for extensive CIS work that took place over a longer period of time.

“I like the bookmarks and snippets. It would ... I think it would be more useful for... like a long term research project, maybe... something that’s lasting at least the week that you’re working on constantly, so then you know if your one teammate was work one night, if you log on the next morning, and kind of see what they had bookmarked and what they have searched, so that’s really nice. Rather than just, you know, usually when I work with teams, we just put our links into a Google Doc and we have to get each link. So that, that was really nice.” (Team 4, #1)

Team members used many of the features built into the Coagmento software: bookmarks, snippets, collaborative editor, and chat. Each of the features were perceived as being beneficial to enhancing teamwork and completing CIS tasks. The bookmark and snippets features were the only features unique to Coagmento that were used by teams during the study. Collaborative editors and chat are found within many distributed systems. As a participant explained, the bookmark and snippets features allowed for a better understanding of what information each team member was finding:

“But with like the bookmark and stuff, and I was able to look at some of her websites and see where sh—and see what, when she was on there and stuff like that.” (Team 4, #2) Similarly, another participant describes the benefits of bookmarks and snippets: “I think the bookmarks definitely helped a lot. Just because like you wouldn’t be sending like... hyperlinks through chat,
and like they’d get lost easily. But... like if I sent a bookmark, I, it was just there for reference for both me and my partner. So, we could like just sort of collaborate upon that. Like, sending a snippet would be also very collaborative.” (Team 8, #1)

Features similar to this allow team members to become aware of searches and information, resulting in team members to then adapt their own searching. A team member explained this process:

“I didn’t know what he was doing all the time, but sometimes I would refresh the bookmarks, or the snippets and I would look at them, and then that helped me sometimes refocus my searches, or narrow it down more to base it off of what he was searching.” (Team 9, #1)

Even though bookmarks and snippets were used and viewed as beneficial, the features of chat and the collaborative editor were used most often. Team members were most familiar with these features, requiring little time to adapt them into their CIS workflows. While participants used many of the features of Coagmento, the most significant features not used within the system were the rating system and the notepad. These features are redundant and their affordances are found in other features. For example, when a team member bookmarks something, they also have the option to rate the bookmark and write a note with the bookmark.

7.3.2 Use of Features; Lack of Sustained Adoption

While participants utilized bookmarks and snippets, the study data also indicated that they stopped using these features over time. Many participants mentioned utilizing these features during task 1 but described reverting back to solely utilizing chat and the collaborative editor. A participant described only using bookmarks and snippets in task 1: “I think I know for at least me, I only did like snips and saved pages on the first task. And the other ones I kinda just went through the website, found the information and then put it on the Google Doc.” (Team 9, #2)

There were two main reasons for the lack of sustained adoption of the bookmark and snippets features. First, the time restrictions put on the study resulted in participants abandoning these features because they lacked the time to properly incorporate them into their workflows. A participant explained the impact of the time restriction, causing team members to revert back to using chat:
“Um... it made it... more interactive than... anything I’ve used before. But like I said, at the end we, we kinda just resorted to the chat feature. The other ones are great, the bookmark and the snippet are useful, but I think just like I said, because of the time restriction, um... chat was just really quick and you didn’t have to go clicking on things and stuff, you can just get your point across right there.” (Team 1, #2)

If these features were familiar to the participants, less time would be required to learn how to use them, possibly leading to more frequent use.

The second reason for the lack of adoption was because participants were more comfortable with chat and the collaborative editor. A participant described not being familiar with bookmark and snippet: “I would say... we didn’t use that a whole lot, probably ’cause we weren’t very acquainted to it.” (Team 9, #2) Participants already knew how to utilize chat and the collaborative editor. Because of their familiarity, team members created workarounds to adopt the affordances of bookmarking and snipping into chat and the collaborative editor by copying and pasting links and information. A team member explained this: “And actually at, at one point, I didn’t even snip anything. I just... copied everything that I wanted to share to him, and then pasted on in chat.” (Team 2, #1) While this might not be faster than actually using the bookmark and/or snippet features, it was easier for participants because they already knew how to do it.

7.3.3 The Impact of Coagmento on Team Cognition

Participants indicated that Coagmento aided them in developing a TMM within the context of distributed CIS. A participant best described this: “I don’t think any features hurt. But it was, if anything it definitely... the software itself definitely helped me... create a good team mental model.” (Team 2, #1) Another participant indicated the value of Coagmento when developing a TMM: “Coagmento utilized the things that you would need to come to a team mental model.” (Team 10, #2) There were multiple features (bookmarks, snippets, chat, and collaborative editor) within Coagmento that were viewed as helping develop a TMM. Furthermore, the chat and the collaborative editor features were also viewed as most significant and critical to developing the TMM. A participant described chat being impactful to developing the TMM, as well as the bookmarking feature:
“I don’t think anything hurt, hurt it at all. The things that helped were definitely the chat, and... that was probably the most helpful one. But also I would say... maybe the bookmark was second most helpful because... then she could say this is the site I’m looking at I think it’s really helpful, and I’d say well this is what I think, and then I’d make sure that like... we’re on the same brain level, like (Laugh) we’re thinkin’ the same things like you know, where, about the tasks, so.”

(Team 10, #1)

Even though the chat limited the level of communication that took place in the distributed setting, participants still indicated that chat helped to develop the TMM through providing a means for communicating, no matter how reduced. Without chat, participants could not explicitly communicate with each other in Coagmento, which would limit the ability to develop a TMM because of the importance of communication.

The collaborative editor was also strongly viewed as helping to develop a TMM. Team members indicated that the collaborative editor allowed for the development of shared knowledge via the ability to see in real time what team members were contributing to the CIS tasks. In addition, the collaborative editor provided low levels of communication through team members working jointly within it. A team member best described the close link between the collaborative editor and the TMM:

“'I think that, you know, that, that mental model was, was really illustrated, illustrated in that text editor. You know, ‘cause the, the ideas that, that we had, like I said before, if they overlapped, right. So if they overlapped, and you know we, we both had the same idea of what, what we’re looking for. And I think that’s most relevant between the first and the second task, right ‘Cause once we established the mental model in the first task, we kind of knew... ‘cause the second task was, was... I guess 'coupled with the first task a little bit, we kinda knew kinda what we were going for. So I, I would say, yeah.” (Team 3, #2)

In addition, another participant highlighted how the shared editor allowed for shared knowledge to be created:

“Yeah. It (shared editor) really gave us that shared knowledge because we both could really see what the other person had done, and then it would kind of... like reassure me that I also was doing like the correct information because I was getting the same or similar answers.” (Team 9, #2)
Overall, even though the distributed setting led to difficulties in developing a TMM, Coagmento possessed features that help to develop the TMM in this setting. In addition to providing communication, these features aided in information sharing and provided a greater awareness of what the team was doing throughout the CIS tasks. Because of these affordances, team members were able to understand their teams’ work and over time evolve their individual mental model to align with what the team was doing.

7.4 Chapter Summary

This chapter presented findings from study 2. The distributed setting impacted how teams approached CIS and the development of team cognition. Overall, the setting limited the amount of teamwork that occurred during CIS, making the overall approach more individually focused. A TMM specific to the context of distributed CIS did develop but it was not a simple process. Specifically, the setting limited team communication, slowing down the development of a TMM. In the next chapter, I discuss the implications of these findings.
Chapter 8

Study 2 Discussion

In this chapter, I present a discussion on the conflicting opinions and perspectives in regard to the perceived benefits and challenges associated with distributed CIS. In addition, I also discuss how this study’s findings have the ability to enhance and improve Coagmento. Next, I describe how to better support for developing team cognition in distributed CIS systems. Finally, I conclude by outlining some of this study’s limitations.

8.1 Distributed Collaborative Information Seeking: Conflicting Perspectives & Individual Differences

Many participants were conflicted in their perception of the distributed setting’s impact on both CIS and the development of TMMs. Participants were also divided on the benefits and challenges associated with the distributed setting. Answers often varied in the interviews, making analysis for this study more complicated than study 1. Study 1’s participants were often very strong and similar in their feelings and thoughts regarding the co-located setting and its impact on CIS and how TMMs develop. Whereas study 2 participants often had conflicting and contradicting opinions on whether the distributed setting helped or hurt the activity of CIS and the development of TMMs. The variation between how participants in study 1 and 2 perceive the two settings is interesting and raises many questions. Mainly, why were participants in study 2 so conflicted and varied in their opinions when compared to study 1’s participants?

A strong analytical theme in study 2 is that the distributed setting primarily hurt the ability for teams to develop a TMM and complete their CIS activities. However, there were many participants who perceived value in the distributed setting. For example, when discussing the benefits and challenges of distributed CIS, participants contradicted themselves in many ways (Table 15). I did not present these benefits and challenges in the findings because they have been highlighted many times in other research (Hinds & Mortensen, 2005; Espinosa et al., 2007).
Table 15: Perceived Benefits and Challenges of the Distributed Setting

<table>
<thead>
<tr>
<th>Perceived Benefits</th>
<th>Perceived Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straightforward direct communication</td>
<td>Lack of nonverbal hinders teamwork</td>
</tr>
<tr>
<td>Less miscommunication</td>
<td>Miscommunication</td>
</tr>
<tr>
<td>Lack of nonverbal can decrease frustration</td>
<td>Lack of communication</td>
</tr>
<tr>
<td>Faster to share information</td>
<td>Slower communication</td>
</tr>
<tr>
<td></td>
<td>Disorganization</td>
</tr>
<tr>
<td></td>
<td>Not “feeling” as though communicating with “real” person</td>
</tr>
</tbody>
</table>

Interestingly, when the benefits and challenges are juxtaposed against each other direct contradictions become apparent. For example, some participants felt that the distributed setting afforded less communication, while others felt the setting increased communication. Similarly, some people viewed the lack of nonverbal communication in the distributed setting as positive, yet others viewed it as a challenge. The same types of mixed perceptions also occurred in regards to TMM development. Some felt that aspects of the setting helped develop the model (direct communication) while others felt it hurt (slow communication) the development.

The conflicting information and perspectives in study 2 are important in understanding the affect the distributed medium has on CIS and TMMs. For the most part, the distributed setting increases perceived difficulties in CIS activities and developing a TMM, but we must acknowledge the perceived benefits as well. The question that I find most important when discussing these conflicting perspectives is why do they exist? And, why are they more abundant in the distributed setting?

There are many possible reasons for these conflicting viewpoints but one of the likeliest might be accounting for individual human differences (Eysenck & Eysenck, 1987; Greenwald et al., 1998). Every person has different personal preferences, opinions, and feelings for how they want to approach a variety of different situations and contexts. Not only are people different in how their brain structures, functions, and processes information to elicit behavior (neuropsychology- (Schneider & McGrew, 2013)), they are also different in their experiences. These differences can become magnified in a distributed CIS task. The participants differing perspectives and opinions could be the result of different experiences or simply how they process information.

As noted in the findings, the CIS approach that participants used in the distributed setting was not as collaborative as the co-located approaches. We must consider if there is less
collaboration due to the impact of more individual differences being present within the distributed setting. Conflicting or differing individual opinions within a team can be challenging to overcome. Consequently, one of the main obstacles to teamwork is working together in parallel despite individual team member differences. Many teams are able to overcome their individual differences by discussing them over time. Yet, team members in the distributed setting might not have been able to overcome these individual differences because of limited communication and time in this study. These limitations prevented common ground from developing which could have helped them overcome their differences (Cooke et al., 2013). The impact of individual differences is not only important in study 2 but to the overall dissertation. Individual differences could also explain why four different CIS approaches exist in study 1. Individual team members and their differences are often discussed in the team. Depending on the discussion, aspects of the individual team members’ preferences could become a part of how teams approach CIS. In addition, individual differences are of particular importance when developing team cognition because they ultimately guide the process of creating team cognition. Team cognition is the joining of many individual team members’ cognition to create new team cognition (Cooke et al., 2007). Each individual team members’ cognition could be significantly different. In the process of developing team-level cognition, team members must take these individual cognitive differences and integrate them within the team. If teams are not able to overcome individual cognitive differences, the development of team cognition may never happen. This could be one of the reasons why teamwork mental models were not present in study 2. It was probably significantly more difficulty for team members to integrate the individual cognitive differences in the distributed setting. Consequently, instead of developing teamwork mental model, only taskwork mental models developed for team cognition.

8.2 Issues and Improvements for Coagmento

Much was learned about the CIS system Coagmento through study 2. Specifically, participants mentioned multiple issues within the system itself that limited how teams approached CIS and developed team cognition. Below I outline these issues and present ways to improve Coagmento. I realize that many of the improvements presented are not new or necessarily novel, but they are design affordances that are missing within Coagmento.
8.2.1 Issues with Coagmento

While participants overwhelmingly indicated that Coagmento was beneficial to both CIS and developing team cognition, some problems were still noted with the system:

*Information overload:* Participants explained that they often had to focus on too many things at once. For example, during CIS tasks, team members often had to multi-task chat, their own searching, the collaborative editor, and the other features of Coagmento. This required too many different focuses, which they had difficulty managing. In addition, the Coagmento system lacked notifications or alerts informing team members when features were used. The lack of notifications resulted in participants having to focus their attention on their individual/team work, as well as the interface itself.

*Lack of privacy:* Specific to the search history feature, participants mentioned that they did not like their team members being able to see what they were searching. Some participants viewed this as a violation of privacy, indicating that they did not want their team members to see everything.

*Too much typing:* As mentioned throughout the findings, there is just simply too much typing that must occur within the distributed setting; Coagmento is no different, with participants often noting that the system relied too much on typing. The typing distracted users from focusing on their teamwork and searching for information. Specific to the CIS context, there is an even larger need for typing because not only is the activity grounded in teamwork that requires social interaction (typing), it is also heavily reliant on finding and sharing information (more typing).

*Interface too clustered:* Coagmento’s features are useful, yet embedding them within the interface resulted in the interface becoming too clustered and complex. Having a side and top toolbar engrained within the interface limited viewing of the website, often blocking content available on the website. Even though the user can change the size of the toolbars, it still confines the webpage. At points, there is simply too much being presented within the interface. Having the interface be too clustered during CIS can be significantly detrimental to the CIS process. There are many aspects of CIS that the team member must already manage on their own (interaction,
cognition, finding information, managing information, sharing information). Because of this teams members need the interface to be clean and not overwhelming because the activity of CIS itself can become overwhelming.

8.2.2 Improving CIS Tools & Systems

In response to the problems identified in Coagmento, study 2 participants explicitly mentioned some recommendations to improve the system. I am not arguing that all these features are necessary in one system. Rather, this is a list of possible improvements for the Coagmento, specifically, and CIS tools in general.

*Video or voice chat:* This is the most important design recommendation for improving CIS approaches and the development of TMMs. Many of the issues associated with CIS and developing TMMs in the distributed setting were directly related to communication limitations. Specifically, almost every participant mentioned that CIS was dependent on too much typing. We have the technology to ensure that communication is not limited to only typing. A simple video or voice chat client built within Coagmento could overcome many of the communication challenges associated with the distributed setting.

*Screen sharing:* Participants often had trouble directing each other to specific information that they found on a website. Usually, direction resulted in the participant typing exact directions to locate the found information. Typing out prolonged direction uses limited time. The ability to share screens could overcome this problem.

*Notification or alerts:* Coagmento has many features, but keeping track of all of them can become a task in itself. Specifically, features like bookmarks, snippets, and notes lack any alert when they are used. For example, when a new bookmark is linked, it simply just shows up in the bookmark tab with no notification to team members. There are two problems with the lack of a notification. First, a lack of notifications results in lessoned awareness regarding the information being shared. Second, because there are no notifications, users must continually check all of the features to see
if they have been updated. This means that users must allocate specific cognition directed at checking each feature, something that should not be required.

*Feedback for typing in chat:* This is a simple fix for Coagmento. In recent years, many chat systems have adopted the affordance of allowing chat users to see when each other are typing. If this feature is not available, then communication among collaborators can be slowed due to counter-productivity.

*Ability to assign roles within system:* Some participants noted that they did not understand what their responsibilities or team role was within Coagmento. This might be an issue of the team itself, but it could be overcome with the ability to assign CIS related roles to each team member. Of course, this is a feature that needs to have the availability to be turned on or off depending on the team. Some teams need more structure than others, so this could be useful depending on the team.

*Simplification of rating system:* The rating system is predicated on a 5 star ranking system. This is a rating system is highly subjective, and not necessarily useful in informing the user. Participants noted that a simpler rating system such as “like” features would be useful due to the many other detailed focuses of the system.

*Saving chat:* When users log out of Coagmento and then log in over time, the chat is not saved across sessions. This negatively affects continuance across sessions. Certain information within features persists across sessions but the main communication method does not save information.

*Checklist for tasks:* A specific area for creating an outline or checklists for tasks might be useful in improving workflow. Participants mentioned that they lost track of their current task because there was no feature in Coagmento that allowed them to check their tasks.

The Coagmento system is already quite advanced, so adding every single new design feature highlighted above is not necessary. Rather, these are potential ways to improve the system. More in depth research, specifically investigating design issues within Coagmento needs to be
conducted to determine which of these features is absolutely needed. The only recommendation I feel strongly about is incorporating the implementation of voice or video chat. This is a simple addition to the system and one that could greatly help team members overcome many of the system’s issues.

8.3 Developing and Supporting Team Cognition In Distributed CIS Systems

In the findings, I outlined how Coagmento impacted the development of team cognition. For the most part, the affordances built within Coagmento allowed taskwork oriented team cognition to develop, but not teamwork oriented team cognition. In this section, I explore possible ways to support the development of both taskwork and teamwork team cognition during distributed CIS activities. Specifically, I describe specific design areas that must be paid close attention to within distributed CIS tools and systems.

In chapter 5, I provided some high-level design recommendations for the development of CIS systems. After having used a CIS system in study 2, I am now able to more accurately make recommendations for developing team cognition after having identified problems within the system. Through analysis, I have identified three critical design components that are fundamental to developing team cognition during distributed CIS: communication, awareness, and trust. These are often important design focuses in many other contexts, and CIS is no exception. While there are many other components that can be discussed, these three were clearly the most impactful within study 2. For each design component, I will first describe it and then highlight how Coagmento did or did not support it.

8.3.1 Communication

The role of communication is at the heart of team cognition. Simply, if communication throughout the team is not available, then it is impossible (or very difficult) to develop team cognition. The more communication that occurs during teamwork allows for more knowledge to be gained about the task the team is working on and about individual team members / team dynamics. Consequently, depending on the scope of the communication, taskwork or teamwork cognition is developed. The communication that takes place in a distributed CIS system may be
limited, so it is extremely important that designers take note of this in regard to how it affects the development of team cognition. Yet, conversely, in the design of a distributed CIS system we don’t want to force too much communication on team members because, as this dissertation has identified, CIS is a mixture of both individual and teamwork. Constant communication in a distributed CIS system could have an adverse effect on the process of CIS. So, while a great deal of communication will more than likely help develop team cognition, it could hinder the ability to complete CIS. Therefore, this is a tricky problem to address for the development and design of distributed CIS systems. Ultimately, a CIS system would want to have affordances that allow for easy, synchronous communication to allow for team cognition development, all while ensuring that there is not too much communication that interrupts the individual aspects of CIS.

*Coagmento’s Support of Communication:* In this study, it was identified that communication was limited due to the distributed CIS system. Yet, enough communication was readily available to develop taskwork team cognition. Overall, Coagmento adequately supported communication aimed at the task through means of information seeking and sharing. What was lacking in the communication that occurred within Coagmento was the ability for team members to accurately communicate their knowledge, skills, preferences, and other interpersonal aspects. Team members simply identified that they did not have enough time or patience to communicate these aspects, due to having to type everything. For this reason, they often focused only on the task itself. Because of this a teamwork team mental model was never established in any of the teams. The simple and obvious solution to addressing this problem is adding video chat. Video chat would allow for faster communication and further develop socio-emotional aspects that are often related to interpersonal communication.

**8.3.2 Awareness**

Awareness is a hallmark within design communities, and within the context of team cognition. Design and team cognition are often not considered. Yet, when they have been, the focus has been on awareness (Endsley, 2012). Awareness directly helps to develop a team shared understanding because it allows for each team member to understand what each it doing (Gutwin & Greenberg, 2004). In the distributed setting, it is much harder to develop team awareness due to each team member not being able to *see* what each other is doing in a real-time physical
environment. For this reason, when distributed CIS systems are developed they must provide multiple affordances to help develop team level awareness. If team level awareness is not present, the development of team cognition will suffer. Specific to the CIS context, awareness is critical to sharing information and developing a shared understanding of information being found across the team. Therefore, distributed CIS systems should afford awareness mechanisms that are both aimed to the task (information based) and the team (social based).

*Coagmento’s Support of Awareness*: Coagmento actually supported team level awareness quite well—the only problem being a lack of notifications or alerts. Although, that awareness, like communication, was aimed at the CIS task and not understanding the team. The Coagmento system has many different features that allow for increased awareness: chat, the collaborative editor, search history, and bookmarks. Through each of these features a greater understanding of what each team member was doing in relation to the task was derived.

**8.3.3 Trust**

Trust is a concept that is directly related to both communication and awareness. In theory, as a team communicates more and team level awareness is developed, team members should then begin to trust their team members more. So, much of developing trust within a CIS system is dependent on developing open communication channels and raising awareness levels within the system. Trust in the distributed medium is critical because if trust is developed in this setting there is an expectation that everyone will do their work within the team, resulting in more overall teamwork (Zigurs, 2003). If trust is not developed, the communication will be limited, which will then drastically decrease the likelihood of team cognition being developed.

*Coagmento’s Support of Trust*: I wouldn’t classify Coagmento as fully supporting the development of trust within study 2’s teams. Often, participants noted that they developed blind trust just based on the fact that each team member volunteered to participate in the study. While many of the awareness related mechanisms built into Coagmento may help develop trust, participants were often ambiguous in their perceptions on how they affected trust. The development of trust within a distributed CIS system very well could be based on the dependency
that team members just need more time to work together to develop trust. Research has shown that trust is simply developed over time (Jones & George, 1998).

8.3.4 Summary

While communication, awareness, and trust are detailed in this section there are many other areas that can help in the design of distributed CIS systems to develop team cognition. For example, leadership, training, and team composition are all areas that could and should be considered in further detail.

In conclusion, the CIS system Coagmento was adequate at supporting taskwork oriented team cognition. Although, the development of teamwork team cognition would have been extremely useful in helping the team work together. Future work needs to be conducted that specifically examines how to develop teamwork team cognition within distributed CIS systems.

8.4 Study Limitations

This study has some potential limitations. First, there were a small number of participants in the study. However, I was still able to collect useful data to help us to understand the CIS challenges in a distributed environment. In addition, the findings are only applicable to teams that consist of two team members. While many teams are dyads, many are also not. It’s important to understand that team sizes can impact multiple aspects of teamwork. A dyad team is the smallest a team can be; so more studies need to investigate larger team sizes within this context. Also, more training with the Coagmento software would have been valuable within this study. While I’m confident that the participants fully understood how to use Coagmento, it would have been useful for them to work more with it in advance to the actual study.

Overall Dissertation Limitations

There is one potential limitation of this dissertation’s overall design. The participants that were used in study 1 were different than the participants used in study 2. This results in a lack of continuity across both studies and has implications when comparing each study. Conceptually, it would have been optimal to have the same participants partake in both studies. Using the same
participants allows for inferences and assumptions to accurately be made and compared in regard to the affect the co-located and distributed environments have on CIS and team cognition. Using different participants in each study might be indicative of the actual participant and not the affect the setting has on the participants. Yet, there are significant logistical challenges and problems that incur when the same participants are used across two studies. First, from a conceptual standpoint, the level of understanding of both CIS and team cognition would be drastically different between study 1 and study 2 if the same participants were utilized. Specifically, the participant teams in study 2 would not be an ad hoc team with no experience. Rather, they would be a team that had previously worked together and already developed some level of team cognition due to their work in study 1. Therefore, making inferences and comparisons between study 1 and 2 would not appropriate because the teams experience would be varied, providing an advantage to the distributed setting due to the teams already worked together. The second problem with using the same participants across each study is purely logistical in nature. It is very hard to study teams in a lab over a period of time because there are significant challenges in ensuring that the same participants will show up for the second study. If the same participants don’t show up then the overall study design is compromised.

8.5 Chapter Summary

In this chapter, I highlighted participants differing perspectives of the distributed setting while noting the importance of individual differences in approaching CIS and developing TMMs. I also described potential design recommendations for the Coagmento system that can be applied to other CIS systems and tools. Next, I describe how to better develop and support team cognition within distributed CIS systems. I end the chapter explaining study limitations. In the next chapter, I will present a discussion explaining the similarities and differences between the two studies.
Chapter 9

Connecting The Studies: Co-located and Distributed CIS

9.1 Similarities and Differences Between Study 1 and Study 2

The methodology and design used in the two studies in this dissertation allowed me to compare the studies. Specifically, the CIS tasks and time given to complete the tasks are the same across both studies. The only major differences between the two studies besides the context of the setting was the use of Coagmento in the distributed setting.

CIS routinely occurs in both co-located and distributed settings. Therefore, understanding the similarities and differences between the studies can help us better understand CIS as a general activity. Specifically, this comparison can help us understand what characteristics of CIS are persistent in both settings while also understanding how the context of the specific setting affects CIS. When comparing the two studies, I found that there were many aspects of the CIS approaches and team mental models that were similar regardless of the setting. At the same time, there were also aspects of the CIS approaches and team mental models that were affected by the setting. Below I will highlight the similarities and differences specific to the approaches and team mental models in both studies.

9.1.1 Similarities and Differences Among CIS Approaches in a Co-located and Distributed Setting

In study 1, I identified four different approaches to CIS. In comparison, I only found one approach to CIS in study 2. Consequently, I identified a total of five different CIS approaches across the two studies. While this is the first work that specifically outlines a detailed process for each approach, related research in different communities highlights how the process of CIS may vary. Morris (2008) found that people approach collaborative web search (CWS) in different ways. She referred to the two very different approaches to CWS as “divide and conquer” (aligns with team to individual/team) and “brute force” (aligns with individual to team). In addition,
Evans & Chi (2008) also noted that social search is varied depending on a variety of different individually and team based activities. While these studies are significant, they did not account for both settings of co-located and distributed. In contrast, this dissertation identified CIS approaches of both the co-located and distributed settings.

Identifying five different approaches to CIS is meaningful for a number of reasons. First, it highlights how CIS is dynamic and situational. Second, I found that the approaches are dependent on the team and the context (co-located or distributed) in which CIS is occurring. Third, and a focal point of this discussion, it shows that there are some similarities and differences among the approaches that occur in different settings (co-located and distributed).

To better understand the similarities and differences among the approaches used in these studies, I am going to specifically discuss three main areas where similarities and differences were found. First, I will describe the variations of individual and team work within the approaches. Next, I will discuss whether the approaches are composed of actual collaboration or more coordination. Finally, I will outline specific characteristics (initial thought, sharing information, communication, and awareness) that are inherent to the approaches and how they are similar and differ across the studies.

9.1.1.1 Individual and Team Work within the Approaches: Variation Among Settings

All of the approaches, regardless of setting, are grounded in a mixture of both individual and team work. Where the approaches differentiate themselves is when individual or team work occurs and for how long it persists. For example, the approaches of Team to Individual and Individual to Team consist of both individual and team based activities, yet they differ in when each activity takes place and how for long it occurs. When and how individual and team work takes place is important regardless of the setting. Looking specifically at study 1’s approaches, we can simplify them to being either individually or team oriented. Yet, while some of study 1’s approaches are more individually oriented than team oriented, collaboration still occurs at a fairly continuous rate throughout the process.

This point helps to explain the major difference between the approaches that occur in study 1 and study 2. The main difference between the approaches in study 1 and the approach in study 2 is that study 1’s approaches are defined by more teamwork/collaboration than study 2’s approach. Study 2’s approach is highly dependent on individual work. In fact, most of the
approach consists of individual work. While there are points during the approach where the team shares information, the activity of CIS is less collaborative in the distributed setting when compared to the co-located setting. Why is this the case? Why is CIS less collaborative in the distributed setting than the co-located setting?

Much of the difference in collaboration between the two settings can be attributed to limitations of the distributed setting to support collaboration. Specifically, many computer mediated communication (CMC) theories (Social Presence Theory- Short, Williams, & Christie, 1976; Lack of Social Context Cues- Siegel et al., 1986; Media Richness Theory- Daft & Lengel, 1986) outline that CMC in a distributed setting lacks physical interaction, thus creating physical isolation that limits physical cues and can lead to impersonalizing and individualizing behavior. Even though team members in study 2 had the ability to communicate within Coagmento, they were still physically isolated. As noted in Chapter 6, issues of time and space have been fundamental in understanding CMC over the years. The issue of space is critical when discussing why there is more individual work than team work in the distributed CIS setting. Physical isolation creates an environment of individualization that affects how participants perceive their work and subsequent teamwork. The physical isolation of participants in study 2 led to more individual work.

Not only does the distributed setting create individually oriented feelings and thoughts, the actual setting affects how team members are able to work together, often limiting aspects of teamwork (Salmon et al., 2010). As presented in the findings, many participants explicitly noted that working in the distributed setting was more difficult than working in a co-located setting. This difficulty directly stems from communication limitations associated with the distributed setting. Many studies have found that communication and information sharing are limited in the distributed setting (Cuevas et al., 2006). In this study, the inclusion of the simple activity of needing to type everything for communicative purposes greatly limited collaboration. Limited communication and information sharing directly impacted the distributed CIS approach to consist of increased individual work.
9.1.1.2 Co-located and Distributed Collaborative Information Seeking: Collaborative or Coordination?

CIS is clearly dependent on collaboration and teamwork, so when those aspects are limited, it raises the question of whether it is really collaborative information seeking. The limited collaborative approach that participants in study 2 used highlights this question. Is the approach in study 2 truly representative of collaborative information seeking, or is it more grounded in coordinated information seeking? The limitations associated with the distributed setting create a stronger environment for coordination rather than collaboration. Yet, it is important to understand that collaboration can still occur in the distributed setting but it is strongly dependent on the individual team. However, in this dissertation, I found that aspects of study 2’s approach orient more towards coordination than collaboration.

Both collaboration and coordination have long been focal points in the Computer-Supported Cooperative Work (CSCW) community. Traditionally, collaboration and coordination have been defined similarly and to some extent used interchangeably. However, while collaboration and coordination do share some characteristics, they are different concepts. Collaboration is defined by Gray (1989) as “a process of joint decision-making among key stakeholders of a problem domain about the future of the domain.” Coordination is defined by Malone & Crowston (1994) as “the process of managing dependencies among activities.” The close relationship between the two concepts has resulted in many studies seeking to understand the differences between them and how they interact with each other. For example, is collaboration an activity that takes place within coordination, or is it vice versa? Understanding the hierarchy between collaboration and coordination is a complicated issue but a literature review by Shah (2010b) does an excellent job synthesizing how the two are viewed in relation to each other. In the review, he presents a model of collaboration that includes multiple aspects of collaboration including coordination. The model consists of five attributes: communication, contribution, coordination, cooperation, and collaboration (Figure 23). Each of these attributes is layered - each is dependent on or is a subset of another attribute. Using this model, coordination is viewed as a subset of the larger concept of collaboration. Similarly, work by Denning and Yaholkovsky (2008) have also indicated that coordination is a weaker form of decision-making when compared with collaboration.
The difference between coordination and collaboration is best explained when their end goals are compared. Coordination is simply the activity of directing and managing what team members are doing. Through this activity the team is able communicate, find, and share information. Collaboration encompasses those characteristics but also produces new ideas and content based on the development of knowledge through common ground. Consequently, collaboration requires more interaction, intent, trust, human involvement, symmetry of benefits, and awareness than coordination does (Shah, 2010b).

I would classify the approaches used in study 1 as consisting of more complex collaboration than study 2’s approach. Study 2’s approach relied on simpler collaborative efforts and in many instances coordination. Study 2 participants minimally worked together and when they did it was to complete simple activities aimed at coordinating each other. Their teamwork often consisted of each other directing one another to information but not discussing it together. In addition, work in study 2 was often conducted by team members providing their team member with information and not directing or requiring them to do anything with the information. Team members would simply share their information and their team member would decide if they wanted to respond to it or use it. The simple direction and lack in depth discussion in study 2’s teamwork is better aligned with coordination than complex collaboration. If complex collaboration was met within study 2’s approach, more detailed discussions, a higher level of interaction, and new ideas would be produced but they were not in this setting. In fact, a review of the chat logs made it clear that their teamwork was coordinated and not collaborative. The logs
often demonstrated that participants would partake in simple direction and just share information, not commenting or collaborating on the shared information.

Although the study 1 approaches varied in degree of collaboration, they all demonstrated aspects of complex collaboration. Team members did not just tell each other what they were doing or only share a piece of information. Rather, they discussed in depth how to work together and what their individually found information meant to the overall CIS task. This discussion allowed the team to develop knowledge directly related to their teamwork. In contrast, team members in the distributed setting did not discuss the implications for found information. Most of the time, if a team member found information it was automatically added to the collaborative document with little discussion. Essentially, the teamwork in the co-located setting helped develop common ground, which supported collaboration. This same process did not happen within the distributed setting.

Team members in both studies were able to work together, yet significant differences in the type of teamwork (coordinated vs. collaborative) were found between the approaches in study 1 and 2. As we move forward in this research, it is important to examine why teams in study 2 never met the threshold for complex collaboration? Furthermore, we need to also examine how we can provide distributed teams with the ability to actually collaboratively seeking information. As Shah’s model of collaboration highlights, communication is the attribute that every function of collaboration stems from. So, when communication is limited it is harder to develop collaboration.

9.1.1.3 Characteristics of Co-located and Distributed CIS Approaches

In addition to significant differences in individual/team work and collaboration/coordination among the co-located and distributed approaches, there were other similarities and differences.

*Initial Cognition Orientation:* In study 1, the cognitive orientation that participants initially focused on was either individually or team focused. That orientation typically led to individual and team based action. Similarly, the approach in study 2 also had initial individual or team based thought. However, the initial cognitive orientation in study 2 was more wide-ranging because team members would either orient their thoughts to individual, team, or both at the same time.
Furthermore, regardless of the initial cognitive orientation, team members’ actions in study 2 is representative of individual work.

Information Sharing: Information sharing occurred in both study’s approaches, yet in different ways. In study 1, information sharing occurred through a variety of methods. Specifically, many of the awareness activities outlined in Chapter 4 describe how team members shared and tracked information. Many of these activities were designed and executed in a planned manner. For example, if a team member found information they would add it to an information list. On the other hand, the approach in study 2 allowed for the sharing of information but it occurred through the affordances of Coagmonto or via simply copying and pasting links within the chat or shared editor functions. When the co-located and distributed methods for information sharing are directly compared, the scope and content of the methods are very similar, yet the way in which they are achieved is different.

Communication: The team member communication in the two settings (and approaches) is drastically different. The level of communication in the study 1’s approaches was much greater than study 2, regardless of the specific approach. The availability of face-to-face communication allowed for greater communication at a faster rate in the co-located setting. As already discussed, the distributed setting hindered communication, resulting in less communication. In addition to the volume and frequency of communication, the overall quality of the content of the communication was reduced in study 2. The communication in study 2 was often just a few words or a sentence, lacking detail and generating little understanding among team members. In contrast, communication occurring in the co-located approaches was more in-depth, consisting of in-depth conversation that produced understanding and implications throughout the team. The difference in communication across the settings is central to why the two setting’s approaches are different. A lack of communication in the distributed setting led to: more individual work, coordinated work instead of collaborative work, minimized information sharing, difficulties developing advanced awareness, and challenges to developing team cognition (discussed in the next section).

Awareness: Awareness developed in both settings. Yet, there are significant differences in how it developed and the strength of it based on the setting. In study 1, many different types of awareness (Search, Information, and Social) were developed, all helping lead to increased overall
awareness. In study 2, awareness was developed through team members updating each other through Coagmento or using its features to keep track of their team members’ activities. The awareness developed in study 2 was not as advanced as study 1. This was mainly due to the active vs. passive nature of awareness developing in study 1 and 2. Awareness that developed in study 1 was passive (or in the background), meaning that team members did not have to actively work as hard to develop it because they had the benefit of seeing each other in real time. While they still had to work to develop awareness, they were subliminally observing their other team members, which better allowed for awareness to develop. In contrast, study 2 participants had to actively develop awareness because they were not afforded the same aspects of co-located work that study 1 participants were. In addition, in some cases, a lack of trust in the distributed environment hindered the overall development of awareness.

9.1.2 Similarities and Differences Among the Team Mental Model in a Co-located and Distributed Setting

In both studies, team mental models (TMM) developed during CIS. Yet, there are distinct differences when comparing the content, strength, and development of the TMM. Below, I outline similarities and differences relating to these aspects of the TMM.

9.1.2.1 Content of the Team Mental Model within Different Settings

In study 1, nine of the eleven teams developed a TMM during CIS. Similarly, in study 2, nine of the ten teams developed a TMM during CIS. So, in both studies, a majority of teams developed a TMM. However the TMMs that developed in both studies vary widely based on their content and overall strength. So, while 18 out of 21 teams developed a baseline TMM, the TMM throughout the teams is not the same. This especially holds true when the TMMs in the co-located and distributed settings are compared.

As discussed before, a TMM is composed of different models. In my studies, I focused on the taskwork and teamwork models within TMMs. More specifically, during study 1, taskwork models were identified in all nine teams with three teams also identifying a teamwork model. Yet, in study 2, while nine teams identified a taskwork model, none of the teams indicated a teamwork model. This raises some interesting questions. First, why did teamwork models not develop as
frequently as taskwork models? Second, when teamwork models did develop, why were they only in the co-located settings?

Understanding why teamwork models did not develop is difficult to investigate because every team is different. However, data from both studies highlights two apparent reasons for why teamwork models often did not develop in either study. Many participants mentioned that the tasks were straightforward enough to complete without needing high levels of interpersonal communication or learning/relying on team members’ specific skills. The tasks in this dissertation had a high level of task interdependence, allowing teams to work on the task with minimal changes in focus. Furthermore, the nature of the tasks were not ambiguous, often allowing participants to delve right into their individual and team research. If the task was open for interpretation, participants might require deeper levels of communication, discussion, and cognition to interpret it. The CIS tasks used in both studies were clear in their goals, which reduced the need for in-depth conversations. Conversations and in-depth discussion are beneficial to the development of a teamwork model. The teamwork model is grounded in interpersonal communication/relationships and understanding team members’ knowledge and skills. Since the CIS tasks were straightforward, these discussions were not needed. Similarly, Stone & Posey (2008) have noted that a distributed team’s performance of a task is often reliant on the task itself and that a co-located team performs judgmental or subjective tasks better than a distributed one. This aligns with the findings in this dissertation that explain for the high prevalence of taskwork models in study 2.

The second reason why teamwork models did not develop in most of the teams was because of time limitations. TMM research has highlighted how teams need to work together for prolonged periods of time in order for a TMM to develop (Mohammed et al, 2009). Specifically, longer periods of time are needed to develop teamwork models (Mathieu et al., 2009). Team members in this dissertation were given thirty minutes to complete the CIS tasks. While this was enough time to complete the tasks and develop a taskwork model, it was often not enough to develop a teamwork model. The teamwork model is the more complicated of the two models and, therefore, takes longer to develop. Thirty minutes is usually not enough time to develop a relationship with someone they have never met before. In addition, understanding individual team members’ knowledge and skills also takes time. Thirty minutes may be enough time to develop an understanding of how to search for information and complete the task but not for developing a teamwork model.
While teamwork models were rare throughout both studies, some did develop in the co-located teams. Yet, none developed in the distributed setting. The limited communication in the distributed environment coupled with the other reasons previously mentioned did not allow for the in-depth discussions needed to develop teamwork models. Since communication takes longer in the distributed setting, participants were only able to focus their limited communication on the task itself and not on understanding their partner. This resulted in a taskwork model not a teamwork model developing in all nine distributed teams.

9.1.2.2 Features Affecting the Development of Team Mental Models in Different Settings

Surprisingly, even though the TMMs were different in the two settings, they often developed in similar ways. In both studies, the development process involved individual team members sharing cognition and ideas specific to CIS. Over time, each individual team member learns about their team members’ cognition and then the team members revise their individual cognition to orient with the team’s goals. Depending on the type of TMM (taskwork or teamwork) this process may only be focused on task oriented cognition/procedures, or it may also include a deeper level of understanding that encompasses the team members’ knowledge and skills. One might not expect the development of the TMM to follow this pattern within the distributed setting because of the communication and awareness limitations that have previously been discussed. However, team members were still able to share enough of their individual cognition within the distributed setting to meet the threshold needed for emerging team level cognition. I am anticipating some of my future research to specifically examine how the individual to team cognitive process is able to emerge in the distributed setting. There are clearly barriers in the distributed setting that affect the content of team cognition and how it is developed, but it did develop.

Other ways that TMMs developed in both settings are through the development of awareness, communication, information sharing, team experience, and leadership in the teams. Awareness played a critical role in both of the studies in the development of TMMs. In each study, while it was developed differently, awareness allowed team members to learn about the task and how their partners approached it. Through shared awareness, team members developed common ground related to the task or in some cases other team members’ knowledge and skills. Communication, along with awareness, was the main way in which team members were able to share their individual cognition and develop team cognition. Even though communication was
limited in the distributed medium, there was enough present to at least develop taskwork TMMs. Information sharing was vital in the development of taskwork TMMs in CIS. Sharing information allowed team members to develop team based cognition directly related to information needed for the task.

An aspect always mentioned as helping to develop the TMM, regardless of the setting, was team experience. Team members with higher levels of team experience mentioned that it allowed them to understand their teamwork and their associated roles at a much faster rate than if they did not have team experience. Teamwork, to some degree, is similar no matter the situation or context. Klein (2008) argues that our decision-making is grounded in previous experiences (naturalistic decision-making). We develop our assumptions of reality and how to react to certain situations through meaningful and relevant previous experience. Using those previous experiences, we then anticipate, predict, and react to real world contexts using our own experiences as a framework to guide us. This decision-making process is directly related to CIS teamwork. Many of the team members in both studies have been on teams before, and in their prior teams, they actively sought information in a collaborative manner. Therefore, to an extent, team members already had previous experiences with CIS. Using those experiences, they then could actively work towards developing or revising their own TMM to the current context and situation. One could argue that we already have many context or situation specific TMMs in place, and depending on the context or situation that we are presented with, we revisit our experiences and recall helpful or related TMMs to deal with the real world situation. This research stream is one that I am extremely interested in and will work towards further understanding in future work.

Leadership is viewed as being fundamental to the development of a TMM in both settings. Even though leadership was viewed as being helpful, there are mixed perceptions of the role of leadership in aiding the development of a TMM. Specifically, many team members prefer different types of leadership. Some mention a “laid back” style of leadership as being effective, while others want a leader to be more hands on and manage more directly the process. In both studies, participants had different opinions on which style was more effective in developing a TMM. Furthermore, in the distributed setting, a few participants mentioned that a lack of leadership was actually beneficial in the development of the TMM. These members noted that an effective TMM was based on equal sharing of cognition, and that the introduction of a leader could result in a TMM that is biased towards one individual’s cognition.
Although TMMs developed in many similar ways, there was one major difference between the development in the co-located and distributed setting. This difference revolved around the concept of trust. Trust has been linked as a fundamental aspect of team decision-making that allows team members to work in concert with each other (Fiore et al., 2003). In a distributed setting, trust is often difficult to develop, resulting in reduced decision-making abilities (Alge, Wiethoff, & Klein, 2003; Kanawattanachai & Yoo, 2002). Within team cognition and TMM research, trust is still an emerging as a major research focus.

Participants in the distributed setting specifically noted the need for trust in their team in order to develop a TMM. Interestingly, study 1 participants never mentioned trust. The issue of trust in the distributed setting is related to the physical limitations of the setting itself. Participants cannot “see” what other team members are doing. This results in either a lack of trust or the need to develop trust without the adequate knowledge or experience to confirm it (“blind trust”). In study 2, participants mentioned that there was simply not enough time to develop full trust in each other; so, many times they were forced to have blind trust in their team member. This unfounded trust might have been adequate for this study because of the nature of the tasks. However, if the tasks were oriented towards a more emotionally charged subject where people have strong feelings about it, then team members might not be able to trust each other without first fully learning about each other. Furthermore, the fact that this was a research study cannot be ignored in regards to trust. A few team members mentioned that they trusted their team member to do their work because it was a study that they volunteered for, implying that if they were not going to participate in the study then they should not have signed up for it.

In addition to trust, team members in the distributed setting also used the setting to their advantage. Communication and workflows that occurred within the distributed setting were often highly structured. For example, if one person said something in the chat, she would wait for the other to respond. Similarly, if someone shared a link, she would wait for feedback on the link. This became a very routine and repetitive activity that often guided teamwork. Over time, team members developed the ability to assume and predict their taskwork based on this repetitive and structured behavior, eventually aiding in the development of the TMM.

In study 1, team members indicated that a TMM often developed. While team members in study 2 indicated that a TMM also developed, they often mentioned that it could have been stronger. The reduced strength of the TMM in the distributed setting was due to a variety of factors: less communication, less awareness, and physical limitations.
9.2 Chapter Summary

In this chapter, I presented a review and discussion of the similarities and differences between study 1 and 2. Specifically, I focused on the similarities and differences related to how teams approach CIS and develop TMMs within a co-located and distributed setting. In the next chapter, I will conclude this dissertation by answering the research questions, explaining this dissertation’s contributions to multiple academic communities, and outlining my future work initiatives.
Chapter 10

Conclusion

CIS is of growing importance in the information sciences and human-computer interaction (HCI) research communities. Current research has primarily focused on examining the social and interactional aspects of CIS in organizational or other settings (Reddy & Jansen, 2008) and developing technical approaches to support CIS activities (Shah, 2010b). As we develop a better understanding of the interactional aspects of CIS, we must also start to examine the cognitive aspects of CIS. To fully understand the activity of CIS, a comprehensive understanding of the interactional and cognitive aspects is needed. In particular, we need to understand CIS from a team cognition perspective. While understanding the social and technical aspects of CIS are fundamental to extending the field, understanding team cognition can significantly benefit CIS research. In particular, examining team cognition can help us better understand the approaches that take place during CIS teamwork and provide insight into identifying and overcoming problems in teams (Cannon-Bowers & Salas, 2001; Fiore & Salas, 2004).

This dissertation focused on understanding CIS from a team cognitive perspective. Specifically, the aim of the dissertation was to examine how teams approach CIS and develop team cognition during CIS. In two separate studies, I explored these issues in both a co-located and distributed setting. Each of these studies has made significant contributions in understanding how teams go about the activity of CIS and if/how team cognition develops during CIS. Similarities and differences across the studies have better allowed us to fully understand the impact of team cognition on CIS.

In this concluding chapter, I discuss the research questions and their answers. I also describe this dissertation’s specific contributions to multiple research communities. I then conclude with closing remarks and detailing my future work.
In chapter 1, I outlined specific objectives and goals for this dissertation. Revisiting the objectives, I articulated the following goals:

- to explore how teams approach CIS;
- to develop a conceptual understanding of team cognition during CIS;
- to understand the impact and affect of a co-located and distributed setting on team’s CIS approaches and the development of team cognition, and
- to develop design guidelines for information technologies that will support multiple CIS approaches and the development of team cognition during CIS.

I went into this dissertation hoping to make an impact on multiple aspects of CIS, as evident by the scope of the objectives and goals. Through two different studies, I have met the goals I set forth in chapter 1. More specifically, I answered all of the research questions and consequently made contributions to multiple research communities. Below I will outline the specific answer to each research question:

**RQ1: What are the different team approaches (cognitive) of CIS?**

(a) How does a co-located and distributed environment affect the approaches?

This dissertation identified and outlined multiple approaches of CIS. A total of five approaches were identified across the two studies. In study 1, four different approaches were identified: Individual to Team V1, Individual to Team V2, Team to Individual, and Team. Each of these approaches was predicated on a variation of individual and team based work. The differentiation between the four approaches depends on when and how individual and team work take place. Overall, the work across all four approaches is generally similar; the patterns of the workflow are what is different. In study 2, one approach of CIS was identified. This approach was highly dependent on individual work with instances of teamwork.

All of the approaches highlight that CIS is dynamic and situational. CIS doesn’t take one form, rather many different ones. Consequently, CIS should never be viewed in a “one size fits all” manner. CIS must be viewed as being dynamic and varied depending on the team and the context. The team itself specifically impacts how they will approach CIS. In this dissertation, I
identified multiple teams within the same context using different CIS approaches (study 1). The teams elicited the differences in how they approached CIS. Teams are composed of many different individuals and how they work together to complete CIS varies greatly depending on individual team members’ experiences, individual preferences/differences, and the development of team cognition. Since each of these focuses vary widely across different teams, we can see how different approaches to CIS take shape.

In addition, and in response to the second part of this research question, the context (co-located or distributed) clearly impacts how teams approach CIS. As noted, the approach utilized in study 2 focused much more on individual work than teamwork. The heightened level of individual work can be directly correlated to the context being distributed. Certain aspects of the distributed setting constrain how teams can and will approach CIS, resulting in more individualized work. Consequently, CIS occurring in the distributed setting is more prone to coordinated information seeking, than collaborative information seeking.

Moving forward, we must continue to understand the many approaches of CIS and the impact teams and the context have on approaches. While this dissertation identified five approaches, there are most likely many more approaches that were never identified. The research community must view CIS as varied, dynamic, and situational. CIS is never static. When CIS is referred to, much like team decision-making, it should consist of many different approaches, models, and methods.

**RQ2: Does team cognition develop within the different approaches identified within RQ1?**

(a) How does team cognition develop during the approaches?

(b) What specific cognitive activities take place that help develop team cognition during CIS?

(c) How does a co-located and distributed environment affect the development of team cognition during CIS?

Team cognition does develop during CIS and it’s identified approaches. This dissertation identified many different ways that team cognition develops during CIS. First, team cognition develops via the transference of individual cognition to the team cognition. In both studies, team members explained sharing aspects of their individual cognition with team members and over time revising their own cognition to align with the goals of the team, subsequently creating team cognition. This was the main method in which team cognition developed in many of the teams
but there were also many other means through which it developed. Communication, awareness, team experience, leadership, and time were also specific aspects of CIS that helped (and in some cases, hurt) the development of team cognition during CIS.

The most significant cognitive activities that aid team cognition revolve around communication and awareness. Multiple methods of communication were used to develop team cognition in both studies. Communication is how team members share their own individual cognition to develop team cognition. Awareness was also used in both studies to aid the development of team cognition. In study 1, many mechanisms of awareness were created: search, information, and social. In study 2, team members proactively kept each other updated and used affordances within Coagmento to develop awareness. In both studies, awareness helped to develop common ground and a shared understanding of the team’s CIS work.

The setting that CIS occurs in affects the development of team cognition. The development of team cognition during CIS is increasingly more difficult in the distributed setting when compared to the co-located setting. While teams developed team cognition in both settings, the content of the team cognition in the distributed setting was mainly oriented towards taskwork and not teamwork. In addition, participants in the distributed medium often acknowledged that their team cognition could have been stronger, explaining that limitations in communication and awareness were present.

**RQ3: Within team cognition, does a team mental model develop within the context of CIS in a co-located and distributed setting?**

A significant way that team cognition developed was through the development of team mental models (TMM). In both studies, TMMs developed. Specifically, in study 1, nine of eleven teams developed a TMM. In study 2, nine of ten teams developed a TMM. As noted above, the differences between the TMMs in each study are grounded in the content of the model and the strength. There are also many similarities in the development of the TMMs across both studies. Yet, the need for trust among team members when developing the TMMs was amplified in the distributed setting.

Moving forward, there is still a need for more research specifically focused on the development of team cognition and TMMs during CIS. This dissertation has laid the foundation for this research focus, outlining that team cognition does develop during CIS, how team cognition develops, and the differences within team cognition throughout the settings of co-
located and distributed. Yet, while this is a starting point there needs to be many more studies exploring similar issues in order to develop a larger sample and understand the impacts that different CIS settings have on team cognition and TMM development.

**RQ4: How can knowledge about CIS approaches and CIS specific team cognition be used to support development of CIS tools and systems?**

The knowledge gained from both the CIS approaches and team cognition within the context of CIS have the ability to strongly support and improve the development of CIS tools and systems. In chapter 5, I outlined high-level design recommendations aimed at aiding the CIS approaches and the development of team cognition. These recommendations focused on the flexibility needed in a system to afford compatibility with the four varied CIS approaches. Specific recommendations are aimed at improving communication and awareness, implementing meaningful visualizations, accounting for individual/team processing, and minimizing cognitive load. In chapter 8, I also provided specific recommendations for the Coagmento system. These recommendations were developed from feedback provided by participants and can be applied to multiple CIS tools and systems. Finally, also in chapter 8, I outlined ways to support and develop team cognition in distributed CIS systems.

**10.2 Overall Study Contributions**

This dissertation has four main contributions all aimed at furthering our understanding of CIS. First, the findings help to better understand the different and varied team approaches during CIS activities. Second, this dissertation helps to bring forth an understanding of the role of team cognition during CIS and how it develops within this context. Thirdly, the ability to study CIS in two different setting (co-located and distributed) has allowed for more insight into how the settings impact CIS. Finally, the findings provide general and specific design recommendations that can be applied to many CIS tools and systems to better aid multiple CIS approaches and the development of team cognition.
Understanding of Different CIS Approaches
As discussed in Chapter 2, the CIS research community has just begun to identify models, processes, and approaches of CIS. One of the most important contributions this research provides is a better understanding of various team approaches during CIS activities. To my knowledge, this is the first set of studies that has accounted for multiple CIS specific approaches with exact step-by-step processes. In addition, this is the first study that has accounted for approaches in both the co-located and distributed setting. Understanding that different teams utilize different approaches of CIS is incredibly important for the overall research community. This has implications in how we conduct future CIS research and the development of CIS tools and systems. If the CIS community aims at helping people search and share information more efficiently, the variances in different approaches need to be accounted for.

Understanding of Team Cognition During CIS
The CIS research community has not considered the development of team cognition during CIS. Until now, previous research mainly focused on the interactions that take place during the CIS process. To my knowledge, this is the first set of studies to ever specifically investigate the role of team cognition during CIS. More specifically, this study is the first to ever identify TMMs within the context of CIS in two different CIS settings. Previously, researchers had never considered TMMs in relation to CIS. This finding is important because the development of a TMM during CIS has the ability to significantly help teams successfully collaborate to seek information. In addition, multiple team cognitive activities, like awareness, were identified better allowing for an understanding of how team cognition and TMMs develop. While the activities identified within this study are not a comprehensive list of how team cognition is developed during CIS, each of them allows for a greater understanding of how teams develop team cognition directly relevant to CIS.

Understanding Differences in CIS Within Co-located and Distributed Settings
This dissertation articulates the impact of different settings on CIS. Differences between the co-located and distributed setting were identified as impacting how teams approach CIS and how team cognition is developed. The co-located setting affords the variability for multiple different approaches of CIS. In contrast, the distributed setting is mainly constricted to only one highly individualized CIS approach. In addition, the distributed setting mainly negatively impacts the
development of team cognition during CIS activities. Moving forward, researchers must further understand the differences that the different settings incur on CIS.

**Developing Design Recommendations**

As mentioned throughout this dissertation, many CIS tools and systems have been developed over the years. Yet, they are often grounded in the assumption that the process or approach of CIS is similar across all teams. Also, most CIS tools and systems use human interaction as the main basis to build the system, rarely accounting for individual or team cognition. In this dissertation, I have outlined general and specific design recommendations that will help aid different CIS approaches and develop team cognition. Yet, more work still needs to be done to develop more design recommendations. Recommendations still need to be developed that specifically account for the five different team approaches of CIS. Each of these approaches consists of different workflows, meaning a CIS system should also be able to aid each workflow.

10.3 Intellectual Contributions to Academic Communities

The anticipated findings from this study will make contributions to four research domains: Human Factors (HF), Information Sciences (IS), Computer Supported Cooperative Work (CSCW), and Psychology.

**Human Factors**

HF researchers have long been interested in understanding the team decision-making process (Wickens, Gordon, & Liu, 2004). While many frameworks and models of team decision-making have been presented over the years, very few explicitly account for and include the importance of CIS. As a researcher, I strongly feel that CIS needs to be accounted for within the overall team decision-making process, not just assumed to exist. This dissertation increased the awareness of CIS as an important step within the overall team decision-making process. In addition, HF has closely looked at team cognition, attempting to understand how it is developed and how it affects team performance. To the best of my knowledge, no one has explored the relationship of team cognition and CIS. This dissertation contributes to the HF community by attempting to understand the link between team cognition and CIS, while also adding to the understanding of team decision-making. One of the most widely acknowledged team cognition constructs within
the HF domain is the TMM (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994). While much research has revolved around the TMM construct, none has focused on the context of CIS. Through this research, I developed a further understanding of the relationship between the TMM and CIS. The HF community has indicated their interest in this relationship due to the success of team decision-making being dependent on successfully finding information to solve a problem. A wealth of research indicates that a TMM can increase performance (Mathieu et al., 2000). Knowing this, it is possible that the development of a TMM within the context of CIS has the ability to help the overall team decision-making process. Team performance was not the focus of this dissertation, but I will consider it in my future research.

**Information Sciences**

Most CIS specific research is published within the IS domain (Shah, 2010b). The IS domain is interested in information behaviors and how information is processed and managed individually, within teams, and organizationally. As mentioned in the background, a great deal of research has been done over the years to understand individual information processing (Kuhlthau, 1991). Over time, researchers transitioned from purely focusing on individual information seeking to also considering the collaboration that takes place during information seeking. While the CIS community has investigated many areas, there are still specific gaps that have not been considered. There is a paucity of knowledge pertaining to specific models, approaches, and processes of CIS. This dissertation has lessened that research gap by identifying five different approaches that help us better understand how information is processed and managed in multiple setting. In addition, very little research has considered the relationship of team cognition and CIS. The findings in each of this dissertation’s studies also begin to develop an understanding of team cognition and CIS.

**CSCW**

Within the CSCW community, most of the group or team based information seeking research focuses on social search. Social search is often viewed as being an activity within the broader activity of CIS. During social search people employ social resources to search for information (Morris, 2013). Social search is not strictly a web activity, yet most work has been focused on web-based practices. Similar to CIS, while much work has been conducted on social search, little has focused on team cognition. Many CSCW researchers are interested in understanding social search from an interactional point of view. Yet, an understanding of team cognition needs to be
considered, in addition to interaction. This dissertation contributes to the field of CSCW in two ways. First, this dissertation adds to the conceptual understanding of social search during CIS by understanding the influence of team cognition, and also by understanding the relationship between interaction and cognition during social search. Second, one of the main focuses of CSCW is designing and developing information systems to support collaboration. This study adds to the growing body of work explaining design guidelines for social search systems.

**Psychology**

This dissertation makes contributions to the field of Psychology. The concepts of team cognition and the team mental model are specifically rooted in Psychology and this dissertation helps to further our understanding of both. Specific to the team mental model construct, contributions have been made that help to empirically describe how a team mental model is developed. In addition, this dissertation also adds to our understanding of how the co-located and distributed settings affect team mental model development. Finally, the identification of a team mental model during CIS is outlined in this dissertation.

**10.4 Future Work**

This dissertation has opened up many different avenues for future research, many of which I hope to address in the upcoming years.

Moving forward with this research, I would like to undertake studies that not only further our understanding of how team cognition develops during CIS, but how the development of team cognition impacts CIS performance. Since CIS is incredibly important to the overall team decision-making process, it would be valuable to understand how team cognition impacts or helps CIS, and subsequently, team decision-making. A great deal of work has focused on team cognition and performance, yet none has focused on the context of CIS. I would also like to study CIS in a naturalistic environment. The role and developmental process of team cognition is certainly prone to change based on the context. Therefore, to fully understand the role of team cognition during CIS there must be multiple studies within multiple contexts. Also, more specific investigations need to be conducted to further understand the relationships between the different CIS approaches and differences in team cognition development. Finally, I hope to continue
working on developing design requirements and recommendations that aid the development of team cognition not only during CIS but in other contexts as well.

10.5 Closing Remarks

My goals for this dissertation were wide-ranging. I sought to integrate three different research communities (team decision-making, team cognition, and collaborative information seeking) to further understand all of them better. Yet, looking back upon the work within this dissertation, I am confident that the goals were addressed.

First, an understanding of the relationship between CIS and team decision-making was gained. CIS is not just a single step during team decision-making, but is continually re-occurring throughout the process. Planning and re-planning happen routinely during team decision making, leading to new goals. In order to understand and meet these goals, teams must constantly adapt to find new information throughout the process. I believe that a detailed understanding of CIS will help improve team decision-making.

Second, I learned that CIS is dynamic, situational, and contextual. CIS is multi-varied in its processes and consists of many different approaches that are dependent on the situation and context. I have mentioned it multiple times within this dissertation but it’s important to remember that CIS is not “one size fits all.” One team might approach CIS completely different than another team. The important part of understanding this is that CIS can be carried out and perceived very differently by many people or teams. Due to this, researchers must explore and consider CIS from multiple perspectives and be open to researching it from different angles to fully understand it.

Finally, team cognition is particularly important to CIS. The cognition that develops at an individual and team level provides the basis for many of the actions and work that takes place during CIS. Team cognition has explained specific instances of successes and failures during teamwork (Cooke & Durso, 2010). Consequently, the study of team cognition has been linked numerous times to predicting a team’s performance (Salas et al., 2008). If the CIS community seeks to fully develop an understanding of CIS, then the focus must account for the social, technical, and cognitive aspects of CIS activities. This dissertation is only the starting point for addressing the cognitive and team cognitive aspects relevant to CIS.
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Appendix A

Demographic Survey

Team _____

What is your gender? Male Female

What is your age (circle)? 18-20 21-23 24-26 27+

Is English your first language (Y/N)? __________

Which college are you currently enrolled in?

- □ College of Agricultural Sciences
- □ College of Arts and Architecture
- □ Smeal College of Business
- □ College of Earth and Mineral Sciences
- □ College of Engineering
- □ Development
- □ School of International Affairs
- □ College of the Liberal Arts
- □ School of Nursing
- □ College of Information Sciences and Technology
- □ Graduate School

Do you have team experience (Y/N)? __________

If so, estimate how many teams you have worked on: __________

How comfortable are you working in a team (1 being the least comfortable, 5 being the most)?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Appendix B

Concept Pool Prompt

Please list in the table all of the concepts you can think of that have to do with the following categories:

<table>
<thead>
<tr>
<th>The Task</th>
<th>Team Interactions</th>
<th>Resources Used</th>
<th>Information Seeking</th>
<th>Information Sharing</th>
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Appendix C

Final Concept List

**Study 1 Final Concept List**
- Verbal communication
- Joint understand of task
- Delegating responsibility
- Source credibility
- Sharing information
- Agreement
- Prior knowledge
- Nonverbal communication
- Online messaging
- Accessibility
- Collaboration
- Determining progress
- End goal
- Internet
- Research
- Computer
- Email
- Personal insight
- Team leader
- Individual generation of ideas
- All members engaged
- Resolving differences
Appendix D

Pilot Study Protocol

1. Introduction to the study and what they will be doing during the session. Outline that they will first be taking part in a task that will take 30 minutes, they will then be generating concepts that were relevant to that task, and they will then learn how to concept map and then concept map based off the concepts that they previously generated. A very brief explanation of the goals and purpose of the study will also be explained. (5 minutes)

2. Two IRBs will then be given to each of the participants- one for them to read over and sign and one for them to keep that has been signed by the PI. (2 minutes)

3. The researchers will then explain to the participants that they will now be taking part in a collaborative information-seeking task. Since this is a pilot session, the explanation of collaborative information seeking will be minimal since it is not overly important for the participants to understand it and we are limited on time. The participants will be sitting at each of their laptops and will be given the first part of the task. They will be instructed to complete this task using the Internet and any other knowledge they may previously have. Once the team feels they have adequately answered the first part of the task they will be told to indicate that to the researchers so that they can then receive the next part of the task. The same procedure will continue until the team runs out of time or finishes all parts of the task. The team will be told from the outset that they will have 30 minutes to complete the task and to complete as much of it as they can. During the task the researchers will audio and video record the participants. (30 minutes)

4. Once the participants have completed the task or time has expired, the team will be interviewed to provide feedback on the task itself. The following questions will be ask of the team:

   Did you understand what you were being asked to do?

   Were you able to complete each of the individual tasks?

   With the time that you had, do you feel you were able to adequately answer the questions?

   Did you find the tasks to be too easy, too difficult, or just right for this experiment?

   Were you able to find enough information on each one of the tasks (top causes of cancer, lifestyle choices, and detection technology)?

   Did you feel you had the resources available to adequately answer the questions?

   Do you have any suggestions to make the task better for this experiment?
Do you have any general comments regarding the task that have not already been addressed?

The answers to these questions will be audio recorded. (5 minutes)

5. Once the team has provided feedback on the task they will then be separated to prepare for the concept generation part of the study. Each team member will be placed near a whiteboard, which they will utilize during the concept generation. Each team member will then be given a sheet of paper that provides the participants with prompts that are related to the task. The prompts are as follows: The Task Itself, Team Interactions, Resources Used, Information Seeking, and Information Sharing. They will then be asked to generate concepts for each of the prompts and write the concepts on the whiteboard. They will be given 15 minutes to generate concepts. Once they have generated their concepts they will then be asked to individually rank the concepts based on importance. A scale of 1-10 will be given where 1 is unimportant and 10 is important. The participant will then write the ranking number next to each of their concepts (5 minutes). Once the participant has ranked all of their concepts the team will then reconvene. Once the team is back together they will then systematically review each member’s concept importance ranking. The goal of this is that the participants reach a consensus on which concepts they find important and unimportant as a team (15 minutes). The concepts that are listed as a 5 or below will then be thrown out of the concept pool (researcher will cross out unimportant concepts so that they can still be seen and logged after the session is over). The team will then eliminate synonyms or concepts that they view as being the same (15 minutes). Once the concept pool has been reduced down to this, the team will then be asked to pick the top 25 most important concepts. (Total Time 50 minutes)

6. After the concepts have been generated the team will then be instructed on what concept maps are, how to produce them, provided with an example, and have the opportunity to produce a small concept map related to choosing a college major. This concept map topic was chosen because it was thought to be salient to the participants and would be easy for them to grasp due to their relevancy with the topic. (5-10 minutes)

7. Once the team has been introduced to concept mapping they will then produce a declarative map of “How did you collaboratively find information as a team during the task?” Each participant will do this individually on a whiteboard. One will notice that unlike the actual experiment, the participants will only being doing the declarative map and not the team procedural, this is simply due to a lack of time. (20 minutes)

8. Once the concept mapping has taken place, the team will be asked a series of questions on if they understood how to concept map. (5 minutes)

   Do you understand what a concept map is?

   Do you understand how to make a concept map?

   Did you feel that you were given enough time to make the concept map?
Did you find making the concept map to be too easy, too difficult, or just right for this experiment?

Do you feel that you found enough information to make a thorough concept map?

Do you have any suggestions to make the concept map generation better for this experiment?

Do you have any general comments regarding the concept map generation that have not already been addressed?

9. Explain to the students that the study is now over. Have them fill out the payment sheet, and then provide them with the money.
Appendix E

Main Research Study Protocol

Before Participants Arrive
1) Email the participants 2 days before their scheduled study date and time, and also the day of the study.
2) Make sure that there are two copies of the consent form sitting next to each laptop. Also, make sure that the consent forms are signed and dated by the PI.
3) Make sure 3 copies of the task, 3 copies of the interview, 3 bhy demographic surveys, 2 copies of the interview protocol, and 3 copies of the concept mapping prompts have been printed. Also, make sure that the 3 examples of the concept maps are in the lab.
4) Clean all whiteboards.
5) Hang signs throughout the IST building indicating where room 314 is. Specifically, hand them out the locked doors near the elevator, at the beginning of the hall that 314 is located at, and outside 314.
6) Check the laptops, audio recorder, and video camera to make sure they are working and have a full charge. The log-in information for the laptops is Nathan’s user id and password.
7) Open up the web browser and go to Google. Depending on whether the condition is collocated or distributed, the usage of Coagmento will be needed. If distributed, make sure that Coagmento (in Firefox) is up and running on all three laptops. The log-in information for Coagmento is: user_1, user_2, user_3, and the password is 173935.
8) If after 7, make sure to check doors by elevator for students, as they lock then.

When Participants Arrive
1) Greet them and ask them to have a seat next to each laptop.
2) If a student shows up more than 10 minutes late to the study, indicate to them that their slot has been filled for that session, and that they will need to get in contact with the researchers to reschedule. If the participant shows up within the 10 minute time slot, allow them to join the team who is working on the CIS task.
3) If 3 people show up, run the study as normal. If 2 show up, run the study as you would with 3. If 1 shows up, explain to them the situation and that they will have to be rescheduled. Be very thankful for them for showing up. If they appear irritated or mad, tell them that you can give them $5 for their time.
4) Once the participants are all seated next to the laptops, explain the consent forms and tell them to read it and sign it.
5) Collect their signed consent forms and file them.
6) Explain that the length of the study is 2 hours long and it will last that entire time. So, if they attempt to rush through certain parts of the study it will not make the study go any faster. The best approach is that they try their best.
7) Ask each participant to fill out a demographic survey.
8) Collect and file the demographic survey.
9) Provide them with a high level overview of what the study entails. Go step-by-step through the study.
10) Sit down with them and start explaining the concepts of team mental models and collaborative information seeking. Refer to the script for explanation of these two concepts.
“This study looks at the relationship between team cognition (specifically team mental models) and collaborative information seeking. To better understand this, we would like to explain to you what exactly both team mental models and collaborative information seeking are. We will start with team mental models and then move onto collaborative information seeking.

A team mental model refers to an organized understanding or mental representation of knowledge that is shared by team members. At the simplest level, a mental model is a cognitive structure or network of associations between concepts in each individual's mind. Team mental models are team members' shared mental representations of knowledge or beliefs about key elements of the teams' relevant environment. Team mental models not only facilitate information processing and foster increased coordination but also enable team members to formulate accurate predictions about what other team members are thinking or will do. A prime example of a team mental model can be seen in this example... The seemingly effortless execution of a blind pass in basketball illustrates when team members correctly predict the positioning and readiness of other team members on the court. The ability to execute the pass is dependent on a shared understanding of the game and the ability to predict or anticipate what other team members are going to do.

Collaborative information seeking has been defined as “the study of systems and practices that enable individuals to collaborate during the seeking, searching, and retrieval of information” [10] (p. 330). Thus, studies of CIS have focused on how people find and retrieve information together. When a problem is presented to a team, one of the first steps to solving that problem is finding information collaboratively. CIS looks at the multiple situations, methods, and motivations people find information when in a team or group. Specific areas CIS looks at are collaborative information searching or retrieval, collaborative information sharing, and collaborative information gathering. If you have ever been in a team, then you have taken part in CIS.

This study is interested in looking at if there is a team mental model specific to collaborative information seeking.”

11) Transition into introducing the CIS task.
14) Explain to the team that they will have a total of 30 minutes to complete 3 tasks. The first task will be given 15 minutes to complete, the second 5 minutes, and the third 10 minutes. Explain that they are allowed to use any part of the internet to seek information, as well as any previous information they may have. Encourage that the participants on the team work together to find information, rather than doing it at a more individual level.
15) Tell the team that they may begin the CIS activity, and that when they are done with the first part of the task to let the researchers know.
16) Start two timers, one for the researchers to keep track off, and one for the team.
17) Start the video camera and the audio recorder.
18) Once they are done with the task, transition into introducing how to concept map.
19) Explain what concept mapping is (referring to the script again). Show them examples of multiple concept maps (should already have these printed out). Lastly, provide them with a basic concept map prompting question that is related to choosing a college major. Let them have 10 minutes to attempt to concept map, and then provide feedback to the team. *This will be an example of a declarative concept map, like the one they will do at an individual level. The procedural concept map will be explained within this part of the study too (what they will do at a team level).

“Concept maps are graphical tools for organizing and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts. The label for most
concepts is a word, although sometimes more than one word is used. Propositions are statements about some object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected using linking words or phrases to form a meaningful statement.

Another characteristic of concept maps is that the concepts are represented in a hierarchical fashion with the most inclusive, most general concepts at the top of the map and the more specific, less general concepts arranged hierarchically below. You may choose to use a hierarchy or not.

Another important characteristic of concept maps is the inclusion of cross-links. These are relationships or links between concepts in different segments or domains of the concept map. Cross-links help us see how a concept in one domain of knowledge represented on the map is related to a concept in another domain shown on the map.

Remember, a concept map is never completely finished, as you can always continue creating and linking concepts to each other.

In this study, we will be doing two types of concept maps, a declarative and a procedural map. The differences are clear, as a declarative map is more interested in broad general knowledge (the knowledge of what), and a procedural is interested the actual procedure used (the knowledge of how)."

20) Instruct them that 2 of them will be completing a CIS declarative concept map individually, while the other participant is interviewed about team mental model and common ground. After 20 minutes has passed, the two participants who were concept mapping will be interviewed, while the other will concept map.

21) Ensure that the concept mapping is video recorded and that the interviews are audio recorded. Also, when the concept maps are completed take a photo of each of them.

Opening Script:

Once again thank you for agreeing to be interviewed today. My name is _______ and I am a graduate student within the College of Information Sciences and Technology at Penn State University. We will spend about 20 minutes together. During this time, I will ask you questions about what you thought during the problem task and how you felt team cognition was developed within your team. I am interested in everything you have to say about this topic, so feel free to say whatever comes to mind.

Questions to be asked:

2. Was your first thought about working with the team or about how you would do it individually and then share with the team?
3. How did you think about approaching collaborating with your team initially?
4. How did your team think about searching for information? What process did your team choose to search for information?
5. Do you feel that everyone on your team thought the same about collaborating and sharing information? If not, why?
6. Cognitively (in regards to thinking), how did your team determine what information was important/not?
7. How did your team move from thinking individually about the task to thinking as a team?
8. Do you feel a team mental model was established within your team?
   -If needed describe TMM.
9. Did the model happen early on in the task or later? Early being within the 1st 10 minutes of the task.
10. What do you think were the issues that led to having/ or not having a TMM?
11. Did a leader emerge on your team? If so, did that help or hurt the development of a TMM?
12. Do you feel your previous experience in teams helped you to better develop a team mental model?
13. How did you decide to share information with your other team members?
14. If you were doing this task on your own, how would you think and go about doing it? Is it drastically different than how your team actually did it?
15. What collaborative tools would you use for seeking information in teams or groups?
16. Do you find it useful to collaborate when seeking information in groups or teams?
21) Explain to the team that they will now be coming back together to do a procedural concept map together.
22) Remind the team what a procedural concept map is and that they need map the entire CIS process from start to beginning.
23) Allow the team 30 minutes to complete the procedural map, while having the researcher guide them and help spur ideas and thoughts.
24) Make sure that the video camera and audio recorder are recording.
25) Once the procedural map is completed, explain to the participants that the study is complete.
26) Have the participants fill out the payment sheet, and then provide them with the money.

After the Participants Leave
1) File the consent forms, demographic surveys, and payment sheet.
2) Extract the browsing history from each laptop.
3) Transfer all the video recordings, audio recordings, browsing history and digital photographs to local storage and cloud. Make sure that the files are named correctly based on the file naming mechanism for team #.
4) Clean up the room and prep for the next study. Turn off the video recorder and audio recorder.
Appendix F

Study 1 Cognitive Interview Questions

Opening Script:

Once again thank you for agreeing to be interviewed today. My name is ________ and I am a graduate student within the College of Information Sciences and Technology at Penn State University. We will spend about 20 minutes together. During this time, I will ask you questions about what you thought during the problem task and how you felt team cognition was developed within your team. I am interested in everything you have to say about this topic, so feel free to say whatever comes to mind.

Questions to be asked:
1. When the task was first given to you, what did you think? Just your first thought.
2. Was your first thought about working with the team or about how you would do it individually and then share with the team?
3. How did you think about approaching collaborating with your team initially?
4. How did your team think about searching for information? Did you go through multiple ideas until you all liked one/ liked first idea/ couldn’t agree?
5. Do you feel that everyone on your team thought about collaborating and sharing information the same? If not, why?
6. Cognitively, how did your team determine what information was important/not?
7. How did your team overcome different ways of individual thinking in order to accomplish the task?
8. Do you feel a team mental model was established within your team? -If needed describe TMM.
9. Did the model/common ground happen early on in the task or later?
10. What do you feel led to having/ or not having a TMM?
11. Did a leader emerge on your team? If so, did that help or hurt the development of a TMM?
12. Do you feel your previous experience in teams helped you to better develop a team mental model?
13. How did you decide to share information with your other team members?
14. If you were doing this task on your own, how would you think and go about doing it? Is it drastically different than how your team actually did it?

*For participants in distributed condition:*

15. Did you feel that being distributed helped or hurt the development of a TMM? Why?

16. Were there any specific attributes within Coagmento that helped or hurt development?

17. What features do you feel are needed to help with developing TMM when being located in different places?

18. Would you rather collaborate collocated or distributed? Why/why not?
Appendix G

Study 2 Study Guide

Before Participants Arrive
1) Email the participants 2 days before their scheduled study date and time, and also the day of the study.
2) Make sure that there are two copies of the consent form sitting next to each computer within the cubicle. Also, make sure that the consent forms are signed and dated by the PI.
3) Make sure 2 copies of the task, 2 copies of demographic surveys, 2 copies of the Coagmento features, and 2 copies of the interview protocol have been printed.
4) Hang signs throughout the IST building indicating where room 314 is. Specifically, hang them outside the locked doors near the elevator, at the beginning of the hall that 314 is located at, and outside 314.
6) Check the computers and Coagmento software to ensure that it is working properly. Ensure that the Coagmento video tutorial is ready. Also make sure the audio recorders are working and have a full charge.
7) Make sure that Coagmento (in Firefox) is up and running on the computers. The log-in information for Coagmento is: username: cisparticipant1 password: alphadog and username cisparticipant2 password: betadog
8) If after 7, make sure to check doors by elevator for students, as they lock then.

When Participants Arrive
1) Greet them and ask them to have a seat next at the designated research cubicle.
2) If a student shows up more than 10 minutes late to the study, indicate to them that their slot has been filled for that session, and that they will need to get in contact with the researchers to reschedule. If the participant shows up within the 10 minute time slot, allow them to join the team who is working on the CIS task.
3) If 2 people show up, run the study as normal. If 1 shows up, explain to them the situation and that they will have to be rescheduled. Be very thankful for them for showing up.
4) Once the participants are all seated next to the computers in the cubicles, explain the consent forms and tell them to read it and sign it.
5) Collect their signed consent forms and file them.
6) Explain that the length of the study is 1 hour and 10 minutes long and it will last that entire time. So, if they attempt to rush through certain parts of the study it will not make the study go any faster. The best approach is that they try their best.
7) Ask each participant to fill out a demographic survey.
8) Collect and file the demographic survey.
9) Provide them with a high level overview of what the study entails. Go step-by-step through the study.
10) Sit down with them and start explaining the concepts of team mental models and collaborative information seeking. Refer to the script for explanation of these two concepts.

"This study looks at the relationship between team cognition (specifically team mental models) and collaborative information seeking in a distributed setting. To better understand this, we would like to explain to you what exactly both team mental models and collaborative information
seeking are. We will start with team mental models and then move onto collaborative information seeking.

A team mental model refers to an organized understanding or mental representation of knowledge that is shared by team members. At the simplest level, a mental model is a cognitive structure or network of associations between concepts in each individuals’ mind. Team mental models are team members’ shared mental representations of knowledge or beliefs about key elements of the teams’ relevant environment. Team mental models not only facilitate information processing and foster increased coordination but also enable team members to formulate accurate predictions about what other team members are thinking or will do. A prime example of a team mental model can be seen in this example... The seemingly effortless execution of a blind pass in basketball illustrates when team members correctly predict the positioning and readiness of other team members on the court. The ability to execute the pass is dependent on a shared understanding of the game and the ability to predict or anticipate what other team members are going to do.

Collaborative information seeking has been defined as “the study of systems and practices that enable individuals to collaborate during the seeking, searching, and retrieval of information” [10] (p. 330). Thus, studies of CIS have focused on how people find and retrieve information together. When a problem is presented to a team, one of the first steps to solving that problem is finding information collaboratively. CIS looks at the multiple situations, methods, and motivations people find information when in a team or group. Specific areas CIS looks at are collaborative information searching or retrieval, collaborative information sharing, and collaborative information gathering. If you have ever been in a team, then you have taken part in CIS.

This study is interested in looking at if there is a team mental model specific to collaborative information seeking within a distributed medium.”

11) Introduce the Coagmento software to the participants. Hand out document that lists the features available within Coagmento and how to use them.
12) Play the Coagmento tutorial video, which explains how to collaboratively work within the software.
13) Ask the participants if they understand how to use Coagmento. If not, answer their questions and provide more information.
14) Transition into introducing the CIS task.
15) Explain to the team that they will have a total of 30 minutes to complete 3 tasks. The first task will be given 15 minutes to complete, the second 5 minutes, and the third 10 minutes. Explain that they are allowed to use any part of the internet to seek information, as well as any previous information they may have. Encourage that the participants on the team work together to find information, rather than doing it at an individual level.
16) Tell the team that they may begin the CIS activity by utilizing Coagmento, and that when they are done with the first part of the task to let the researchers know.
17) Start two timers, one for the researchers to keep track of, and one for the team.
18) Once the first task is completed (15 minutes), present task 2 (5 minutes), then task 3 (10 minutes).
19) Once the time has expired for all 3 tasks, explain to the participants that they will now each participate in individual cognitive interview aimed at understanding their thought process during CIS, the development of a team mental model, and the effect of the distributed medium on team cognition.
20) Separate the participants and begin the interview. Set a timer for 30 minutes.
21) Follow this script for the interviews:

*Opening Script:*
Once again thank you for agreeing to be interviewed today. My name is ________ and I am a graduate student within the College of Information Sciences and Technology at Penn State University. We will spend about 30 minutes together. During this time, I will ask you questions about what you thought during the problem task, how you felt team cognition was developed within your team, and your perspectives on Coagmento. I am interested in everything you have to say about this topic, so feel free to say whatever comes to mind.

Questions to be asked:

Cognitive Interview focused on CIS Process and Development of TMM-use probing techniques

1. Did you complete all 3 tasks?
   -Probe for more info...

2. When the task was first given to you, what did you think?
   -Probe for first thought. Ground them by asking them to think back to task.

3. Was your first thought about working with the team or about how you would do it individually and then share with the team?
   -Probe for why

4. How did you think about approaching collaborating with your team initially?

5. How did your team think about searching for information?
   -Did you go through multiple ideas until you all liked one/ liked first idea/ couldn’t agree?
   -Take me through your CIS process...ground by having them revisit context (multiple probes during this)

6. Do you feel that everyone on your team thought about collaborating and sharing information the same?
   -If not, why?

7. Cognitively, how did your team determine what information was important/not?

8. How did your team overcome different ways of individual thinking in order to accomplish the task?
   -Probe for individual thinking then transition to team

9. Do you feel a team mental model specific to CIS was established within your team? (If needed describe TMM)
   -Probe for how developed. Ask for specific examples during CIS process that helped or hurt development.

10. Did you feel that being distributed helped or hurt the development of a team mental model?
    -Why? In what ways?

11. Did the model develop early on in the task or later?
    -Have them think back to task and process

12. What do you feel led to having/ or not having a TMM?
-Probe depending on answer
13. Did a leader emerge on your team?
   - If so, did that help or hurt the development of a TMM?

14. Do you feel your previous experience in distributed teams helped you to better develop a team mental model?
   - Why?

15. What effect did the Coagmento interface have on your interaction with your teammate?

16. Were there any specific features within Coagmento that helped or hurt the development of a team mental model?
   - Probes if needed: chat, bookmarks, etc.

17. Did you feel as though you were aware what your team member was doing during the tasks?
   - Probe for TMM

18. Was there too much, too little, or the right amount of information present within Coagmento?
   - Probe for TMM

19. Did Coagmento’s interface allow for individual thought during the CIS process?
   - Ground this by revisiting when they were talking about individual thought earlier, and have them revisit thought process
   - Probe for TMM

20. Explain how the lack of non-verbal communication affected the development of team mental models in the distributed medium?
   - Probe for TMM

21. Was it clear within Coagmento what each team member's role was?
   - Revisit task
   - Probe for TMM

22. Compare collaboratively seeking information face to face vs. distributed and how you feel a team mental model would develop differently in each medium?
   - Multiple probes depending on answer.

23. What are some potential features or ideas that could be implemented into a CIS system (like Coagmento) where people are distributed, which could help develop team mental models?
   - Probe and give examples if need to kick start idea generation.

22) After the interview is over, thank each participant for his or her time and explain the study has concluded. Have each participant fill out the payment sheet and then pay each $20.

After the Participants Leave
1) File the consent forms, demographic surveys, and payment sheet.
2) Extract the browsing/chat history from each computer.
3) Transfer all audio recordings and browsing/chat history to local storage and cloud. Make sure that the files are named correctly based on the file naming mechanism for team #.
4) Clean up the room and prep for the next study. Turn off the audio recorder, as well as log out of the computers.
Appendix H

Study 2 Cognitive Interview Questions

Opening Script:
Once again thank you for agreeing to be interviewed today. My name is ________ and I am a graduate student within the College of Information Sciences and Technology at Penn State University. We will spend about 30 minutes together. During this time, I will ask you questions about what you thought during the problem task, how you felt team cognition was developed within your team, and your perspectives on Coagmento. I am interested in everything you have to say about this topic, so feel free to say whatever comes to mind.

Questions to be asked:
1. Did you complete all 3 tasks? Probe for more info based off answer…
2. When the task was first given to you, what did you think? Just your first thought.
3. Was your first thought about working with the team or about how you would do it individually and then share with the team?
4. How did you think about approaching collaborating with your team initially?
5. How did your team think about searching for information? Did you go through multiple ideas until you all liked one/ liked first idea/ couldn’t agree? Take me through your CIS process…
6. Do you feel that everyone on your team thought about collaborating and sharing information the same? If not, why?
7. Cognitively, how did your team determine what information was important/not?
8. How did your team overcome different ways of individual thinking in order to accomplish the task?
9. Do you feel a team mental model specific to CIS was established within your team? If needed describe TMM.
10. Did you feel that being distributed helped or hurt the development of a team mental model? Why?
11. Did the model develop early on in the task or later?
12. What do you feel led to having/ or not having a TMM?
13. Did a leader emerge on your team? If so, did that help or hurt the development of a TMM?

14. Do you feel your previous experience in teams helped you to better develop a team mental model?

15. What effect did the Coagmento interface have on your interaction with your teammate?

16. Were there any specific features within Coagmento that helped or hurt the development of a team mental model? (probes if needed: chat, bookmarks, etc)

17. Did you feel as though you were aware what your team member was doing during the tasks? TMM follow-up question

18. Was there too much, too little, or the right amount of information present within Coagmento? TMM follow-up question

19. Did Coagmento’s interface allow for individual thought during the CIS process? TMM follow-up question

20. Explain how the lack of non-verbal communication affected the development of team mental models?

21. Was it clear within Coagmento what each team member’s role was? TMM follow-up question.

22. Compare collaboratively seeking information face to face vs. distributed and how you feel a team mental model would develop differently in each medium?

What are some potential features or ideas that could be implemented into a CIS system (like Coagmento) where people are distributed, which could help develop team mental models? Probe and give examples if need to kick start idea generation.
Appendix I

Study 2 Team Procedural Concept Map Analysis

Team 6:

Process:
Team 6’s CIS process started off with individual searches. During the individual searches they blurted out information that they found to be important to the task and the team. This sharing of initial information leads to collaboration. Collaborative work revolving around information seeking then leads to the ability to answer the CIS tasks. A specific method that this team used was the “recycling” of their workflow across tasks. This allows for less time being spent on planning, and more time spent on the searching of information.

Themes:
The main theme found across this map is that the entire process of CIS was very decision oriented. The entire process of CIS was aimed at making decisions, whether that be finding information, answering the CIS tasks, or working together. Another theme is the utilization of collaborative activities to lead to decision-making. There are multiple instances within the map where collaboration is directly linked to decision-making.

Important Concepts and Kernels:
Collaborate: This concept connects to multiple decision-making concepts and multiple levels. More specifically, the ability to collaborate led to and understanding of information sources and the many aspects associated with judging their credibility.
Recycled Task 1 Research Methods: This concept connects to many different concepts, which allow for collaboration and decision-making.

Team 7:

Process:
The process of CIS that team 7 took started out with discussing the CIS task together as a team. During this discussion the team configured a team approach to CIS. Once the discussion ended, the team individually searched. After individual searching, the team collaborated to discuss their search results and shape their results. The rest of the process consists of team members individually researching and then collaborating and researching again until they answered all three CIS tasks.

Themes: There is an iterative nature to the process of this teams CIS activity. Mainly the team switches back and forth from discussing and collaborating on the task to researching individually. This process is constant throughout the entire concept map and represents one of the many ways in which CIS may occur. CIS consists of both individual and teamwork. Also, a second theme is that most of the decisions teams occur during Task 1, indicating the importance of the early stages of CIS.
Important Concepts and Kernels:

Collaboration: The concept of collaboration is used twice, both times with multiple connections. The connections vary from research, decision-making and more collaborative activities. Collaboration was used to help the team conduct actual searching but also to make decisions.

Research: The concept of research is used many times within the map but specifically there is a cluster at the end of the map that is of significance. The research concept is the parent to multiple other concepts that fall under the themes of collaboration, resources, and decision-making.

Team 8:

Process:
The overall CIS process within this map starts with individuals conducting a search and then collaborating to seek information and address the CIS task. Specifically the collaboration leads to decisions that are based on team understanding. The process of collaborating and making decisions based on the collaborative results is iterative throughout the entire map.

Themes:
One of the main themes of this map is the divergence from utilizing individual work to team associated (with the focus on the teamwork). The task starts of with individual research and that is then extended into collaboration leading to shared knowledge. This is an important microcosm and theme of the entire map. Another important theme within this map is the close link and relationship that collaborative concepts have with team understanding and decision making concepts. Throughout the entire map, there is often a linkage from a collaborative activity to the development of team understanding or a decision being made. More specifically, there is a cluster at the bottom of the map that revolves around collaborative activities, team understanding, and decision-making. We can see that all three of these activities are directly related to each other and lead to the completion of CIS. The theme within the map indicates that team collaboration helps to develop a team understanding, which is then utilized to make decisions. In the bottom right corner we can see this theme through the connection of multiple concepts - group discussion used shared knowledge used to answer prompt. The group discussion is the main facilitator in helping teams collaboratively seek information through developing a shared understanding of how to do it. This process then leads to action and decisions being made.

Important Concepts and Kernels:
This concept map produces quite a few kernels, most directly related to collaboration and team understanding.

Group Discussion- This concept is directly linked to the concepts of team leader, shared knowledge, and joint understanding. In addition, it is the parent to multiple levels of different concepts (example: group discussion-shared knowledge-revise and add to prior knowledge-better and faster results). The concepts overall importance is linked to decision making and developing team understanding.

Understanding Teamwork Knowledge & Skills- This concept has multiple concepts coming and out of it, along with multiple layers of concepts extending from it. Similar to group discussion, the concept is often linked to decision-making and collaborative aspects of CIS.

Increase Group Comfort- This concept has multiple connections in and out of it and connects to concepts in different parts of the map (known as crosslinks) signifying greater importance. Much
like the previous two kernels, this kernel also is specific to collaboration, decision-making, and team understanding.

More Discussion- This concept is directly related to the previous 3 kernels in terms of its overall meaning.

Individual Research- This is the first concept on the map and while it does not have as many connections as the other kernels, it initiates much of the overall CIS process. If this concept were not there, then much of the overall process would not exist.

Team 9:

Process:
The CIS process of team 9 starts out with a period of individual understanding that transitions into individual searching. Next, a team leader develops and helps the team figure out how to collaborate to answer the CIS tasks. During collaboration team members are working individually and together, using forms of communication to both make decisions and develop a team understanding. Near the end of the process, the team addresses issues of formatting.

Themes:
There are three main themes within this concept map. First, there is an integration of individual thought and work within the larger collaborative process. Throughout the entire map, one can see that these are points in time where individual team members are working on completing individual task during collaboration. Secondly, there is a theme that indicates the importance of both verbal and nonverbal communication in allowing the team to work together. Both concepts connect to many other concepts and allow for decisions, team understanding, and individual work to be completed during the CIS process. Lastly, there is a relationship between individual understanding and work and team understanding. Specifically, there is a back and forth between the two. At two instances within the map, they are specifically linked together and influence each other in different ways.

Important Concepts and Kernels:
Verbal Communication: Multiple concepts connect to this concept, allowing specifically for decision-making, team understanding, individual work, and collaboration.
Nonverbal Communication: Multiple concepts connect to this concept, allowing specifically for decision-making, individual work, and collaboration.
Individual Understanding: This concept is indicated early in the map and leads to multiple important activities, such as team understanding, decision-making, and collaboration.

Team 10:

Process:
Team 10 begins their CIS process by discussing the task and how they want to approach it. During this time, the discussion is heavily dependent on each team members’ previous experiences, which are also grounded in each team members’ individual mental model. Through this discussion the team decides on their goals and a leader emerges. Next, the team delegates their teamwork to each individual. After individual searching occurs, the team comes back together and collaborates to reevaluate their goals until they finish the task.

Themes:
There are two main themes in this concept map. First, the concept map shows the team mental model developing over time. The team specifically identifies the importance of an individual model in grounding their overall team discussion and later indicates after individual searching and collaboration that the team mental model has developed. The second theme shows a strong relationship between decision-making and collaboration. Usually, collaboration occurs within the map and the decisions are made.

Important Concepts and Kernels:
*Collaboration:* This is the only key concept or kernel within the entire map. Collaboration is linked to the initial team discussion and specifically previous knowledge and individual team mental models. In addition, collaboration is linked to identifying the overall team goal.

**Team 11**

Process:
The team starts out CIS by first discussing the task as a team and figuring out their approach to CIS. They then identify the individual responsibilities allowing for individual information seeking. Information seeking allows for multiple decisions to then be made in regard to the task. Through these decisions, the team organizes and presents a final document for the task.

Themes:
None

Important Concepts and Kernels:
*Seek Info:* Seek information is initiated by an outline that the team configures. This then leads to ideas being found and the process of seeking information is impacted by the concepts of personal insight and individual misunderstanding.

**Team 12**

Process:
The team starts CIS by individually reviewing the task and searching keywords. They then transition into collaboration, which is dependent on communication among the team. Collaboration then leads to multiple decisions being made, which are aided by sharing of information throughout the decision-making process.

Themes:
The first identified theme was the transition from individual information seeking to collaborative information seeking. The team started out by individual researching the task using keywords and through this they developed individual ideas that they brought into the collaborative process. The second theme is one that is identified in previous maps, being the relationship between collaboration and decision-making. Once again, this team identified that collaboration led to a multitude of decisions being made.

Important Concepts and Kernels:
*Research:* Although not indicated, this is individual research and it leads to the ability to generate individual ideas based on the research. Specifically, this concept is linked to the decision making concepts of initial findings and evaluating information.
Collaboration: Collaboration is brought forth by individual research and then leads to multiple decision-making and other collaborative concepts.

Communication: Much like collaboration, communication is closely linked to both collaborative and decision-making concepts.

Sharing Information: Much like communication, sharing information is closely linked to both collaborative and decision-making concepts.

Evaluating Information: Evaluating information is connected to multiple concepts of collaboration and decision-making.

Team 13

Process:
Team 13 begins their CIS process by individually researching. Each team member then brings their individual research results into the team discussion. During the team discussion, the team compares their results and then makes decisions on how they will work together. Teamwork then results in decisions being made regarding the task and the information to utilize during the CIS process.

Themes: The main theme in this map is how well defined the team’s CIS process is. It is very clear that the team starts off with individual searching, moves to teamwork and then makes decisions. Each of these steps in the process builds upon each other. For example, in this process, teamwork could not occur if the individual research did not previously occur.

Important Concepts and Kernels:
Individual Insight: This is viewed as the most important concept and kernel in the beginning stages of CIS. It directly connects with multiple other Individual, Resource, Task, and Collaborative concepts.
Discussion: Discussion is viewed as the starting point for collaboration and then leads to other types of collaboration and eventually decision-making.
Teamwork: Much like discussion, teamwork leads to other collaborative concepts and many decision-making concepts.
Developing a Final Answer: This concept is viewed as critical to the whole decision-making process. It is at the heart of all of the decision-making concepts with all of them either connecting to or from developing a final answer.

Team 14

Process: This process of team 14 is very collaborative. First, they start off collaborating by sharing ideas and then being to conduct group research. During the group research the team is constantly collaborating, and it would appear based on the map that they are doing all information seeking together. Group research then allows for decisions to be made in read to task and developing an end result.

Themes: This team’s CIS process is highly unstructured and very dependent on collaboration and teamwork throughout the process. This is the first team in this study that has appeared to be this collaborative. In addition, collaboration is leading to decision-making once again.

Important Concepts and Kernels:
Collaboration: Collaboration occurs very early in the map and is then linked to multiple other concepts of searching and decision-making.

Debate: Debate is at the center of all the decision-making concepts and also directly connects to collaboration.

Personal Opinions: This concept comes last in the map and has multiple cross-links to collaborative and decision-making concepts.

Team 15

Process: It is not clear based on the map whether team 15’s process begins at an individual or team level. There is preliminary work that is being conducted within the first part of the map, yet it is unknown whether it is team or individual work. Midway through the first task, the team explicitly starts sharing information that leads to decisions being made. Once the team makes their decisions, they finalize their task document. This process continues into task 2, which the team builds on previous information that they have found in task 1. As task 2 and 3 are completed, the team notes that collaboration becomes easier and the research is more complete.

Themes: The first theme is initial understanding of the task and seeking background knowledge relating to it. This early understanding stage occurs for about half of the first task, implying its importance. The second main theme within the map is that the team appears to build off of their found information within each task, which also enables collaboration to become easier. This also represents a certain level of structure within the CIS process.

Important Concepts and Kernels: Compilation of Information: Compilation of information has more linkages than any other concept on the map. This concept is linked directly to decision-making, collaboration, and task concepts.

Team 16

Process: Much like Team 15, it is not entirely clear if the CIS process begins with team or individual work. It would seem that it does begin at an individual level due to a relationship indicating working together to condense information shortly after the first few concepts. The rest of the collaborative process consists of individual research, coming together and discussing it as a team, and then collaborating to make decisions. The beginning part of the process appears to be highly dependent on individual work, where the end of the process becomes more collaborative.

Themes: This teams map is very research and information concept heavy. More so than any other team, team 16 shows that they value both the research and the information being found just as much as they value the collaborative process itself. The theme in this map is that information is just as important as collaboration, something that is not always prevalent in the other maps. The second theme is that verbal communication spans across the entire map and acts as the glue for the entire CIS process. A second theme of this concept map is that it is very structured and iterative in its nature, meaning that the team continually did similar activities during CIS.

Important Concepts and Kernels: Verbal Communication: This concept is linked throughout the map to information, decision-making, collaboration, and searching concepts.
Nathan James McNeese: Abridged Curriculum Vitae

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Doctor of Philosophy in Information Sciences and Technology, December 2014
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PUBLICATIONS
Archived Conference Publications (7)
Journal Articles (1-in submission)
Book Chapters (Invited) (1)
Workshop Papers (1)
Research Posters (2)