COLLABORATIVE INFORMATION BEHAVIOR IN LEARNING TASKS:

A STUDY OF ENGINEERING STUDENTS

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Abstract

Collaborative information behaviour is an emerging area in information science that deals with the identification, seeking, searching, and use of information by two or more people to accomplish a task. This dissertation investigates the collaborative information behaviour of senior undergraduate engineering students working on group design-projects at a Canadian university. The dissertation presents a longitudinal research using a constructivist grounded theory methodology in two different but related studies undertaken in successive academic years. The main research method consisted of a web-based survey, bimonthly semi-structured interviews with eight students, and the project deliverables for six different project groups. Project deliverables included weekly reports that described group and project activities, and the projects' interim and final reports.

The research results show that learning tasks associated with engineering design projects were information-intensive tasks; information seeking, searching, and use have been ongoing needed activities during the lifespan of these projects. There was found to be a strong relationship among learning task stages and phases, task complexity, and collaborative information behavior. Collaborative information behaviors occurred variably at different project stages and levels, and their nature were task-dependent. Students' perception of task complexity triggered collaborative seeking and use of a variety of information sources, with preferences for information from perceived subject-experts. It was also found, in

many situations, when students' perceived task complexity increased, their information behavior tended to be more collaborative.

The study highlighted the need for groups to construct and share a collaborative situation awareness in order to maintain and regulate their activities in information seeking and use; this shared awareness was enabled by students' interactions in their group meetings or their use of collaborative software tools for information sharing. Learners sought and created meaning from information through collaborative information synthesis over long intervals by prioritizing, judging relevance, and building connections of information.

The research investigated collaborative information behavior in learning tasks through a detailed analysis of findings that resulted in a holistic conceptual framework illustrating the dynamic interplay of the components of task-based collaborative information behavior in learning tasks. Collaborative information behavior was conceptualized with details in its three distinct but interrelated dimensions: (1) learner's knowledge, (2) learners' activities and interactions, and (3) information objects; the representation of interdependence of these three dimensions confirmed the complexity of collaborative information behavior as a human behavior that cannot be investigated by focusing on a single dimension and eliminating the other ones.

The dissertation presents original research that extends our conceptual understanding of students' collaborative information behavior in learning tasks and also provides more insights into how collaborative information behaviors are dynamically shaped by the characteristics of the learning task.

Résumé

Le comportement informationnel collaboratif est un sujet émergent en sciences de l'information qui est relié aux moments où deux acteurs ou plus cherchent, repèrent, sélectionnent et utilisent l'information pour accomplir une tâche. Cette thèse propose une étude sur le comportement informationnel collaboratif des étudiants de premier cycle en génie dans le contexte de projets de groupe en conception technique offert dans une université canadienne.

La thèse décrit une recherche longitudinale utilisant deux études différentes, mais connexes, menées dans des années successives. Les méthodes principales de recherche consistaient en un sondage en ligne, entretiens semi-structurés avec huit étudiants chaque deux mois, et la collection des éléments livrables des six différents groupes. Les livrables des projets comprenaient des rapports hebdomadaires qui décrivaient les activités des groupes et aussi les rapports intermédiaires et finaux des projets.

Les résultats présentés dans cette thèse montrent que les tâches d'apprentissages associées à des projets de conception technique ont été intensives de l'usage d'information, la recherche et l'utilisation de l'information étaient des activités nécessaires que continuaient pendant la durée de ces projets. Il a été constaté une forte corrélation entre les stades et phases de tâches d'apprentissage, la complexité des tâches, et le comportement informationnel collaboratif. Les comportements informationnels se sont produits variablement à différentes étapes du projet, et leur nature étaient dépendantes sur les tâches. La perception qu'ont les étudiants de la complexité des tâches déclenchées le

recherche et l'utilisation d'information en collaboration d'une variété de sources d'information, avec des préférences pour l'information obtenu des spécialistes dans le domaine du projet. On a également constaté, dans des nombreuses situations, lorsque la complexité perçue de la tâche par des étudiants a augmenté, leur comportement informationnel avait tendance à être plus collaboratif.

L'étude souligne la nécessité de groupes de construire et partager une connaissance de la situation de collaboration dans le but du projet, de maintenir et de réglementer leurs activités dans la recherche et l'utilisation d'information; cette prise de conscience partagée a été activée par les interactions des étudiants dans leurs réunions de groupe ou leur utilisation d'outils logiciels de collaboration pour partager d'information. Les apprenants ont cherché et créé signification de l'information grâce à la synthèse d'information collaboratif sur de longs intervalles par ordre de priorité, à en juger la pertinence et l'établissement de liens d'information.

La recherche a enquêté le comportement informationnel collaboratif dans les tâches d'apprentissage par le biais d'une analyse détaillée des conclusions qui ont abouti à un cadre conceptuel holistique illustrant l'interaction dynamique des composantes du comportement informationnel collaboratif basé sur la nature de la tâche d'apprentissage. Le comportement informationnel collaboratif a été analysé de manière détaillée dans ses trois dimensions distinctes mais interdépendantes: (1) la connaissance d'apprenant, (2) les activités et des interactions des apprenants, et (3) les objets d'information ; la représentation de l'interdépendance de ces trois dimensions a confirmé la complexité de la comportement informationnel collaboratif comme un comportement humain qui ne peut pas être étudiée en se concentrant sur une seule dimension et d'éliminer les autres.

La recherche présentée dans cette thèse propose une recherche originale qui augmente notre compréhension conceptuelle du comportement d'information collaboratif des étudiants dans les tâches d’apprentissage et fournit également des indications sur la façon dont les comportements d'information collaboratifs sont influencés par les caractéristiques de la tâche d'apprentissage.

Dedication

To my father for teaching me the joy of reading and learning,

my mother for her endless love and encouragement,

and to my daughter Sara who brings hope and happiness into my life.

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1. INTRODUCTION

> When we searched for information as a group, we were usually all looking for different information. However, we each had different expertise in the project, and had (over the course of the project) each gained different background knowledge. Making a decision about what was good or bad information, and what to search for next. Once we found something interesting, it was not something easily done as an individual without the knowledge of the whole project team (Laura).

> I do not remember that we have ever searched for information together as a group but we spent a lot of time during our meetings to discuss and evaluate information that each of us has found (Mark).

In the quotations above, Laura and Mark, senior undergraduate engineering students at a Canadian university, reflect upon their experience searching for and using information during their assigned projects. Laura focuses on the fact that the different opinions and perspectives in her working group enriched the outcomes of the task at hand. Mark recalls that his group as a unit had not searched for information in a coordinated manner but had spent a considerable amount of time in their meetings discussing and evaluating the relevancy to their project of the information they had found.

These cases illustrate only two of the many ways in which students experience information seeking, search and use. The examples reflect different situations and individual perspectives in their experience of group work. The students observed for the purpose of this study described how they differentiated good and bad information for use in their projects. Studies that aim to understand how people need, seek, search, and use information are described as studies in information behavior (Case, 2007).

Studies in information behavior address different ways people behave when interacting with information. The development of information behavior research over many decades has led to the construction of models of information behavior in order to describe the interacting concepts that represent this phenomenon; these models are referred to as conceptual models of information behavior (Järvelin & Wilson, 2003). These conceptual models follow different approaches: contextual ones, such as Wilson's information behavior model (Wilson, 1999), that describes internal and external variables that may impact human information behavior; Taylor's Information Use Environment (Taylor, 1991) focuses on people's actual use of information in a particular environment; and process-based models, such as Kuhlthau's Information-Search Process (ISP) model (Kuhlthau, 1991, 2004), that envisages the information search as a sequence of processes, and tend to investigate the affective and cognitive dimensions of human information behavior.

These models, as well as many other conceptual models of information behavior (e.g., Ford, 2004; Ingwersen & Järvelin, 2005), have all assumed that the information seeker is an individual who is interacting with complex information spaces. However, some recent studies in information behavior have focused on the way people collaborate and communicate when they retrieve and use information in groups (e.g., Foster, 2006; Talja & Hansen, 2006). As a result, some researchers in information science began to challenge the individualistic approach in conceptual information behavior models by exploring the collaborative dimension of information behavior (e.g., Bruce et al., 2003; Karamuftuoglu, 1998).

The quotations from students, above, support the argument that the individualistic approach towards information behavior needs to be refined and investigated through its collaborative nature in group-based settings. Studies of the way people seek, search for and use information in groups of two or more working together to perform a particular task are described as studies in *collaborative information behavior*.

Collaborative information behavior, according to Hansen and Järvelin (2005), is the "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 a work task related information seeking and retrieval process either in a specific workplace setting or in a more open community or environment." (p. 1102). In the same study, the authors explained that this definition should be seen as preliminarily; it needs further refinement through studies, observations and investigations.

Studies in collaborative information behavior have pursued different research objectives. Some focused on information users' personalities and cognitive dimensions (Hyldegård, 2006b), while others have investigated the effect of some contextual dimension such as the work task and its information requirement on the group's information behavior (e.g., Hertzum, 2010; Reddy &

Dourish, 2002; Reddy & Jansen, 2008). Others have targeted specific groups of information users such as health care providers (Reddy & Dourish, 2002), academic researchers (Talja & Hansen, 2006) or graduate students (Hyldegård, 2006b).

Although there is a considerable body of literature that has examined undergraduate students' information behavior, less is known about the information behavior of students working collaboratively as a group in assigned learning tasks. During this dissertation I have developed and used the following working definition of collaborative information behavior, based on Wilson's (2000) definition of individual information behavior, to be:

> Collaborative information behavior is the totality of human behavior when two or more people work together, in relation to sources and channels of information, and including both active and passive information seeking and use.

The collaborative information behavior of undergraduate engineering students as reflected in the quotations at the beginning of this chapter is the focused phenomenon under investigation in this dissertation. These quotations show the complexity of students' information behavior when they worked on their assigned learning tasks. They also reflect patterns of interaction with regard to individual and collaborative information behavior, and show how collaborative information behavior is interwoven with the requirements of the learning task from the students' perspectives. An investigation of the effect of the group-based learning task on students' collaborative information behavior is the focus of this study.

1.1 Rationale of the study

A tremendous number of information behavior studies has focused on the ways that engineers as professionals seek and use information in their work tasks (e.g., Allard, Levine, & Tenopir, 2009; Allen, 1977; Tenopir & King, 2004). Leckie, Pettigrew, and Sylvain (1996, p. 164) reported that engineers were the first professionals whose information behavior was studied in information science and that engineers' information behavior is always a result of complex interactions among different variables.

Information behavior in engineering design projects has been the subject of some studies by researchers in the field of information science (e.g., Hertzum & Pejtersen, 2000; Pejtersen, Sonnenwald, Buur, Govindaraj, & Vicente, 1997; Prekop, 2002; Sonnenwald & Lievrouw, 1997). Engineering design is an activity that results in specifying an artifact, given constraints that indicate one or more functions to be fulfilled and/or objectives to be satisfied by the artifact (Best, 2006; Jugulum & Samuel, 2008). An engineering design problem may have several acceptable solutions, but one solution can be the most satisfactory according to the specified criteria.

Engineering design projects involve implicitly or explicitly many information related activities to a considerable degree during the lifespan of the project. Some projects may need more information than others depending on the project nature. In complex engineering projects, there is a vital need for information to solve problems and make decisions (Hertzum, 2000). Tasks that often require a considerable amount of information to search for and use are described as *information intensive tasks* (Byström & Hansen, 2005, p. 1050). Studies of information behavior in engineering also revealed that engineering tasks, particularly in design and product development, always require a high level of collaboration that often results in collaborative activities in information seeking and use (Sonnenwald, 1996).

This dissertation is an attempt to understand the effect of learning tasks associated with real engineering projects on the collaborative information behavior of senior undergraduate students. The engineering design project as a learning task requires not only a report on the design solution as its final product but also a process with different stages and different information requirements as specified by the course instructor and perceived by the students.

Investigation of the effect of tasks on information behavior is important because tasks are the *driving force* underlying information behavior (Ingwersen & Järvelin, 2005). However, task-based collaborative information behavior studies were conducted mainly in work related activities such as patent registration (Hansen & Järvelin, 2000) or in a city planning office (Serola, 2006). Less is known about the effect of such work tasks when students perform them as learning tasks. The paucity of task-based studies in information behavior has resulted in a call for more research to determine the relationship between learning tasks and the information behavior of students (Tanni & Sormunen, 2008).

Many studies in information behavior (e.g., Limberg, 2007; Vakkari, 2003) have called for new research that would highlight the significance of the task in which information behavior is being studied, in order to move beyond the view that information is essential to yet separate from the work itself (Reddy & Dourish, 2002). Wildemuth and Hughes (2005) argued that "empirically grounded theories related to information behavior's embedding tasks are needed … [T]asks should be the focus of our studies rather than minor consideration in studies focusing on information behaviors" (p. 276).

Thus, two significant gaps in existing research into the task-based collaborative information behavior of undergraduate engineering students have prompted the research study presented in this dissertation:

1. **The characteristics of the learning tasks that are associated with engineering design projects.** Studies examining the effect of the learning task on information behavior are scarce, particularly in such undergraduate professional programs as engineering. Although some studies have investigated the effect of learning assignments on information behavior, many have focused on learning tasks associated with writing an assignment on a particular topic (e.g., Kuhlthau, 1991; Leide, Cole, Beheshti, Large, & Yang, 2007). The engineering design project as a learning task requires students to not only write a final report describing the selected solution but to define the design problem, understand possible solutions, find justification for and select one solution, and implement that solution by creating a prototype.
2. **The task-based collaborative information behavior of undergraduate students.** Very few studies have been undertaken on the collaborative information behavior of undergraduate students working as a group on

learning tasks in general, and even fewer in professional programs such as engineering. I plan to address this important gap in the current research by investigating how undergraduate students experience collaboration as they define their information needs, seek appropriate sources, search for information and use it in relation to their assigned learning tasks.

Methodologically, many of the studies of undergraduate students' information behavior are mainly quantitative, with data collected either through traditional closed-ended surveys or simulated lab-based experimental methods in which students are given a hypothesized topic to work on. Few studies have used in-depth qualitative methods that can empirically reveal the complexity of the process of undergraduate students' information seeking and use by taking into account all possible contextual and situational factors that may facilitate or constrain information behavior. Research in students' information behavior needs to be studied in a natural setting, as it may be deceptive to assume that we can draw reliable conclusions about human information behavior from lab-based experiments in, as Holt (1995) described them, limited, unusual, and often very anxious situations.

I have addressed these research gaps and limitations from previous studies by conducting my research in a naturalistic setting through a longitudinal study to understand the real experiences of students when they seek, search and use information for their learning tasks.

1.1.1 Research problem

To address these defined research gaps, the goal of this dissertation is to gain a conceptual understanding of undergraduate students' collaborative information behavior in engineering projects. Students are assigned learning tasks associated with real-world engineering projects in which actual engineering design issues need to be resolved. Engineering design projects examined in this study have the same characteristics as engineering design work tasks that have been investigated in many other studies of the information behavior of professional engineers. However, as an added dimension, my study of these undergraduate projects looks at those tasks required of students as they learn the design process while at the same time they develop a solution to the design problem.

The aim of the study is twofold: (1) to analyze the characteristics of the project as a learning task that affects the information behavior of engineering students, and (2) to understand the collaborative information behavior of students within the context of their project.

Thus, my main research question is:

> **What is the effect of assigned learning tasks associated with engineering design projects on students' collaborative information behavior?**

To answer this question, I need to understand both the characteristics of the learning tasks associated with real engineering projects and the corresponding nature of students' collaborative information behavior while pursuing these tasks. The main investigation was planned to find out the effect on students' collaborative information behavior of the engineering design project, as both a *thing* with characteristics and a *process*.

1.1.2 Research approach

I investigated collaborative information behavior in undergraduate engineering students at a Canadian university in two successive academic years through two different but related studies:

Study 1 was conducted through a web-based survey and analysis of students' deliverables in a group-based engineering design course after eight months and near the end of the academic year.

Study 2 was conducted in the consecutive year with a different cohort of students who were enrolled in the same course as those in Study 1. Data were collected through bimonthly semi-structured and in-depth interviews with each interviewee.

This research was designed as a qualitative research study (Denzin & Lincoln, 2005; Lincoln & Guba, 1985) that followed a constructivist approach using constructivist grounded theory (Bryant & Charmaz, 2011; Charmaz, 2006; Strauss & Corbin, 1990) as its methodology. Data analysis was based on inductive content analysis as originally described by Glaser and Strauss (1967) and later developed by Strauss and Corbin (1998) and Charmaz (2006) using the constant comparative method (Strauss & Corbin, 1994) to analyze and then categorize research data to create concepts that constitute an emerging theory.

During this study, I followed a constructivist approach to focus on the level of collaboration among individuals working in a group setting and who were actively and continually constructing their collaboration (Schmidt & Bannon, 1992; Sonnenwald, 1995). This was done to avoid two reductionisms that often occur in studies in the emerging area of collaborative information behavior as highlighted by Hertzum (2008, p. 961): (1) individual reductionism, when the study focuses on the individual, and collaboration is neglected or reduced to equal the sum of the individuals' activities, and (2) group reductionism, when the study focuses on the group as a unitary actor and collaboration is seen as a black box, thereby suggesting a smooth and near automatic process.

1.2 Dissertation structure

In this chapter the research problem, which investigates collaborative information behavior by students working on assigned engineering design projects, has been introduced. Table 1.1 details the rest of the dissertation's structure: (1) literature review, (2) research design, (3) results and findings, (4) further analysis of findings, and conclusions.

Table 1.1: Dissertation structure

Part	Chapters
Literature Review	2. Background
Research Methodology	3. Research design 4. Research conceptual framework
Results and Findings	5. The learning task dimension 6. The learner's knowledge dimension 7. The activity and interaction dimension 8. The information objects dimension
Further analysis of findings and conclusion	9. Bringing it together: A conceptual framework of collaborative information behavior
References and Appendices	

In the next chapter, I provide an extensive literature review of the main bodies of literature relevant to this dissertation.

2. BACKGROUND

This study belongs to the field of information science and more specifically to the area of information behavior, although it also intersects with research in such other disciplines as engineering education and the learning sciences. As described in the introductory chapter, the main research question focuses on the interaction between the characteristics of the engineering project as a learning task and students' collaborative information behavior. In this chapter, I begin with definitions of key research concepts followed by an overview of four main bodies of literature: (1) collaborative information behavior, (2) task-based information behavior research, (3) research on information behavior in engineering, and (4) project based learning tasks in engineering education.

The main focus of this chapter is to define research-related key concepts and to critically situate this study within the emerging research in collaborative information behavior that helped me to identify the salient characteristics of collaborative information behavior. The chapter also highlights gaps in the literature on collaborative information behavior in a variety of fields, and especially on undergraduate students' collaborative information behavior in assigned learning tasks. I also describe the information-science research that focuses on the information behavior of students in problem-based or project-based learning tasks.

2.1 Definition of key concepts

One of the challenges in information science is the variety of definitions available for commonly used key concepts in the literature. The difficulty of defining basic concepts in information science is noted by Vakkari (1997, p. 460), who argued that one of the striking features in many information studies is the use of central concepts without definitions. In support of his view, he gave an example in which the meaning of information as a basic concept in information studies is taken as a given concept and not explicitly defined in many studies. The purpose of this section is to provide definitions for five crucial concepts: (1) information, (2) information behavior, (3) collaborative information behavior, (4) context, and (5) situation. Other concepts will be defined in later sections as they are encountered in this study.

2.1.1 Information

Information is the first and the most difficult concept that needs to be defined. An earlier study described information as an "elusive and controversial concept that cannot be described as a singular concept, but as a series of concepts with complex relationships" (Yuexiao, 1988, p. 470). In a recent survey of research on information seeking, needs, and behaviors the author defined information as "any difference that makes a difference to a conscious, human mind" (Bateson, 1972, p. 453), adding that information is "what appears significant to a human being, whether originating from an external environment or a 'psychologically' internal world" (Case, 2007, p. 40).

According to Davis and Shaw (2011, p. 10), the different definitions of information are based on the perspective of whether information is held as an objective phenomenon (i.e. information-as-thing) or a subjective phenomenon (i.e. information-as-knowledge). Talja, Tuominen, and Savolainen (2005) explain how emerging approaches in information science research have reshaped definitions in the field. They reject the idea of information as an entity-like, objective, and natural informing brick; rather they identify information in the sense of its use:

> Information is not a pill an individual can swallow in order to become informed, but a plastic substance that can be shaped in many ways. An information user is not a passive information processing system but actively makes sense of the surrounding reality and attaches personal meaning to information. (p. 83).

In this dissertation, information is approached from a knowledge-based perspective as a subjective phenomenon; it is the result of the transformation of knowledge structures into information objects, when perceived and interpreted, and it affects and then transforms the interpreter's internal state of knowledge (Ingwersen & Järvelin, 2005). Information can be anything that can change a person's knowledge (Buckland, 1991), including any "objects in the world, what is transferred from people or objects to a person's cognitive system, and…the components of internal knowledge in people's minds" (Marchionini, 1995, p. 5).

2.1.2 Information behavior

Case (2006) reviewed the literature on information behavior published from 2001 to 2004 and identified more than 2,000 documents that are potentially relevant to information behavior. He noted that information behavior is a broad field that in its widest interpretation includes just about any paper that deals with information and people, and so he excluded items that were site-specific, system-specific, or service-specific (p. 294). He identified a framework to categorize the literature into the following areas: information seekers by occupation, information seekers by role, information seekers by demographics, and finally the theories and models of information seekers.

This work has been carried forward from 2004 until early 2008 by Fisher and Julien (2009). They defined information behavior as the area that "focuses on people's information needs, on how they seek, manage, and use information, both purposefully and passively, in various roles that comprise their everyday lives" (p. 317). They began their review by emphasizing *context*, which will be defined in the following section as a key variable in studying information behavior. Roles, occupation and demographics are subcategorized as human factors in information behavior research.

The impact of so many definitions of information behavior is reflected in the large number of developed theories. Fisher, Erdelez, and McKechnie (2005), for example, collected 72 different theories or models of information behavior. A very basic definition of information behavior as "how people need, seek, give and use information in different contexts" (Pettigrew & McKechnie, 2001, p. 44) is useful to define the constituents of information behavior.

However, this simple definition does not cover the complexity of the phenomenon under investigation in this study. I would rather follow Wilson

(2000): “the totality of human behavior in relation to sources and channels of information, including both active and passive information seeking and information use” (p. 49). This is further enhanced by Ingwersen and Järvelin (2005): ”human behavior dealing with generation, communication, use, and other activities concerned with information” (p. 21).

These two perspectives on information behavior are aligned with the objectives of this study. They each focus on human information behavior as both active information seeking (when users purposively and intentionally seek information) and passive information seeking (when users create a meaning from given or encountered information without intentionally seeking that information). Information seeking is the purposeful process that people engage in to change their state of knowledge, which can viewed as a fundamental human process that is mainly related to learning and problem solving (Marchionini, 1995, pp. 5-6).

Active and passive tendencies in information behavior are major considerations in studying collaborative information behavior in a learning task. The seeking and using of information include not only the acquisition of documents through a purposive activity but also the development of ideas, understandings and meanings from any information that was acquired by any member of the group. For example, in the case of a group member who has actively sought information and then shared that information object within the group, the remaining group members may use and incorporate this new information into their existing knowledge base even though they did not intentionally seek that information themselves.

2.1.3 Collaborative information behavior

Collaborative information behavior has been defined in different ways depending on the context in which it was investigated and studied. Various terminologies have been interchangeably used in studies of collaborative information behavior to include: *Collaborative Information Seeking* (Hertzum, 2008), *Collaborative Information Retrieval* (Hansen & Järvelin, 2005), *Collaborative Information Seeking & Retrieval* (Foster, 2006), *Collaborative Information Retrieval Behavior (Bruce et al., 2003), Collaborative Information Searching* (Morris & Horvitz, 2007), *Collaborative Web Searching* (Large, Beheshti, & Rahman, 2002), *Collaborative Information Synthesis* (Blake & Pratt, 2006), and recently as *Collaborative Information Behavior* (Reddy & Jansen, 2008). All these definitions emerged from research that focused on specific activities within groups. Of interest were a number of questions: how information users communicated their information need, how they collaborated to seek and search information, what tools they used for sharing the retrieved information, and how they coordinated the constituent information retrieval activities across multiple participants. Because it is the core phenomenon of this study, collaborative information behavior needs to be defined in this dissertation and the approach to it delineated.

In a study that focused on collaborative search in design teams, collaborative information retrieval was defined as “the activities that a group or team of people undertakes to identify and resolve a shared information need” (Poltrock et al., 2003, p. 243). This definition described collaborative search and retrieval even though it also describes information needs, seeking and use. Sonnenwald and Pierce (2000) described collaborative information behavior as the dynamic collaborative information activities of a group in which individuals must work together to seek, synthesize and disseminate information.

In a review of the literature on collaborative information seeking and retrieval, collaborative information behavior was inclusively defined as "the study of the *systems and practices* [emphasis added] that enable individuals to collaborate during the seeking, searching and retrieval of information" (Foster, 2006, p. 330). My research, however, focuses on human information behavior and not on collaborative tools, collaborative systems, collaborative web search, collaborative querying, or collaborative filtering.

Similarly collaborative information behavior was defined as "an activity where two or more actors communicate to identify information for accomplishing a task or solving a problem…[it] includes processes of problem identification, analysis of information need, query formulation, retrieval interactions, evaluation, presentation of results, and applying results to resolve an information problem" (Talja & Hansen, 2006, p. 114). This definition included both human cognitive aspects (problem definition, identification and analysis of information needs, and applying information to solve the problem) and technical aspects (using an information retrieval system, querying, and filtering results collaboratively).

Research in collaborative information behavior is still an emerging field; there is no specific entry for collaborative information behavior in the recent edition of the *Encyclopedia of Library and Information Sciences*, where its meaning overlaps that of collaborative information retrieval (Twidale & Nichols, 2009, p. 1081).

Karunakaran, Spence, and Reddy (2010) emphasized that a clear definition of collaborative information behavior needs to be agreed on within the research community. They suggested that current research in this area can be categorized into main streams: (1) *a technical stream* and (2) *a social stream*.

The technical stream included collaborative information searching and retrieval, collaborative web search and querying, and collaborative filtering. The social stream included problem definition and collaborative *sensemaking*, collaborative information seeking, encompassing collaborative information search and retrieval, and collaborative information use.

The study presented in this dissertation is situated within the social stream of collaborative information behavior; specifically it is a study of human collaborative information behavior guided by Wilson's definition of human information behavior. Thus, I have developed a working definition of collaborative information behavior to guide this study: *Collaborative information behavior is the totality of human behavior, when two or more people work together, in relation to sources and channels of information, including both active and passive information seeking and information use*. This working definition was based on Wilson's (2000) definition of information behavior discussed in the previous section.

2.1.4 Context

While there are many definitions of context in the literature, an early review of contextual approaches in information science concludes that that there is no term more often used, less often defined, and when defined, defined so variously as *context* (Dervin, 1997). The significance of context in information behavior studies is important: as Kuhlthau (1999) put it, "to neglect context is to ignore the basic motivation and impetus that drives the user in the information seeking process" (p. 10).

The concept of context is commonly used in information studies but defined differently from one study to another. Courtright (2007) reviewed the concept of context in information behavior studies that described the setting, environment, information world, life world, information use environment, and information ground. She described the challenges of defining and using context in information behavior research, pointing out that context appears in the research literature as largely amorphous and elusive. In the same study she tried to identify and discuss the main issues surrounding the understanding of context in the research area. A context can be understood by analyzing its boundaries, the elements that constitute it, its ontological status, its stability and its relation to information behavior.

Studies reviewed by Courtright (2007) show how difficult it is to include context as a research dimension given its dynamic and relational nature. She cites the multiple methods, including ethnographic observation and interviewing, used in the study of actors in context, as both examples of and keys to unlocking the complexity of context.

Context is generally considered background to whatever phenomenon researchers want to investigate and explain (Pettigrew, 1988). Talja, Keso, and Pietilainen (1999) have reviewed different approaches to context in information behavior research at the metatheoretical level. They identified and compared *objectified* and *interpretive* approaches to context.

In the objectified approach, context is seen to be an objective reality and information behavior as situational. In such an approach, research data are usually analyzed as facts of an existing objective reality. In this approach, data may consist of documents "which contain more or less truthful statements about what has happened in reality or about participants' experiences and cognitive processes" (Talja et al., 1999, p. 759). In the interpretive approach, context is that point where the researcher, inclined towards a particular theory, and the research data meet. So viewed, research data are analyzed as representations of a subjective reality and not just descriptions of facts.

2.1.5 Situation

As context has become a foundational concept in information behavior research, much has been said about situation as a concept related to context. According to Allen and Kim (2001), context is the "socially defined setting in which information users are found…. [W]ithin each of these contexts, different situations occur…. [I]ndividuals may be situated in different ways in the context" (pp. 1-2).

Sonnenwald and Lievrouw (1997) argued that context is larger than a situation; context may consist of a variety of situations just as different contexts may have different possible types of situations. In a review of situations in information science, situation was conceptualized as the *dynamic aspect of context* that constitutes a set of related activities (Cool, 2001). The review showed that in most cases, context and situation were used interchangeably and the definition of situation is not that clear. The review presented six perspectives including two that are related to this study: the concept of the *problematic situation*, and the *person-in-situation approach*.

One of the common approaches in information behavior studies is to understand the cognitive states that act as originators for information seeking activities. The problematic situation is an internal state wherein people recognize that their current knowledge is insufficient to solve the problem at hand. This problematic situation was modeled in the anomalous state of knowledge approach (Belkin, Oddy, & Brooks, 1982), and also in Dervin's Sense-Making approach that focuses on a situation that includes a cognitive gap representing the perceived lack of knowledge (Dervin, 1983).

The other approach in describing situations is Allen's person-in-situation approach (Allen, 1997). This approach models the situation where personal and situational variables interact to initiate information needs followed by information seeking and use. Allen's model will be detailed in section *2.2.1.2.*

2.2 Research in collaborative information behavior

The main phenomenon under investigation in this dissertation is the collaborative information behavior of engineering students, described in the previous chapter as an emerging area of research in which some conceptual models have been introduced but not yet empirically tested. In this section, I provide an overview of that research, on collaborative information behavior, related to the purpose of this study. In reviewing the literature in collaborative information behavior, I will start with conceptual models of individual information behavior. The main reason for reviewing the literature on individual information behavior in this chapter is that collaborative information behavior is a phenomenon that results from the collaboration of individual actors, as described by Schmidt and Bannon (1992), who are actively and continually constructing their collaboration.

Another reason for reviewing established conceptual models in information behavior is to position the conceptual model of collaborative information behavior and learning task developed at the end of this dissertation within research on information behavior, as there is no single well-established conceptual model so far that provides a clear understanding of collaborative information behavior.

2.2.1 Conceptual models of information behavior

All research has an underlying model of the phenomena it investigates that could be tacitly or explicitly assumed (Järvelin, 2007). These models are called conceptual frameworks (Engelbart, 1962), paradigms, conceptual models, or just models (Wilson, 1999).

Engelbart (1962) specified the components of any conceptual model: (1) the essential objects or components of the system to be studied; (2) the relationships of the objects that are recognized; (3) those changes in the objects or their relationships that affect the functioning of the system, and the ways such changes occur; and (4) the promising or fruitful goals and methods of research.

Conceptual models can be viewed as broad guidelines and methodological tools that are used to guide research by formulating hypotheses and theories. In information behavior there are many conceptual models that are implicit, unarticulated, yet socially shared, but still under construction, and they are not necessarily ready to be used as a theoretical background. However, these conceptual models can be investigated and tested further in different studies (Järvelin & Wilson, 2003).

Dervin (1999) noted that conceptual models can be used to release research from implicit assumptions and draw them into the daylight for examination. A conceptual model provides a working strategy for research by orienting the research methodology towards specific sets of research questions. A conceptual model cannot, however, be assessed separate from the empirically testable research questions and hypotheses it helps formulate (Järvelin & Wilson, 2003). A conceptual model can be assessed only in terms of its instrumental and heuristic value by evaluating the research strategies and the resulted theories it creates, and so if the substantial theories prove to be fertile, the conceptual model can be seen to be fertile too (Vakkari, 2003).

Järvelin and Wilson (2003) discussed the merits of various conceptual models in information behavior research and emphasized that waiting for substantial theories to emerge from frameworks takes time. They suggested two arguments as general scientific principles to be used to judge the merits of conceptual frameworks of information behavior: (1) the phenomena should be studied in all situations and especially under extreme conditions, and (2) the conceptual models should be limited in a meaningful way as a system of studying information behavior in particular contexts.

Conceptual models in information behavior are categorized as *summary frameworks* or *analytic frameworks* (Järvelin & Wilson, 2003). Summary frameworks provide overviews of the research domain and list factors that would affect the model; they can only provide suggestions of causative factors in information behavior. On the other hand, analytic frameworks provide more details about the complexity of the information behavior, including contextual and situational factors (Järvelin & Wilson, 2003). Conceptual models in information behaviors as represented in this section were selected based on their substantial theories being relevant to collaborative information behavior.

2.2.1.1 Dervin's Sense-Making approach

Dervin's Sense-Making approach has developed over many years as a research methodology in information behavior. This approach was introduced by Brenda Dervin into the field of Library and Information Science in 1972 (Tidline, 2005). The Sense-Making approach is a methodology that focuses on how individuals create meanings from the information they use in particular situations. Within this approach, information users are seen as active information seekers who construct their knowledge and do not act as passive receivers of information within situations in which they act (Hyldegård, 2006a).

Dervin introduced the Sense-Making approach to the field of information science not as a conceptual framework but as a set of assumptions, a theoretical perspective, a methodological approach, a set of research methods, or a human tool designed for making sense of a reality assumed to be both chaotic and orderly (Dervin & Foreman-Wernet, 2003). Sense-Making as an approach is used in capitalized letters to be distinguished from *sensemaking* that describes, according to Weick (1995), the activity of making and unmaking sense by constructing meaning and placing items into cognitive frameworks.

Dervin's Sense-Making approach relies on four dimensions: a *situation* (in time and space), a *gap*, a *bridge*, and an *outcome* (Dervin, 2003). The situation refers to the space-time contexts in which information problems arise and in which a sense is constructed; the gap identifies the difference between the contextual situation and the desired situation which can be seen as a knowledge gap that prevents people from moving forward; the outcome refers to the impact, the effect consequences of the Sense-Making process; while the bridge describes the experience that closes the gap between situation and outcome (Dervin & Foreman-Wernet, 2003). Dervin's Sense-Making approach focused on the dynamic nature of information behavior that changes in space and time and implies that human information behavior is always situational, based on the individual's cognitive knowledge gap. Figure 2.1 shows a metaphor of the relationships between the main components of Dervin's Sense-Making approach in which the arrows of space and time represent its dynamic nature.

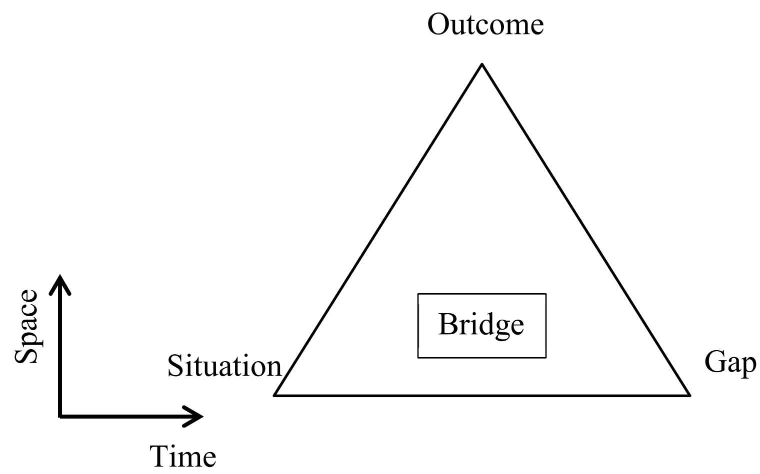


Figure 2.1: Dervin's Sense-Making approach

The gap in the Sense-Making approach that results in a cognitive state of knowledge in the information seeker is similar to what has been described by Belkin et al. (1982) as the anomalous state of knowledge (ASK) when an individual develops an information need when she/he does not possess sufficient knowledge to complete a task at hand.

Apart from developing this approach, Dervin (1992) has developed a guide to research methods in information behavior, with suggested methods for interviewing participants and framing questions for interviews. Dervin's Sense-Making approach has been used in different settings within myriad perspectives (Dervin, 2005), as a tool for metatheoretical critique, a methodology for research, a theory about communication and as a guide for communication design and practice, as well as a research tool (Tidline, 2005).

Dervin's Sense-Making is not an information behavior model but rather a model of a methodology to study information seeking and use (Wilson, 1999). It should be considered as a highly abstracted meta-theoretic tool rather than an exact picture of reality.

Although the Sense-Making approach is based on an individual user who is seeking meaning, the model can be expanded to cover collaborative aspects of information seeking given the dynamic influence of time, space, and situation. Further investigation of information behavior that followed Dervin's approach has found that individuals in some situations constitute social, organizational entities and these entities have been described as collectives (Dervin & Clark, 2003; Savolainen, 1993) .

2.2.1.2 Allen's person-in-situation behavior model

Allen (1997) developed the person-in-situation behavior model, according to which individual and social variables are combined into an integrated model, thus representing an integrated view of the individual's problem situation that may help to understand the *situated* individual group member. The purpose of this model was to extend information user studies that focused on occupational categories to include any groups of users who shared situations that generated information needs (Allen, 1997, p. 111). Although the focus of the model is on individuals' information needs, a unified and coherent understanding of information needs can only be obtained as researchers consider the *problem situations* that give rise to needs and the information-seeking behaviors that resolve those needs, in terms of interactions between personal and situational variables. The model was influenced by Dervin's Sense-Making approach, which drew attention to the situations in which information users found themselves and the ways these situations affected their information needs and information behavior.

According to this model, information needs are explanatory constructs that are determined by certain goals, purposes or objectives, explaining why people behave and act as they do. Information needs occur in many different situations and there are many ways that people experience information needs, given that "people are simultaneously individuals and members of groups" (Allen, 1997, p. 112). Allen distinguished two types of information needs: those that occur at the individual level and those that occur within groups of various kinds. Both types of needs are influenced by *personal* and *social* as well as *situational factors*.

Allen proposed a model (Figure 2.2), developed by Hyldegård (2006a), to describe how personal, social, and situational variables interact in generating information behavior. Such a model, he believed, should be integrated into studies of the information behavior of groups of users.

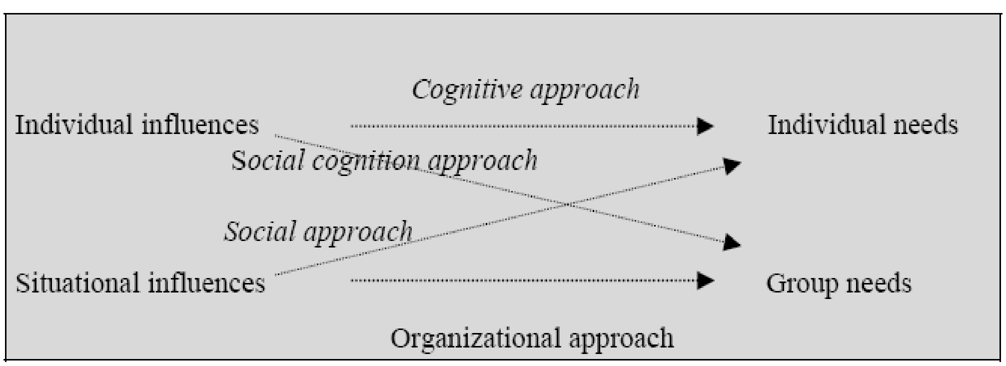


Figure 2.2: Allen's person-in-situation-behavior model

The four approaches to information needs in Allen's model are the *cognitive*, the *social*, the *social cognitive* and the *organizational*:

1. The cognitive approach describes the relation between individual influences and individual behavior. It seeks to explain behavior with respect to what people think and know, and the cognitive processes involved in thinking, learning and problem solving. In a later study, Pettigrew and McKechnie (2001) defined this cognitive approach in information behavior research as a set of constructs for understanding a phenomenon through fundamental focus upon the cognitive attributes of the individual.
2. The social approach describes the relation between social situational influences and individual behavior, emphasizing the social embedment of the process of defining and meeting needs. This approach is based on the fact that people are always embedded in social situations and it is sometimes difficult to distinguish clearly between those influences on information-seeking behavior that are individual and those that are social.
3. The social-cognitive approach describes the relation between individual influences and group behavior, and the collective nature of information needs. A group may have information needs that go beyond the individual information needs of its members, but group needs do not replace the individual needs; rather, group and individual needs are concurrent.

4. The organizational approach describes the relation between situational influences and group behavior, as a group may be influenced by its larger situational and social context.

Allen and Kim (2001) tested this model in three experiments with 48 undergraduate students using a bibliographic database as an information system and an assigned, imposed search task (Allen & Kim, 2001, p. 8). The findings of these experiments agreed with the proposed model, in that the information behavior of individual users is affected by inner cognitive influences and personal factors, but at a lower level also by situational interaction with others as they performed individual tasks.

Allen's integrated model of information behavior focused on the relationship between "the problem situations that gave rise to needs, and the information seeking behaviors that resolve those needs, in terms of interactions between personal and situational variables" (Allen, 1997, p. 121). Even though this model is based entirely on approaches of interaction in psychology, using laboratory based experiments and using entirely statistical methods, Allen's model still provides useful insights into collaborative information behavior as it identifies the four major approaches to particular situations.

2.2.1.3 Kuhlthau's Information Search Process (ISP) model

One of the commonly used models in information behavior studies is the Information Search Process (ISP) developed by Carol Kuhlthau. Based on a series of longitudinal studies, it looks at how secondary-school students perceive the process of seeking and using information in their course-related assignments. The developed ISP model has also been tested in other settings, with users in such professional work environments as securities analysis and the law. (Kuhlthau, 2004).

Kuhlthau's ISP model was influenced by many theories from other fields, particularly the psychology of learning, and mainly theories that view learning as a constructivist process. These included John Dewey's theory on acting and reflecting in learning (Dewey, 1933, 1944), the psychological perspectives of George Kelly's personal construct theory (Kelly, 1963), and Jerome Brunner's integrated perspective on learning and his theory of perception that focused on how people dynamically make sense of the world rather than being passive receivers of information. These borrowed theories, in addition to such other theories from library and information sciences as Dervin's Sense-Making approach, have resulted in the six-stage ISP model: initiation, selection, exploration, formulation, collection, closure, and presentation.

Figure 2.3 presents these six stages along with a description of possible associated feelings, thoughts and actions of information searchers throughout the process of information searching:

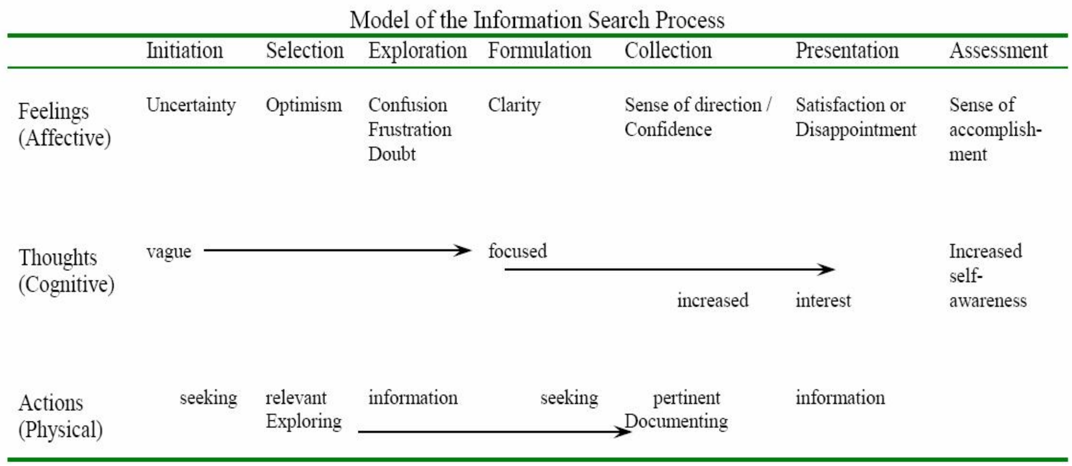


Figure 2.3: Kuhlthau's Information Search Process (ISP) Model

The model presents feelings, thoughts and actions that are inter-related in the information search process and, as the model indicates, the finding of a focus represents a turning point for the information seeker. Negative feelings start to decrease whereas positive feelings start to increase. Search activities also tend to decrease at this point, while writing activities tend to increase and finally replace the search activities in the presentation stage. Kuhlthau (2008, pp. 66-68) confirms that the ISP model should not be viewed as linear but as a model that constitutes sequential steps that may occur over a period of time; despite the neat division into stages, the movement from one stage to another takes place in spirals and is caused by a complex interplay between activities, thoughts and feelings.

The ISP model represents the process by which the seeker constructs meaning from sources of information: it links information search to *information impact*:

> From the user's perspective the primary objective of information seeking is to accomplish the task that initiated the search, not merely the collection of information as an end in itself. The impact of information is what the

> user is interested in and what motivates the information seeking (Kuhlthau, 2008, p. 68).

Thus, information impact is the user's perception of what information is needed and how this information will be used to accomplish the task that motivated the information search process. Kuhlthau has taken a constructive view of the information seeking process; she approached information seeking as part of information users' learning processes, and as being primarily concerned with how individuals find meaning. She described the interaction between learning and information seeking as:

> The individual is actively involved in finding meaning that fits in with what he or she already knows, which is not necessarily the same answer for everyone, but sense-making within a personal frame of reference. Information from various sources is assimilated into what is already known through a series of choices (Kuhlthau, 1991, p. 361).

The ISP model has been used as a framework for studies in information behavior of students (e.g., Holliday & Li, 2004; Kracker, 2002; Kracker & Wang, 2002; Todd, 2005; White, Dumais, & Teevan, 2009). While all these studies have focused on the information user as an individual, other research studies have used the ISP model to study information users as students working in groups for a learning assignment. For example, Limberg (1999) used the ISP model in studying the information behavior of senior high school students during their group-based assignments, and Hyldegård (2006b) studied the information behavior of graduate students in library and information science to find out if the ISP can be extended to group's information behavior.

By applying the ISP model to graduate students' information behavior, Hyldegård (2006a) found that contextual and social factors have affected group members´ activities and also their cognitive and emotional experiences during their group learning assignments. The study also showed that individual group members did not demonstrate similar behavior, indicating that groups cannot be perceived or modeled as *an individual entity*. Based on the results of this study, it was hypothesized that the learning task and its effect on students' performance is even more complicated when the task is solved in a group-based setting rather than being an individual task.

Kuhlthau's ISP model did not describe the actual use of information during the process. However, Kuhlthau described the information search process in her model as users always seeking meaning from the found information. This is reflected in the title of Kuhlthau's book, *Seeking Meaning*, as a description of the outcomes or the impact of the information-search process (Kuhlthau, 2004). Seeking meaning from information is then the main impact of the information found during the search process.

2.2.1.4 Ellis's behavioral model

Ellis (1989) identified eight different behavioral features that are associated with information search:

1. Starting: The means employed by the user to begin seeking information.
2. Chaining: The user follows footnotes and citations in known material or from known items through citation indexes.

3. Browsing: The user searches for information by semi-directed or semi-structured searching.
4. Differentiating: The user uses known differences in information sources as a way of filtering the amount of information obtained.
5. Monitoring: The user keeps up to date through current-awareness while searching.
6. Extracting: The user selectively identifies relevant material in an information source.
7. Verifying: The user checks the accuracy of information;
8. Ending: The user is tying up loose ends through a final search.

Ellis' model has been developed through empirical research of information behavior in such different fields as the physical and social sciences (Ellis, Cox, & Hall, 1993), engineering, and product development in an industrial environment (Ellis & Haugan, 1997).

Ellis' model is similar to Kuhlthau's ISP model in not including the situational and contextual aspects of information behavior, but Ellis (1989) confirmed that "the detailed interrelation or interaction of the features in any individual information seeking pattern will depend on the unique circumstances of the information seeking activities of the person concerned at that particular point in time" (p. 178). Ellis did not construct a conceptual framework for his model in a graphical format. Instead, Wilson (1999, p. 255) has developed a stage process version (Figure 2.4) of Ellis's behavioral model. The behavioral features do not necessarily take place in sequence and they may be initiated in different stages of the information search.

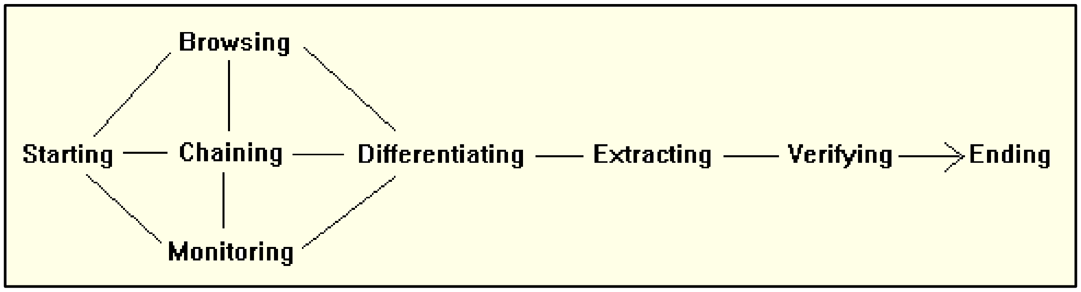


Figure 2.4: Ellis's information behavior model

In the same paper, Wilson explored whether the Ellis and Kuhlthau models could be bought together as one model. Wilson (1999, p. 256) developed an integrated model (Figure 2.5).

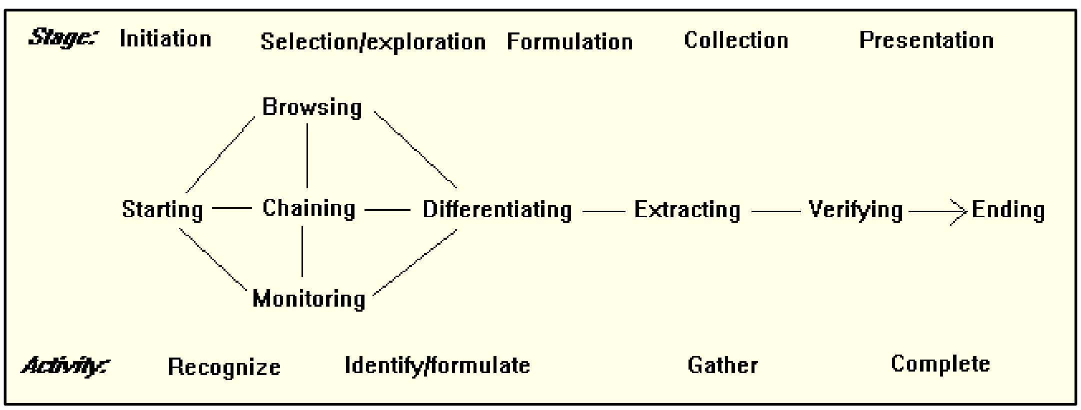


Figure 2.5: Integrated Ellis and Kuhlthau model

The compound model of Ellis and Kuhlthau reveals the complementary aspect of these two separate models. Wilson (1999) argues that differences in the two models are based on the different standpoints that Kuhlthau and Ellis took in developing their models. As Wilson put it, "the two models are fundamentally opposed in the minds of the authors: Kuhlthau posits stages on the basis of her analysis of behavior, while Ellis suggests that the sequences of behavioral characteristics may vary" (Wilson, 1999, p. 256). Ellis represented the behavioral features as elements of behavior that have no definite sequence for different information seekers or for the same person in different times. Ellis's conceptual framework did not include such contextual factors as the work task nor did it predict what situations might occur, as his model did not explicitly include any external factors.

2.2.1.5 Wilson's information behavior model

Wilson developed his models in information behavior based on his nested view of information behavior research (Figure 2.6). In this nested model, information behavior research includes human behavior that is associated with both information seeking behavior and information search behavior (Wilson, 1999, pp. 263-264).

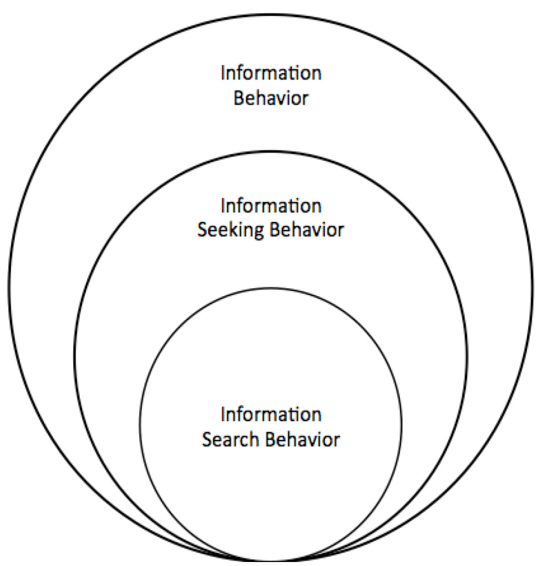


Figure 2.6: Wilson's nested model of information behavior

In this nested model, information seeking behavior is a subset of human information behavior, concerned with the possible and different methods people may use to determine and gain access to information resources. Information searching behavior is defined as that subset of information seeking behavior related to the interactions between information user (with or without an intermediary) and information systems.

Over many years, Wilson developed a general model of information behavior to frame an understanding of associated aspects of human information behavior. Wilson (1981) started to develop a framework of information seeking in a conceptual model. However, he described at that time how difficult it is to express and model the interactions of the complex real world in a single conceptual model. Wilson's 1981 model (Figure 2.7) situated the information seeker at the center of his or her life-world. The model described the interaction between the information seeker's personal needs (psychological, cognitive, and affective), the role of the information seeker (work role and performance level), and the environment (work, socio-cultural, politico-economic, and physical). The model also described *barriers* to the information seeker that he or she had to cross to achieve goals of information seeking.

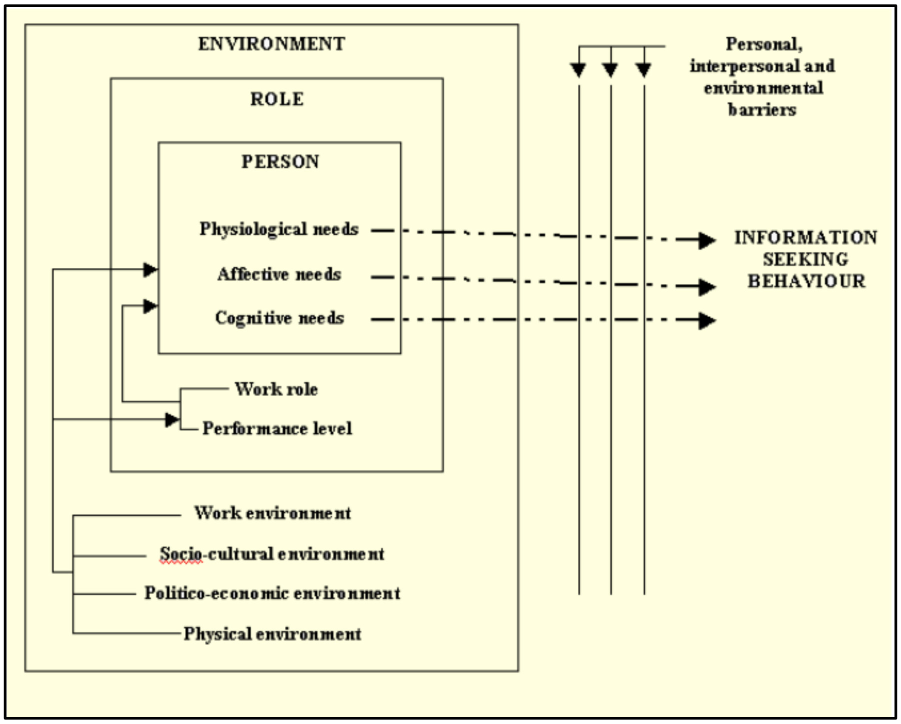


Figure 2.7: Wilson's 1981 information-seeking behavior model

Wilson described his developed model as a holistic picture of the information user. It focused on the human and social dimension of the information user, or as Wilson (1981) put it in describing his first model, "the individual would be perceived not merely as driven to seek information for cognitive ends, but as living and working in social settings which create their own motivations to seek information to help satisfy largely affective needs" (p. 12).

Wilson's information-seeking behavior model has included implicitly a set of hypotheses about the context of information behavior that can be studied. Wilson conceded later that the implicit inclusion of context was a weakness of his original model; it lacked any indication of the processes whereby context has its effect upon the person and the factors that resulted in the user's perception of different barriers (Wilson, 1999, p. 253).

Wilson has further developed other versions of his original model by integrating other developed models and findings in related studies in information behavior (Wilson, 1997). Figure 2.8 shows one of the modified versions of Wilson's 1981 model in which he has explicitly referred to the context of information need and the related behavioral features as described by Ellis.

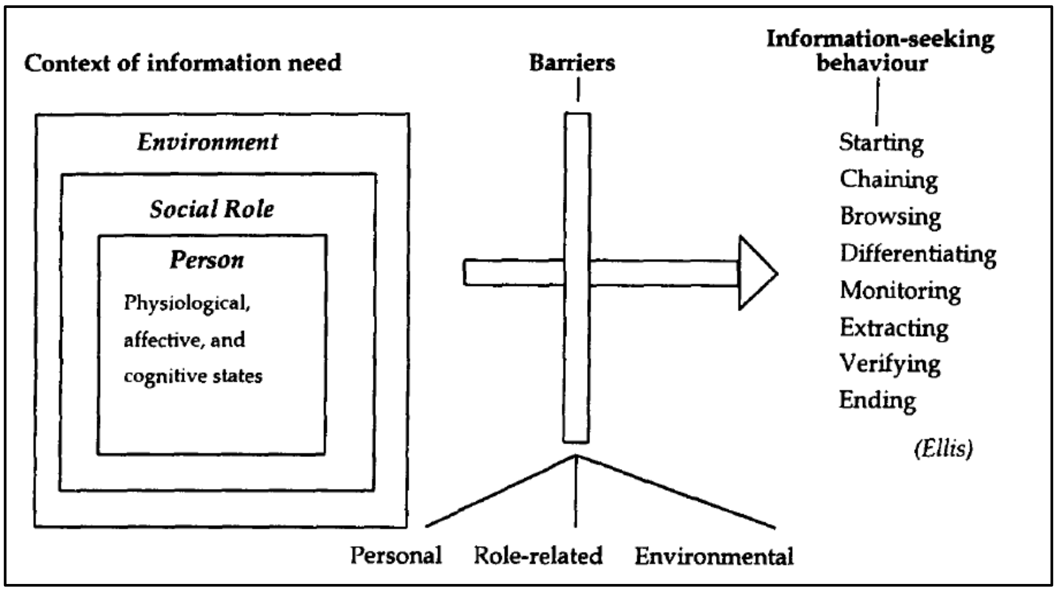


Figure 2.8: Wilson's 1997 information seeking behavior model

Wilson (2005) developed a more detailed model of information behavior that he described as the evolution of his information behavior model, drawing upon research from a variety of fields other than information science, including decision-making, psychology, innovation, health communication and consumer research. He pointed out how necessary it was to understand the relationships among the various diagrams and models leading to his general model of information behavior; thus, these should also be taken into account when using the model to guide the development of research ideas. In Wilson's view, the information behavior model (Figure 2.9) is one that shows behavior at a macrolevel rather than a model of a set of activities or a situation (Wilson, 1997, 2000, 2005) .

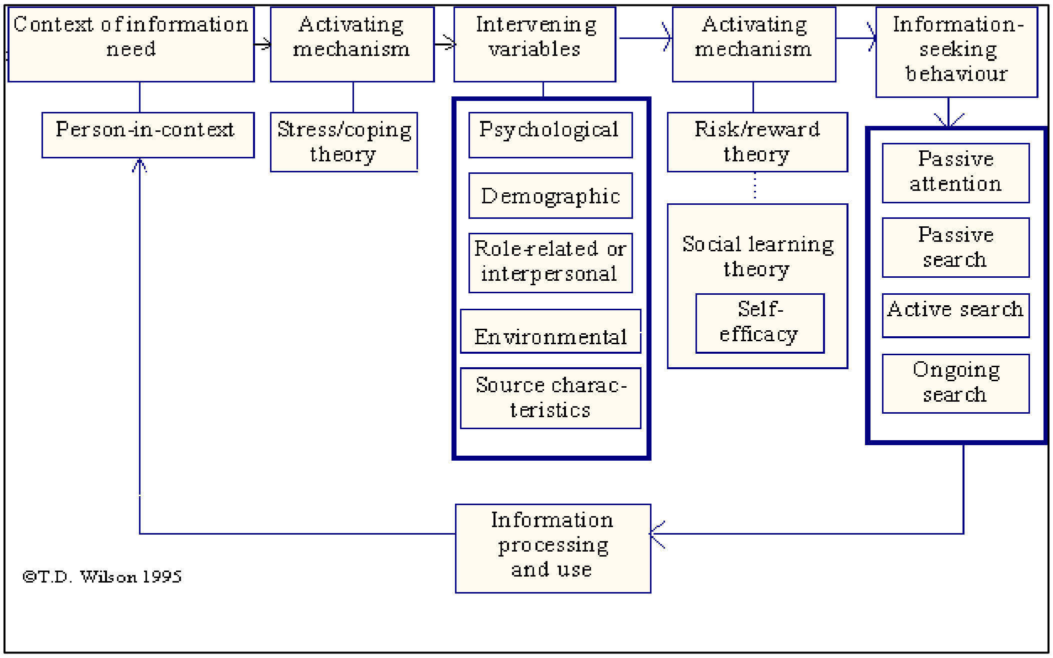


Figure 2.9: Wilson's information behavior model

According to the model, and also in accordance with his 1981-model, the *person in context* is the focus. Information-seeking behavior arises as a consequence of an information need perceived by a person. The context of (or factors influencing) any of these needs may be the *person* (the psychological and demographic characteristics), a *social role* due to the person's work or life, or the *environments* within which work or life takes place.

The model focused on information seeking behavior activities as results from various activating mechanisms and intervening variables. The form or strategies of information seeking behavior may be either *passive* or *active*, implying an information system (mediator or technology) or demands upon other sources (e.g. personal). According to this model, the passive seeking behavior is referred to *passive attention* and *passive search*, where the former mode means passive absorption of information from the environment, whereas the latter mode means those occasions when a particular type of behavior results in the purposeful acquisition of information that happen to be relevant to the individual.

The active seeking behavior covers *active search* and *ongoing search*, where the former mode takes place when a person actively seeks out information, and the latter mode takes place when a search is continuously carried out to update or expand the area of information. As demonstrated in the model, information searching related only to the active and targeted search elements in the model, implying interactions between information user and information sources.

Information processing and use, a feedback-loop element in Wilson's model, refers to that situation in which the information obtained by the user is processed and becomes part of the person's knowledge. At this point it may be used directly or indirectly to influence the environment and create new information needs. This approach can be seen here as similar to the seeking meaning approach in Kuhlthau's ISP model or the sensemaking approach in Dervin's Sense-Making approach.

Wilson has developed his model over many years and has guided many research studies into the information behavior of students (Brophy, 2001; Cole, 1998; Cole, Kennedy, & Carter, 1996; Heinstrom, 2005; Jamali & Nicholas, 2010; Kim & Sin, 2007; Korobili, Malliari, & Zapounidou, 2011; Limberg & Sundin, 2006; Stokes & Urquhart, 2011). Similar to the other conceptual models of information behavior in this section, the model is designed around the information user as an individual, but the notion of a *person in context* in this model can be aligned with Allen's person-in-situation model that includes a *group* in some situations. The inclusion of social learning theory as an activating mechanism made Wilson's model a recognized one in information behavior research because of its inclusion of personal, social, as well as environmental factors that affect human information behavior.

2.2.1.6 Taylor's Information Use Environment (IUE) model

Information use is one of the three principle elements of information behavior, along with information needs and information seeking (Wilson, 1999). It has already been noted that information use has not received much attention in the research literature compared to information seeking. Information use was viewed to be always related to information needs: information is needed and then it can be used. However, how information is actually applied to achieve the original goal that triggered information seeking is not usually researched (Bartlett & Toms, 2005b).

Taylor (1991, p. 218) proposed a model of the Information Use Environment (IUE) as a construct to relate the information user and the context of information use. IUE describes the elements that affect the flow and the use of information into, within, and out of any definable entity and to determine the criteria by which the value of information will be judged.

Taylor recognized that the framework is influenced by Dervin's Sense-Making approach (Dervin, 1983) and by Dervin and Nilan's review on information needs and use (Dervin & Nilan, 1986). The latter highlighted the need for a paradigm shift in information behavior research from system-centered user studies to focus on understanding information needs, seeking and use in context. Taylor anticipated that his model would serve as a bridge between (1) users and their environments, and (2) the world of the system designer, information manager, and those who really make the system work.

The IUE model has four main categories: (1) a set of people who share work or a setting with assumptions, preferences for various information channels and also attitudes about certain phenomena, (2) a realization that problems and their different dimensions and structures affect these sets of people in making decisions on the usefulness of information, (3) the setting's constraints and how they influence information need, seeking, and use, and (4) the approach to problem resolution and how it influences information behavior.

In his model, Taylor defined information behavior as the product of the four elements resulting from: (1) the interaction of users' assumptions about their task, (2) kinds and structures of the problems as perceived by users, (3) the constraints and opportunities of typical environments within which a set of people works, and (4) the conscious assumptions made about what constitutes a solution to the problem and what makes information useful and valuable in their context.

The IUE model was constructed around the notion that information, either oral or recorded, is sought within the context of recognized problems and concerns perceived by users to be relevant to their problems (Taylor, 1991, p. 220).

Information behavior as defined in the IUE model is the totality of *activities* through which information becomes *useful*: (1) activities that describe the active search resulting from an area of doubt that originated from a recognized problem, and (2) the *usefulness of information* that describes how users experience different ways to resolve a problem through clarification, alteration, or actual solution as a result of information retained.

The IUE is dynamic, changing in response to the appearance of new information, as people act and interact with information within a specific environment. IUE is the setting within which information is used; as Taylor (1986) put it:

> Tasks and problems are generated...The structure of the environment, in many complex ways determines what information is acceptable 'i.e., has value' for clarification, solution, or alteration of a problem, or for the accomplishment of a task. A message is then given value by a 'user' who sees its potential 'usefulness' because he or she is in a particular environment and can relate the message to the problems and tasks of the environment (Taylor, 1986, p. 15).

Choo (2006) used Taylor's IUE model as a framework to study the information behaviors of managers and describes the adaptability of Taylor's IUE model because of:

> The ways in which people view their problems and what they anticipate as resolution constitute a built-in though unconscious means of controlling the amount of information used. Thus, people's perceptions and anticipations indirectly control the breadth and depth of their information search…including the time and effort to spend on searching, where to

search, how information encountered is to be filtered, and how much and what kinds of information are required (Choo, 2006, p. 55).

Taylor (1991, p.230-231) proposed a taxonomy of classes of information use. These classes were derived from expressed needs in users' questions and not through empirical research or through discussion with users about their actual information need and the information's potential use. The classes of information use as perceived by users included:

1. Enlightenment: the desire for context information or ideas in order to make sense of a situation.
2. Problem understanding: Information is used for more specific and better comprehension of the perceived problem.
3. Instrumental: Information is used to find out what to do and how to do something.
4. Factual: Information is used to acquire precise data. Taylor described two contrarians to factual data to be the quality of the data and the user's perception of quality.
5. Confirmational: Information is used to verify a piece of information that was previously acquired.

Taylor studied three different information environments using the IUE model with an analysis of the IUE and included other information-related terms such as information gathering, information support technology, information transfer, and information systems.

The IUE model was further incorporated in other studies that included the use of information as a part of studying information behavior (e.g., Choo, 2006; Durrance, Souden, Walker, & Fisher, 2006; Kuhlthau, 2004; Rosenbaum, 1996).

In these studies, the IUE model provided a framework within which to examine information behaviors, highlighting information use and its impact on information behavior. The IUE model focuses on the actual use of information; information use is the main factor that may drive all information behavior related activities. Information use in this sense is a proponent to information impact as described by Kuhlthau (2008) as the definite purpose for which information is needed and sought.

The study of information use in isolation from information need does not lead to a comprehensive understanding of the information related processes (Bartlett & Toms, 2005a). Information behavior within a given information use environment is framed by the nature of the problems people are exposed to and what they consider to be possible resolutions to those problems, and is affected by the dimensions of a problem's structure, its complexity and underlying assumptions. The steps information users plan to take towards meeting their goal have an effect on what information is deemed to be useful.

2.2.1.7 The holistic cognitive model

Ingwersen and Järvelin (2005) developed a holistic cognitive framework for research in information behavior based on previous research. Their developed model reflects an understanding of information seeking and searching as a process involving various cognitive, emotional, and situational actors in context. The framework identifies five broad categories or dimensions, each with corresponding variables relating to information behavior (Ingwersen & Järvelin, 2005, pp. 313-314):

1. *The Organizational Task Dimension:* includes the work task or any non-job related tasks, collaboration, and the system environment.
2. *The Actor Dimension:* covers the information user's declarative knowledge and procedural skills, his/her perceived work task dimension
3. *The Information Object Dimension:* includes document genres and collections which may contain information relevant to the task as perceived by the actor.
4. *The Algorithmic Dimensions:* the algorithmic search-engine dimension along with the representation of documents.
5. *The Access and Interaction Dimension:* strategies of information access and the user's interaction within social and system contexts.

The developed holistic cognitive model (Figure 2.10) shows the complex relationship between these different dimensions, but it should be viewed as flexible, not static, in the sense that it opens up the study of many and different relationships, involving few or many components of this model.

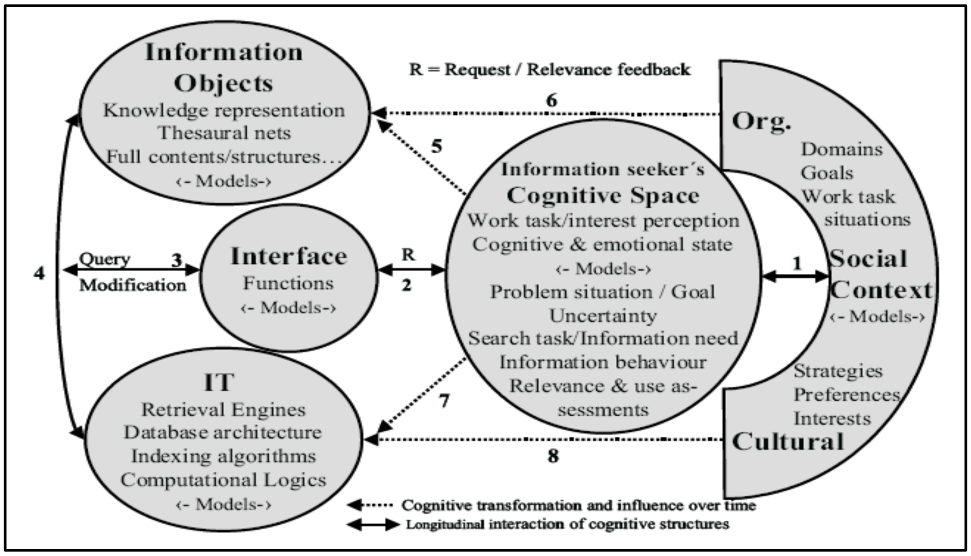


Figure 2.10: The holistic cognitive model of information behavior

The details of this holistic cognitive model are not included in this dissertation, but the model is included here as an example of the recent development in conceptual frameworks in the field of information behavior research. This model goes beyond traditional user studies by providing the main dimensions needed to be considered when researching information behavior.

2.2.1.8 Summary of information behavior conceptual models

The reviewed literature on conceptual models of information behavior constitutes a small part of the literature on information behavior I reviewed during the preparation of this dissertation. The conceptual models are those that have affected the design of my research, based on my original research question.

Dervin’s Sense-Making approach describes the information need as a gap that the user attempts to bridge in a specific situation, space, and time. Allen’s person-in-situation model describes the interaction between individual and situational influences on individual and group needs. Wilson’s model is more general and lists different variables that will affect information behavior, including the person in context and the distinction between active and passive information users. Kuhlthau and Ellis describe the process of active information seeking. The information search process as described by Kuhlthau is mainly used for seeking meaning from information. Taylor's IUE model focuses on the different ways that information use can happen in an information environment. Finally, the holistic framework clarifies the many dimensions that can be incorporated in information behavior research.

The previous models were based on the information user as an individual. Before reviewing the literature on collaborative information behavior, we need to define first what is meant by collaboration.

2.2.2 What is collaboration?

The collective aspects of information behavior have been little studied. The study of collaborative information behavior is a rather new approach still under development in information behavior studies. In his review of the literature on collaborative information seeking and retrieval, Foster (2006) noted that most of the research on collaborative information behavior did not focus on the nature of collaboration itself.

Talja and Hansen (2006, p. 116) have argued that researchers in collaborative information behavior "have not been interested in the dynamics of group work, the emergence and sustenance of collaborations, or human relationships within collaborative work processes" (p. 116). Rather, collaborative information behavior research has looked mainly at collaboration in the processes of information seeking, retrieval, filtering, and synthesis of information. Research in collaborative information behavior views collaborative information related activities as deeply embedded in many types of work and other kinds of everyday life practices.

Few researchers have defined what is meant by collaboration in their studies of collaborative information behavior. The literature shows that collaboration has been used intuitively and interchangeably with other terms such as coordination and cooperation (e.g., Hara, Solomon, Kim, & Sonnenwald, 2003; Shah, 2010). Margerum (2011, pp. 7-9) described collaboration as an approach to solving complex problems; it became a ubiquitous term because it is an umbrella concept incorporating many other aspects such as communication, coordination, and consultation. It is important to understand what collaboration is in order to identify those activities specific to collaborative information behavior.

Gray (1989, p. 5) described collaboration as "a process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible." In another definition, collaboration is "a mutually beneficial relationship between two or more parties working toward common goals by sharing responsibility, authority, and accountability for achieving results" (Chrislip & Larson, 1994, p. 5). Collaboration has also been called "the process of shared creation where two or more individuals with complementary skills are interacting to create a shared understanding that none had previously possessed or could have come to on their own" (Schrage, 1995). These definitions showed that there are many different perspectives when we look at collaboration, but all of them focus on the output of collaboration as a shared meaning or a shared understanding.

Surowiecki (2004) describes four conditions for a successful collaboration to occur:

1. Diversity of opinion: Each person should have some private information, even if it is just an eccentric interpretation of known facts.
2. Independence: People's opinions are not determined by the opinions of those around them.
3. Decentralization: People are able to specialize and draw on local knowledge.
4. Aggregation: Some mechanism exists for turning private judgments into a collective decision.

In an early study in collaborative information behavior, Iivonen, Sonnenwald, and Kraft (2000) defined collaboration in its relationship to information behavior as "[The] human behavior that facilitates the sharing of meaning and completion of activities with respect to a mutually shared superordinate goal and which takes place in a particular social, or work, setting" (p. 81). Sonnenwald (1995) introduced the concept of *contested collaboration* in collaborative information behavior to describe explicit and intended communication among team members in a work setting.

Another study (Hara et al., 2003) focusing on scientists' perspectives on scientific collaboration, concluded that collaboration can be seen as a continuum from *complementary collaboration* to *integrative collaboration*. In the case of complementary collaboration, some kind of division of a project occurs. When collaboration can be characterized as integrative, a fully integrated and shared project takes place. The study also identified several factors that affect collaboration and its potential to shift collaboration from complementary to integrative, of which compatibility was one of the most important. Complementary collaboration required personal compatibility with respect to work style, writing style, and work roles. Fully integrative collaboration required even more: compatibility in the approach to the work task and compatibility of personality. This often included personal friendship and the trust that comes with friendship. The other factors included work connections, incentive, and socio-technical infrastructures.

Aligned with the previous section of information behavior, the review of studies in collaboration showed that there can be many perspectives when collaborative information behavior is researched. These can include the reasons, purpose, benefit and outcomes of collaboration. The following section will describe the empirical research in collaborative information behavior.

2.2.3 Empirical studies in collaborative information behavior

The collaborative nature of information behavior has been studied in general (Foster, 2006), in specific domains such as patient care (Reddy & Jansen, 2008), design teams (Poltrock et al., 2003), or in education (Hyldegård, 2009). The focus of these studies has been to investigate the nature of collaborative information seeking in contrast to the contemporary models of information seeking which focused on the individual nature of information seekers.

The research methods applied in collaborative information behavior studies have varied from qualitative to quantitative to mixed-method approaches in real-world tasks or simulated scenarios. Hyldegård (2009) noted an increasing number of studies that focus on the social dimension of information behavior in real-world collaborative settings, but there are few studies in the field of information science which can provide empirical data about the process of collaborative information behavior compared to other research domains such as computer-supported collaborative work (CSCW) and social psychology (where group dynamics and behavior have a long tradition). The purpose of this section is to present some of the empirical research literature that focused on collaborative information behavior.

Allen (1977) identified the role of the *gatekeeper* in his study of the differences between the information seeking behavior of engineers and scientists. The gatekeeper, according to Allen, is the key person in a communication network who takes responsibility for locating information and sharing it with the group; the gatekeeper collaborates with the group to identify useful information. The study showed the importance of personal and social contacts in information seeking, and also showed some differences in information seeking behavior between engineers and scientists.

O'Day and Jeffries (1993) discussed sharing information and sharing search results within group situations; the study highlighted the role of information intermediaries and identified four levels of information sharing: (1) sharing results with other members of a team, (2) self-initiated broadcasting of interesting information, (3) acting as a consultant and handling search requests made by others, (4) archiving potentially useful information into group repositories.

Sonnenwald and Pierce (2000) studied information behavior qualitatively in a dynamic military work context of command and control, where they highlighted the phenomenon of *interwoven situational awareness,* defined as individual, intra-group and inter-group shared understanding of the situation. The study identifies the need for dense social networks of frequent communications between participants, the work task they are involved with and the situation. They noted a continuing necessity for information exchange during work operations.

Prekop (2002) explored the information behavior of military working groups in Australia. The research was a longitudinal qualitative study of the collaborative dimensions of information seeking behaviors observed by members of a working group. The researcher used two major types of data from the working group: the minutes of the working group's meetings, and semi-structured interviews with a sample of working group participants. The research identified three components as important within the collaborative information-seeking activity: (1) information seeking roles, (2) information seeking patterns, and (3) the contexts in which the roles and patterns are performed. Prekop also identified seven different information related roles that were explicitly assigned to project participants or informally adopted by them. The study resulted in a conceptual model describing the roles of users in collaborative information seeking as: information gatherer, information referrer, information verifier, information-seeking instigator, information indexer or abstracter, group administrator, and a group manager.

Information sharing as an activity in collaborative information behavior was further studied by Talja (2002) through empirical observation and interviews of 44 academic researchers in different domains about information sharing at both the research group level and the departmental level. The study resulted in identification of five types of information sharing: (1) strategic sharing, (2) paradigmatic sharing, (3) directive sharing, (4) social sharing and (5) non-sharing. While the study described information sharing as a collaborative activity, Hansen and Järvelin (2005) argued that sharing information is usually about sharing already acquired information, while collaborative information behavior deals mainly with searching for information.

Fidel, Pejtersen, Cleal, and Bruce (2004) conducted a large-scale study to explore collaborative information activities in a professional setting. The study investigated three professional teams: a software engineering design team at Microsoft, an aviation engineering project at Boeing, and a customer-service team at Boeing. The studies showed that collaborative activities took place when engineers were identifying, analyzing, and defining their information problems as well as when devising strategies for information-seeking; while the act of retrieval itself was generally performed individually, the collaborative activities were found to be highly affected by the work context.

The results were used to build a multidimensional approach to the study of human-information interaction when studying collaborative information behavior. The researchers used the Cognitive Work Analysis model that was originally developed by Vicente (1999). They relied on interviews and observations as the major techniques for data collection. They also reviewed team members' diaries and reports in addition to monitoring email threads as source of research data. The research suggested a multidimensional approach to studying collaborative information behavior activities as including: the cognitive dimension, the specific task dimension including the nature of the information sources and the nature of the needed information, the organization of the team's work dimension, and the organizational culture dimension. The analysis of information behavior through one interdependent dimension only is difficult, as focusing on a single dimension may provide a partial understanding and might be misleading. The researchers recommended that *explicit awareness of many dimensions can assure investigators that their analysis is comprehensive,* suggesting that the inclusion of various dimensions in information behavior can support a real understanding of the phenomenon under study.

Hansen and Järvelin (2000) investigated collaborative information retrieval in a work setting at the Swedish patent office, which was described by the authors as an information-intensive domain. Patent engineers were involved in different collaborative activities that are dependent on the tasks they work on.

Collaborative information seeking and use was found to dynamically occur among coworkers and also with different people in other organizations. Patent engineers were found to interact socially to acquire information without engaging in any explicit search activity.

The results of the study were further investigated in a second study (Hansen & Järvelin, 2005) in which the researchers focused on how collaborative activities manifest themselves and how frequent they are, when collaborative activities take place in information-seeking and retrieval processes, and what are the characteristics of collaborative activities. The study showed that collaborative activities can be identified and categorized in relationship to different stages of the information seeking and retrieval process.

One of the important issues identified in the previous studies is that collaborative information behavior is tightly interwoven with work and other mundane practices in such a way that it cannot be studied separately from them (Fidel et al., 2004). Any decontextualized approach to collaborative information behavior cannot provide an adequate understanding of the phenomenon of collaborative information behavior but yields only narrow findings that do not capture real-life practices (Hansen & Järvelin, 2005).

Reddy and Spence (2008) conducted an ethnographic field study of a multidisciplinary patient care team in an emergency department to identify the group's information needs and the situations that trigger collaborative information-seeking activities. The authors identified four triggers for collaborative information behavior activities: (1) complexity of information needs, (2) lack of immediately accessible information, (3) lack of domain expertise, and (4) fragmented information sources. The results were used to develop a model for collaborative behavior in context that links collaborative information behavior with individual information behavior. The developed conceptual model of collaborative information behavior is modeled along the axes of participant behavior, situational elements and contextual triggers (Reddy, Jansen, & Spence, 2010).

Hyldegård (2009) reported the findings from longitudinal studies exploring Kuhlthau's ISP model in a group-based academic setting. The research was part of a doctoral thesis (Hyldegård, 2006a) whose focus was on graduate students' activities and cognitive and emotional experiences during the task process of writing an assignment. The purpose of her study was to investigate if group members' collaborative information behavior would differ from the individual information seeker in the ISP model, and to what extent this behavior is influenced by contextual (e.g., a work task) and social (e.g., a group-based work) factors. The study showed that differences in information behavior were identified among group members as associated with contextual and social factors beyond the information search process.

The research objectives of these reviewed studies in collaborative information behavior were different. All of these studies attempted to build new approaches with respect to groups' information behavior. They did not use any pre-existing conceptual model of information behavior, except for Hyldegård (2006b) who investigated if Kuhlthau's ISP model could be extended to cover collaborative information behavior, and the study of Reddy and Spence (2008) that was guided by Wilson's information behavior model.

These studies in collaborative information behavior showed that research in this area cannot be performed independently of work domains, tasks, and everyday life environments in which information needs are embedded. Collaborative information related activities can therefore best be captured by naturalistic research that pays attention to the dynamic interplay of work practices and information practices that is situated in a real world context. Context has been identified to be a major dimension that needs to be highlighted in studying collaborative information behavior and cannot be isolated from the findings of studies. The following section describes how tasks as contextual factors have been integrated in the literature on task-based information behavior.

2.3 Task-based information behavior

Most of the literature in both individual and collaborative human information behavior has focused on the importance of including the task as a contextual aspect in information behavior studies. Tasks have drawn more and more attention to recent research in information science as a recognized factor in information seeking and use. For example, the previously reviewed literature of information behavior in engineering showed that the engineering project as the work task has been identified as a key factor of information behavior (e.g., Leckie et al., 1996; Sonnenwald & Pierce, 2000).

A task-based approach to information behavior studies examines the relationship between tasks and information seeking and search processes, as well as the task features and anticipated outcomes in a given context (Byström & Hansen, 2005; Vakkari, 2003). This perspective has started to be utilized in emerging work on collaborative information behavior (e.g. Reddy & Jansen, 2008; Sonnenwald & Pierce, 2000) to recognize the interplay of actors, environments and task demands in studying information behavior. The following section describes some definitions of tasks in information behavior studies.

2.3.1 Approaches to tasks in information behavior research

The concept of task and work tasks in information studies has been the scope of some studies (e.g., Byström & Järvelin, 1995; Byström, Sundin, & Limberg, 2006; Hyldegård & Ingwersen, 2007; Vakkari, 1999). Tasks have been broadly defined as "what someone does to achieve a goal" (Hackos & Redish, 1998, p. 56). Vakkari (2003) pointed out that defining the task and corresponding subtasks depends on the circumstances.

Work tasks have been described as the tasks that are driven by specific goals and requirement as well as consisting of one or more subtasks, as opposed to everyday-life tasks (Ingwersen & Järvelin, 2005). With such a definition, a work task has been described as being independent of the type of setting, whether professional or educational.

The influence of contextual aspects of tasks on information behavior has been described as the *task environment* or *the embedded task* of information seeking (Pirolli, 2007). The embedded task is a motivation to the user to seek information, and the outcomes of the information seeking will be evaluated by the user in relation to the expected outcomes for the embedded task. Wildemuth and

Hughes (2005) have recommended that embedded tasks should be the focus of information behavior studies rather than being a minor consideration because of the significant effect of task on information behavior.

Vakkari (2003) argued that tasks have been always described either as a process or a prior condition for information seeking but without characterization; many studies in information behavior started with the need for information as the starting point and not the underlying problem or the work task that in fact initiates the information seeking process. Tasks have been viewed as an important element of the context of information behavior (Cool & Spink, 2002; Freund, Toms, & Clarke, 2005). Byström and Hansen (2002, p. 240) argue that the context of tasks in information behavior has been always *vague and not well understood,* which made the resulting studies of information behavior in different contexts difficult to compare.

Berryman (2006) argued that there was always a need to develop a task structure in information behavior studies because tasks do not only associate with how users seek and use information but also constitute the basis for users' assessment of whether or not they have found enough information to use for their tasks.

Thus, it is crucial to include contextual and situational factors of the task when studying information behavior. Tasks not only lead users to look for information, but also affect the ways task performers seek and use information. The investigation of tasks in information behavior studies can lead researchers to identify main dimensions of the task to be included in information behavior studies as described in the following section.

2.3.2 Dimensions of tasks in information behavior research

Different approaches to tasks in information behavior studies have focused on the work task as a starting point in order to investigate its influences on users' information seeking and use (e.g., Byström, 2007; Byström & Hansen, 2002; Vakkari, 2003). Xie (2009) examined how different tasks have influenced users' information seeking strategies and also their selection of information types and sources. Kim and Soergel (2005) reviewed the literature of task-based information behavior and identified task characteristics that may impact information behavior. These included *intrinsic task characteristics*, *extrinsic task characteristics*, *task performer*, and *relationship between task and performer*.

Studies of task-based information behavior have mainly investigated the relationship between these variables and the types and number of information sources used and relevance judgments made. The following section will describe task complexity and task stages as two main dimensions in task-based information behavior research.

2.3.2.1 Task complexity

Task complexity has been approached from different perspectives in information studies. It was initially guided by findings from other research areas, particularly in psychology, management and organizational behavior.

Wood (1986) suggested that when studying, measuring, or calculating task complexity three types of factors should be included: (1) component complexity,

(2) coordinative complexity, and 3) dynamic complexity as a function of the total task complexity. Campbell (1988, p. 48) described the importance of two main perspectives when analyzing task complexity: (1) *objective task complexity* as characterized in the task and (2) the *subjective or perceived task complexity* by task performers.

Research in task-based information behavior defined tasks as subjective or objective. Objective tasks can be seen as external to the performer and have special characteristics that are independent of their performers, while subjective tasks are seen as internal to the performers and defined by them; this means that task performance is dependent on performer's understanding and comprehension of the task requirements.

According to Campbell (1988, p. 47), the objective task complexity can be classified into different characteristics of the task nature: simple, decision, judgment, problem, or a fuzzy task. Campbell also identifies four attributes of objective task complexity: multiple paths to tasks, multiple desired outcomes of tasks, conflicting interdependence among paths and desired outcomes, and uncertain or probabilistic links among paths and desired outcomes.

The use of an objective task complexity perspective in information studies views the information behavior of users in a complex task by viewing the task based on the objective task complexity. An example of the use of objective task complexity is to compare the information behavior of targeted expert versus novice users or among different user groups who perform the same task (e.g., Brand-Gruwel, Wopereis, & Vermetten, 2005; Hölscher & Strube, 2000; Hsieh-

Yee, 2001). Another example provided by Maynard and Hakel (1997) examined the effect of objective task complexity on task performance and determined the extent to which task complexity was operationalized through the amount of information that participants needed in order to complete their tasks.

Alternatively, subjective task complexity is a variable used to measure task performers' perceptions of the complexity of the task they perform depending on factors that can be personal, situational, or contextual. Thus, measuring subjective task complexity based on individual perception is more difficult than measuring objective task complexity based on the task nature and its characteristics.

Studies in information behavior that focused on the influence of subjective task complexity had different units of analysis such as information seeking behavior, information types and sources used, or information search strategies. Byström and Järvelin (1995, p. 194) measured subjective task complexity based on the task performer's point of view regarding a priori determinability of the task outcomes, uncertainty about the expected outcomes, the difficulty of the task process, and the required information to perform the task.

Bystrom and her colleagues (Blomgren, Vallo, & Byström, 2004; Byström, 1999, 2002, 2007; Byström & Järvelin, 1995) studied the relationship between task complexity, information types, information channels, and information sources by describing task-based information seeking as a problem-solving process consisting of needs analysis, selection of actions, the search process, and the evaluation of the results.

In one of their studies, Byström and Järvelin (1995) investigated the effects of subjective task complexity on information seeking and use. They found that these effects can be described as systematic or logical. In their research in the public administration sector, they found that as task complexity *increases*, (1) the complexity of information needed increases, (2) the needs for domain information and problem solving information increases, (3) the sharing of general-purpose sources (literature, personal collections, and people in particular) increases and that of problem and fact-oriented sources decreases, (4) the success of information seeking decreases, and (5) the internality of documentary sources decreases while that of people as sources increases.

In reviewing studies that focused on task complexity, it was found that task-based information seeking as a process depended on situational, personal, and organizational factors as well as the perceived task complexity. In a literature review of information seeking patterns of managers, work-related variables, including the nature and complexity of the tasks in addition to situational and organizational variables, have been found to determine managers' choice of information sources. Managers' information behavior was also found to be dependent on informational variables associated with information resources such as information sources availability and quality (de Alwis, Majid, & Chaudhry, 2006).

2.3.2.2 Task stages

Not all information related activities happen at one single point in the task; studies showed that information users go through different stages in order to achieve their tasks. Kuhlthau (2004) identified six stages in the information seeking processes: initiation, selection, exploration, formulation, collection, and presentation. She also specified physical actions, cognitive thoughts, and affective feelings that are related to these stages as detailed previously in section 2.2.1.3.

Vakkari (2003) identified three stages in task performance: pre-focus, formulation, and post-focus. While the pre-focus stage corresponds to Kuhlthau's initiation and selection, the post-focus stage associates with collection and presentation.

Byström and Hansen (2005) developed a conceptual framework for tasks in information studies that describes three main interrelated stages: *task construction*, *task performance* and *task completion.* Each task stage can include multiple subtasks: information seeking tasks and information search tasks are subtasks of the main task and they dynamically change in different task stages.

Within these three task stages, three main types of information have been identified: task specific information, domain information, and task solving information. Tasks often have different kinds of subtasks in different stages and these stages may differ in their complexity and then in their information requirements (Ingwersen & Järvelin, 2005).

2.3.3 Learning tasks in information behavior studies

A learning task is defined as a teacher-designed but a learner-centered activity that focuses on a specific area of knowledge that is purposefully designed to help the learner to achieve specified learning outcomes by active interaction with the available learning resources (Tanni & Sormunen, 2008, p. 895). Learning tasks range from simple exercises and essay writings that require gathering information about a given topic, to complex projects where learners need to identify and define a problem before developing a solution to it (Ford, 2004).

Learning tasks can be generally described as work tasks for the students in an educational setting, but they may differ from work tasks that have been studied in the literature of library and information science that targeted the work tasks of professional groups (e.g., Allen & Wilson, 2003; Leckie et al., 1996; Li, 2009; Serola, 2006). Learning tasks designed by the teacher could have similar features to professional work tasks, but they differ in having embedded learning outcomes (Limberg, 2005).

In a learning task, students have to develop a solution to a given problem or to write about a topic over an extended period of time. Students may pursue their own ways of investigation that require them to identify what information is important to them, to construct new meanings, and to explain their new understandings through predefined stages in their learning tasks (Eskola, 2005; Kuhlthau, 2004; Limberg, 2007).

Learning tasks are initiated by a learning assignment that is introduced to students to incorporate a description of the whole process of the required task. This assignment defines the requirements for the final documentary or presentational product of the task (McGregor & Streitenberger, 2004).

Limberg (2007) considered that the inclusion of learning task is highly connected to information seeking in the context of learning. She described learning tasks as similar to other tasks in that they have a beginning and end as well as specific goals to be accomplished throughout the task. She identified two particular conditions that were found to affect information seeking during learning tasks in formal education: (1) the tasks are always imposed, and (2) learning tasks are always related to the intended learning outcomes of various contents and abilities.

Vakkari (2003) called for more attention to the features of learning tasks in studies of the information behavior of students, as the purpose of information seeking and use has been neglected in many research studies of students' information behavior. Limberg (2005) investigated students' conceptions of information seeking in their learning assignments and defined three major emerging conceptions of information seeking based on students' experience: information seeking as fact finding, information seeking as balancing different pieces of information in order to choose the right one, and information seeking as analyzing and scrutinizing for understanding complex issues in the assigned learning task.

Pitts (1994) investigated students' use of information while they were engaged in a science assignment and discovered that it was impossible to examine the students' use of information without including other aspects of their learning assignment into the study. She identified aspects of learning and how they are constantly intertwined with the information seeking process. Limberg (2005) carried out a study of high school students engaged in group projects, focusing on how groups of students working on a group project selected sources and dealt with information sources. She concluded that when a consensus was reached within a group on the information sources relevant to a topic it led to a reduced critical analysis of the project topic.

In higher education, Eskola (2005) studied the information behavior of undergraduate students in both problem-based learning and traditional lecture-based learning. She found that students in problem-based learning faced challenging tasks that required them to collaborate and to look extensively for information from various resources and to think critically about evaluating information sources.

Dodd (2007) reviewed the literature of problem-based learning and its impact on undergraduate students' information behavior; he found that students used more self-selected information resources than in other courses when the sources were mainly recommended by the teacher. The study also showed that time restrictions were a major factor that affected students' information behavior.

O'Farrell and Bates (2009) reported on a study of information behavior of undergraduate and graduate students during group projects using an online survey. They found that the sharing of information sources was perceived as a factor in the success of the project, but students had difficulties determining the relevance of information among the group members.

Foster (2009) used discourse analysis to study information seeking and use of undergraduate students by conducting a time-based group investigation of students' information behavior in their assigned group topics. The study showed that information sharing was an influencing factor in creating a shared focus in the group and that the establishment of an agreed focus among group members was a key towards effective collaboration on the task.

In a longitudinal study, Vakkari and Hakala (2000) explored how changes in problem stages affected changes in relevance criteria during the task-performance process. They identified a relationship between a changing understanding of task and how information users judged the relevance of documents. Vakkari, Pennanen, and Serola (2003) reported how they used Kuhlthau's ISP model as a basis to investigate how the stages of task performance were related to the ISP model stages in a longitudinal study of 11 graduate students preparing a research proposal for their thesis. The study showed a close connection between the students' problem stages in task performance and the information sought. There were also variations in information seeking due to task related factors. The study also showed that types of information sources changed according to the different stages of the learning task.

Todd (2005) studied how learners transform information into personal knowledge by analyzing the development of their knowledge in terms of content, number and structure of relational statements that the learners made on their topics. The major conclusion was that the statements represented development of topical knowledge in two distinctive patterns: (1) the additive approach characterized the progressive acquisition of facts, and (2) the integrative approach characterized a pattern focusing on explanations and results rather than descriptions of facts.

Kuhlthau (2004, p. 58) described the outcome of the information-seeking process as learning; the information user's process of learning from information should be recognized as an important element in information behavior: "in neglecting learning in information seeking, researchers should be aware of a critical gap in the theoretical foundations of information science research" (p. 189).

Limberg (2005) argued that learners who hold a certain conception of information seeking and use have developed learning outcomes corresponding to that conception, recommending further studies on the interactive relationship between learners' understanding of subject content and their experience of information seeking.

Sundin and Johannisson (2005, p. 107) related the inclusion of task in information behavior studies to the traditional question in information science: for what purpose is information sought? The answer is that information seeking is not carried out for its own sake but to achieve an objective that lies beyond the practice of information seeking itself.

In learning tasks, learning is the primary goal of students' information seeking and use. Students' activities in information seeking and use should be studied, analyzed, and then interpreted in the context of their learning tasks as these activities contribute to their learning in these assigned tasks (Chung & Neuman, 2007).

Limberg (1999) described information behavior in learning tasks as the interaction between the two phenomena of information behavior and learning.

Students' conceptions of information seeking and use are not independent of the content of the information used. She concluded that students' conceptions of the content of information sources have strongly influenced both information seeking and use in the learning process and that interaction between information behavior and learning is primarily influenced by the use of information. She identified three important aspects of information as related to students' learning: (1) students' conceptions of relevance criteria of the found information; (2) determining when the found information is enough; and (3) determining the bias of the found information.

In this dissertation, I approached learning as described by Mayer (2002), being a process that leads to change in knowledge, beliefs, behaviors, or attitude. This change occurs as a result of experience and increases the potential for improved performance and future learning. The reviewed literature that studied learning tasks in information behavior studies have called for more empirical research that looks at the process of constructing meaning from information sources in learning and determines how this meaning is related to the learning task itself. This dissertation is an attempt to fill this gap in the research on information behavior in learning tasks by investigating the relationship between the learning task and students' information behavior in a natural setting using a longitudinal study.

2.4 Information behavior research in engineering

Over the last five decades, a tremendous amount of research has focused on the ways that engineers as a group of professionals seek and use information in their work tasks (Allen, 1977; Gralewska-Vickery, 1976; King, Casto, & Jones, 1994; Nelson & Pollock, 1970; Pinelli, Bishop, Barclay, & Kennedy, 1993; Pinelli, Bishop, Barclay, & Kennedy, 2009; Taylor, 1991). Tenopir and King (2004) argued that the nature of performed tasks in engineering design projects make engineers "some of the heaviest users of information" (p. 44).

Among this body of research, studies have identified the factors that affect the information behavior of engineers. These include such parameters as the accessibility of information sources (Bruce et al., 2003; Fidel & Green, 2004), the quality of information sources (Sonnenwald, 1995), the types of information sources (Carstensen, 1997), the levels of education and the nature of the work itself (Kwasitsu, 2003), the cost of information seeking (Gerstberger & Allen, 1968), and the preference of engineers to approach people as information channels rather than use documentary sources (Hertzum & Pejtersen, 2000).

A comprehensive literature review of engineers' information needs, seeking, and use was initiated by King et al. (1994) and carried forward a decade later by Tenopir and King (2004). These two comprehensive reviews showed that availability, cost, and the proximity of information channels were key factors for engineers to select where to get information, especially in private and corporate environments. Engineers in academic and research settings also share the same tendencies, but they use more academic and scholarly journals as they are aware of their availability to them through their libraries. The study was continued by Allard et al. (2009) to study information use in innovative high technology firms in the United States and India. Within the frameworks of previous research in engineers' information behavior, they found the same recurring themes as previous research, including: the tendency of engineers to rely on their internal communications, documents, and information from colleagues; the effect of cost of information; and ease of access to information. The study showed that web-based search engines and internet-based resources have created a shift in engineers' information behavior, but it was noticed that engineers did not often address the quality and trustworthiness of the found information (p. 454). The study also found out that engineers spent about one fourth of their work day engaged in some type of information seeking and use: this is less than what was identified in previous research (e.g., Cave & Noble, 1986; Christian & Seering, 1995; Lowe, McMahon, & Culley, 2004). One reason for this decrease in time may be the development of and significant changes to information environments available through the Internet.

Studies in engineering tasks showed that information behavior is a result of a complex interaction among different variables (Leckie et al., 1996, p. 167). One of the common findings that always distinguished engineers' information behavior is that engineers always prefer to get most of their information from colleagues and from internal reports. Court (1997) explained this preference as a time-saving approach while Gerstberger and Allen (1968) suggested that this tendency is indicative of engineers' preference for the least needed effort. Hertzum and Pejtersen (2000) argued that engineers prefer to seek information from their colleagues because the available technical information in documents only contains technical solutions and results and does not include the context of the design process, something that is not often documented. On the other hand, Veshosky (1998) believes that engineers prefer to use internal documents and approach colleagues for information because engineering design projects are always context-specific and often involve proprietary information that is not available outside the work environment.

The information needs of engineers and their use of information sources were also found to vary according to career stage, from entry level engineers to junior and then senior engineers. Entry level and junior engineers were found to prefer approaching colleagues to get assistance or directions on possible ways to acquire the needed information for their tasks, while senior engineers preferred the use of documentary information sources, especially the sources they had used in the past (Cheuk & Dervin, 1999; Gralewska-Vickery, 1976).

Studies of engineers' information behavior have been extended to investigate the collaborative nature of information seeking and use in particular engineering work tasks (e.g., Bruce et al., 2003; Button & Sharrock, 1996; Fidel et al., 2004; Hansen & Järvelin, 2005; Potts & Catledge, 1996; Prekop, 2002). These studies showed that engineering tasks, particularly in design and product development, often require a high level of collaboration that includes related activities in collaborative information seeking and use. Sonnenwald (1996) investigated possible roles that engineers take in engineering design processes and found that designers assume several roles that dynamically change during the design process.

Leckie et al. (1996) studied and modeled the information seeking behavior of engineers as a group of professional workers. The approaches taken by engineers to seek information are directly impacted by their awareness of information sources. Although Leckie at al.'s study was not intended to be directly applicable to students in engineering programs, the model identified the role of professional students as a group of professionals that may have specific tasks, such as giving professional readings, or learning opportunities, as in conferences and meetings (Leckie et al., 1996, p. 182). This model of information seeking by professionals has been used as the framework of a study of the information behavior of engineering students in their final university year who were interviewed about their information seeking in their engineering projects. The study found many similarities between the information behaviors of engineering students and those of professional engineers (Kerins, Madden, & Fulton, 2004).

Most of the studies of the information behavior of engineering students have been of groups of undergraduate students exhibiting general information behavior trends common among different academic disciplines (Kim & Sin, 2007; Rowley & Urquhart, 2007). A limited number of studies, such as Li and Baer (2009), have looked at engineering students as a particular group focused on the use of subscribed library information sources as opposed to free online tools. Kerins et al. (2004) compared the information behavior of engineering students to what was known about the information behavior of professional engineers.

Other studies of the information behavior of engineering students were conducted by engineering librarians to investigate the use of library collections, tools, or services (e.g., Finn & Johnston, 2004; Haglund & Olsson, 2008; Napp, 2004) or the impact of library instruction on students' learning in engineering programs (e.g., Ercegovac, 2009; Oxnam, 2003).

Julien (2009, p. 5063) claimed that disciplinary differences among undergraduate students are not often seen as sharply as those observed among different disciplinary groupings of scholars and scientists, and that students' information behavior in different disciplines is more similar than different. In contrast to Julien's claim, Whitmire (2004) investigated disciplinary differences and their influences on undergraduates' information behavior. The study used Bilgan's typology of academic disciplines (Biglan, 1973a, 1973b) that classified academic disciplines along three dimensions: the first is based on the level of discipline paradigm development (hard or soft), the second on the practical application of the discipline (pure or applied), and the third on the degree of involvement with living or organic objects of study (life or nonlife). According to that model, engineering has been classified as a hard, applied, and nonlife discipline. Whitmire (2004, p. 637) concluded that these categories represented the three dimensions in which undergraduate students were engaged in the least number of information seeking activities. According to this finding, engineering students were found to belong to a category that undertakes fewer information seeking activities compared to other disciplines.

The previous studies of the information behavior of engineering students were found to cover a limited number of variables that may affect the information behavior of engineering students without relating students' information behavior to the context of engineering courses or the learning tasks they perform. Also these studies did not address the information behavior of engineering students in group-based learning tasks in which students have to work in groups to perform a particular task.

2.5 Project-based learning in engineering education

Engineering has been traditionally called an applied science, as the main responsibility of engineers was primarily seen as the creation or the development of products and technologies (Tenopir & King, 2004, p. 37). One of the objectives of engineering is to apply ideas and science for the common good; engineering is an essentially social and collaborative process that makes observations of the physical world and products that can be used by others (Pinelli et al., 2009). Engineering is a "decision-making process…in which basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective" (ABET, 2012, p. 2). Engineers solve problems and make decisions by connecting pieces of knowledge and technology to synthesize new products, systems, and services (Sheppard, Macatangay, Colby, & Sullivan, 2009, p. 3).

Engineering is a context-based profession in which engineers apply their knowledge and competences as needed in different professional situations. Thus, engineers always scope, generate, evaluate, and realize ideas in different contexts and work environments (Sheppard, 2003).

Post World War II, the rapid pace of technological innovation and the interconnected global economy reshaped the practice of engineering, especially as technology became a significant presence in everyday lives. Consequently, engineering knowledge became no longer limited to the traditional combination of science, mathematics, and technical skill, but expanded to include economic, social and environmental theory and information.

The skills required of an engineer grew in number and became increasingly complex. Engineers now had to have strong analytical ability, practical ingenuity, creativity and excellent communication in the areas of business management and leadership, exhibiting high ethical standards, professionalism, dynamism, agility, resilience, flexibility, and a commitment to lifelong learning (National Academy of Engineering, 2004).

These recent changes in the nature of engineering have affected engineering programs in higher education. Engineering education is profession-based and profession-driven, through which impetus students are prepared for their profession by meeting the expectations of different employers (see, Felder & Brent, 2003; National Academy of Engineering, 2005).

As a result, engineering education programs have challenged the traditional educational lecture-based approach by introducing more courses that are designed as problem-based or project-based. The transition from strictly traditional approaches in engineering education represented significant opportunities for change by implementing project-based learning to create a learning environment to provide students with the possibility of achieving sustainable and transferable skills, while at the same time exposing them to the complexities of work related issues (Kolmos, 2006).

In many countries, engineering education, as profession-based educational programs, must meet criteria established by national accreditation bodies. For example, the Engineering Accreditation Board in the United Kingdom (EAB, 2010), the American Bureau of Engineering and Technology in the United States (ABET, 2012), and the Canadian Accreditation Engineering Bureau in Canada (CEAB, 2011) establish criteria for engineering programs in these countries to follow and to meet before they can offer accredited degrees in engineering.

In Canada, the accreditation criteria for engineering comprises 12 attributes and competences that graduates of engineering programs should demonstrate at the end of their educational program: a minimum knowledge base of engineering, problem solving, communication skills, professionalism, economics and project management, impact of engineering on society and the environment, use of engineering tools, ethics and equity, individual and team work, investigation, lifelong learning, and design (CEAB, 2011, pp. 12-13).

Engineers are mainly involved with design as an integral practice of their profession. Engineering designs often start in response to a particular situation, sometimes an already defined problem to which they must provide a solution. Dym, Agogino, Eris, Frey, and Leifer (2005) described engineering design as “a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" (p. 103). In engineering design projects, engineers often respond to typically ill-defined problems that could have many acceptable solutions. In many engineering projects, the development of a solution to an engineering design problem cannot normally be found by routinely applying a mathematical formula in a structured way without a clear understanding of the project objectives and its environment (Dym & Little, 2008).

Engineering design, an engineering competency, is one of the core aspects of engineering educational programs. Design is addressed in both traditional lecture-based courses and in dedicated project-based courses that require students to work on design projects that always involve significant technical and intellectual challenges to integrate their engineering understanding, knowledge and skills to the solution of real problems. Design-based courses are offered mainly in the final year of a university program, providing students with different simulated or real-world projects. These projects act as the gateway through which students pass from their academic professional program to their professional practice. Many programs have preferred to partner with industry and the community to provide real-world projects, enabling students to gain a real work experience during their academic course rather than learning from simulated or hypothetical projects (Dutson, Todd, Magleby, & Sorensen, 1997; Dym et al., 2005; Todd, Magleby, Sorensen, Swan, & Anthony, 1995).

An engineering design-based course in the final year of the program is often called a *capstone* to distinguish it from other design-based courses that are offered in the first year of the program as *cornerstone* courses or in the middle years of the program as *foundational* courses. Meyer (2008) described the capstone experience in engineering education as "the transition from students of theory to practicing engineers" (p. 286). It is in this setting that students begin to truly understand the relationships between different aspects of their chosen engineering disciplines, as well as the necessary balance between scientific theory and design practice. In the same chapter, he added that the capstone experience introduces students to the messiness of the real world that always challenges professional engineers.

Project-based learning is driven by authentic project work, organized around disciplinary and interdisciplinary design problems, presented in a student-centered environment to small groups of students, with the teacher acting as a facilitator. The learning environment is student-centered, active, cooperative, and allows a better opportunity to take account of personal learning preferences (de Graaff & Kolmos, 2007; Prince & Felder, 2006).

Project-based learning is entirely aligned with the constructivist paradigm in learning as students make decisions about constructing new knowledge based on their existing knowledge background, expectations, and interest in a real-life context with all of its uncertainty and complexity (de Graaff & Kolmos, 2003).

To avoid ambiguity when referring to project-based learning and problem-based learning, I approached project-based learning as a subset of problem-based learning. They have many similarities. In fact, some researchers argue that problem-based learning and project-based learning can be seen as the same pedagogical approach (Boud, 1985). Prince and Felder (2006) defined project-based learning as the use of a learning assignment to carry out one or more tasks that lead to the production of a final product such as a design, a model, a device or a computer simulation. Therefore, project-based learning is similar to problem-based learning in several aspects as they both involve teams of students in open ended assignments that resemble the challenges and problems those students will face as professional engineers.

Project-based learning is an approach to learning rather than a teaching technique. As the project encompasses several problems that require students to create or develop a solution at the end of the project, emphasis is placed on self-regulated learning. This encourages students to be open-minded and reflective, to develop critical and active learning skills, to apply and integrate their prior knowledge, and also to acquire new knowledge that helps them resolve the project's problem. This real-world-problem approach makes the knowledge relevant and can increase the transfer of knowledge and skills from academic courses to the real world (Bransford, 2000). This is an essential component of engineering competency development; engineering students develop their competencies in such a way that they can be transferred seamlessly to their professional work after graduation.

In project-based learning, students work collaboratively in assigned groups to provide solutions to identified problems. Group-based learning is an established pedagogical method popular across many disciplines in higher education for increasingly varied and innovative learning purposes and situations (Thorley & Gregory, 1994). Group-based learning is considered beneficial to students because it provides them with a self-regulated learning environment that enables them to be active rather than passive learners. It also promotes their interpersonal skills and autonomy in learning by generating, evaluating, and implementing ideas; this process engages them to ask questions, search for information, brainstorm, design, and test possible solutions (Blumenfeld, Soloway, Marx, & Krajcik, 1991; Mello, 1993).

Engineering is an information intensive professional practice. Information has been always considered a critical resource for major tasks that may include design, planning, control, reporting, procurement, prototyping or decision making. As the project complexity increases, the need for effectively gathering, compiling, controlling and integrating information becomes much greater (Hansen & Järvelin, 2005).

Engineering design projects are often performed by a group of people. This may be because projects need different aspects of engineering knowledge and expertise that an individual engineer may not have. It may be also because the project has a definite timeline and requirements that cannot be performed by a single engineer. Group-based engineering courses are planned in a way that requires students to work collaboratively in order to achieve the outcomes of their assigned projects. During these projects, students will have to define their needed information, seek out appropriate sources, and use the information they find to solve the engineering problem in their projects. The following section gives an overview of information behavior research in engineering as it relates to this study.

2.6 Chapter in summary

The literature discussed in this chapter can be summarized in four main areas that are related to this research: (1) research in collaborative information behavior, (2) task-based information behavior, (3) information behavior research in engineering, and (4) project-based learning in engineering education. This section summarizes the main issues that were identified in the literature.

The literature outlines the development of information-behavior studies, from a reductionist view of the individual as a user simply processing information to one in which we consider the social and contextual factors affecting information behavior.

1. Collaborative information behavior is a new emerging area in information science. It points to the need for empirical research on definite user groups, specific defined contexts, and the inclusion of the task as an essential component in this research area.
2. Studies in the emerging field of collaborative information behavior showed some developing trends, as researchers observed information users while they worked in groups to accomplish definite task goals. However, the findings of these studies were dependent on researcher's original research objectives, which did not always focus on the effect of the context of the task on users' collaborative information behavior.

3. In comparison with existing conceptual models in individual information behavior, there is no well-established model of collaborative information behavior that may guide studies in this area.
4. Collaborative information behavior in context demonstrates the importance of taking into account many factors and variables that may affect collaborative information related activities such as different situations, tasks to be performed, and roles of group members.
5. The task is considered a major factor affecting information behavior. Therefore, an understanding of information behavior cannot be separated from the performed task characteristics.
6. Engineering design projects were reviewed as examples of tasks that require task performers to search and use information during the lifespan of these projects. A considerable amount of research has been done on the information behavior of engineers in different projects; the studies ranged from individual engineers to groups of engineers who work together in the same project. However, there are no empirical studies that have investigated the characteristics of engineering design projects when associated with learning tasks or the ways in which these characteristics affect task performers' information behavior.

Guided by the literature and the identified need for more empirical research to focus on context based collaborative information behavior, this dissertation will seek to provide further understanding of collaborative information behavior for particular groups of undergraduate students. The next chapter details the research design and methodology of the dissertation.

3. RESEARCH DESIGN

The research design describes the plan and the procedures for research that extend "the decisions from broad assumptions to detailed methods of data collection and analysis" (Creswell, 2009, p. 3). Research design involves selected plans of what kind of data are needed to investigate the research inquiry and to "specify approaches for gathering or generating that data" (Gibson & Brown, 2009, p. 47). Within this chapter, I present the research plan, its design, its selected methodology, and also research and ethical considerations.

3.1 Research paradigm

It is important to explicitly describe both the research paradigm of this study and my standpoint as the researcher. According to Gliner and Morgan (2000, p. 17), a paradigm is a research philosophy that guides how the research is to be thought about and conducted. The research paradigm is the researcher's broad framework that comprises perceptions, personal beliefs and the understanding of several theories and practices that are used to conduct the research.

A paradigm is a representation of the researcher's set of beliefs that guide action in connection with a disciplined inquiry. The research paradigm affects whether the selected research type will be qualitative, quantitative, or mixed methods. It also affects the selection of research methodologies. As Guba and Lincoln (1988) put it, "paradigms do imply methodologies, and methodologies are simply meaningless congeries of mindless choices and procedures unless they are rooted in the paradigms" (p.114).

Hjørland (2000, p. 513) argued that research in library and information science tended to focus on providing solutions to practical problems without first analyzing how the adoption of various epistemological standpoints affected the definitions of the problems to be solved.

As my research paradigm, I have followed a constructivist approach that says humans actively construct an understanding by developing subjective meanings of their experiences in their worlds. I have been mainly influenced by the original writings of Berger and Luekmann's (1967) *The Social Construction of Reality* and Lincoln and Guba's (1985) *Naturalistic Inquiry*. The constructivist paradigm can be described in its ontological and epistemological characteristics (Guba, 1990, pp. 25-27):

1. Ontologically: The constructivist paradigm takes a relativist position; there are no tangible realities that can be reduced and approximated, but only varied, multiple, and constructed realities in peoples' minds.
2. Epistemologically: Constructivism sees subjectivity as the only option in the research process. A constructivist approach to research relies mainly on participants' views of the situations being studied. Subjectivity is the core of constructivist research; according to Guba (1990), "subjectivity is not only forced upon us by the human condition... but because it is the only means of unlocking the constructions held by individuals. If realities exist only in respondents' minds, subjective interaction seems to be the only way to access them" (p. 26).

Subjective meanings are developed by humans and thus create varied and multiple realities in humans' perceptions based on their situations. In preparing and conducting this research, I have been influenced by the approaches taken by two major constructivist researchers: Jerome Bruner (education), and Brenda Dervin (information science).

Bruner's research was based on the previous works of Jean Piaget's (1950; 1969) studies on conceptions and development of research methods in education, Vygotsky's (1978) research on reflective thinking, and Kelly's (1963) phases of construction. Bruner's (1973, 1986, 1990) works in learning science have centrally considered the nature of *knowledge*, *the knower*, and *the knowledge-getting process*. His studies in learning sciences have verified the constructive view of the nature of human thinking.

Bruner's (1973) *Beyond the information given; studies in the psychology of knowing* says that "the individual is seen not as a passive, indifferent organism but rather as one who actively selects information, forms hypotheses, and on occasion distorts input in the service of reducing surprise and of attaining understanding" (p. 3). This constructive view describes how the use of information creates a *personal understanding* depending on the *human perception*. Bruner (1986, pp. 51-54) viewed the constructive approach of perception as humans creating hypotheses that accommodate everything they encounter in their real life, and these hypotheses are similar to imaginative stories that support them to consider possible alternative personal perspectives on the world.

Brenda Dervin developed the Sense-Making approach as a meta-theory in information science from her early investigations in communications and information studies from 1972 onwards. She articulated it as a generalized approach in 1983 (Dervin, 2005). The components of the Sense-Making approach have been described in section 2.2.1.1. The main advantage of the Sense-Making approach in information studies lies in the constructivist approach it follows. People move through time and space, each step is conceptualized as a bridge to cross a gap across situations that lead to outcomes. The constructivist view of information in this approach is rooted in seeing information as "created at a specific moment in time-space by one or more humans" (Dervin, 1992, p. 63). Gap-bridging in this approach does not necessarily reflect problem solving or that people should be in problematic situations to seek information, but as a general human condition in a given time-space that is tied to a particular situation. According to this description of gap-bridging, people take steps in time and space to make sense of information "regardless of whether the step is manifested as habitual and unconscious; capricious and accidental; or invented and planned" (Dervin, 2005, p. 27).

Case (2007, pp. 158-159) described the development of Dervin's Sense-Making approach as an addition to previous works in information science. He viewed it as theoretically grounded in the constructivist learning theories of John Dewey (1933), George Kelly (1963), and Jerome Bruner (1973). The Sense-Making approach can be seen in this study as a translation of the constructivist view of learning and knowledge-getting in the context of information behavior research.

Dervin developed the Sense-Making methodology to describe a research method that can be used in information behavior search to include suggested data collection tools and analysis (Dervin, 1992, 1997, 1999, 2003). The research methods were designed to identify situations in process-oriented ways. It is important to emphasize that the influence of Dervin's Sense-Making to this study lies within its epistemological constructivist approach and not by using Sense-Making as a research methodology for this research.

3.2 Research methodology

As in all types of research, the study must be designed to the most appropriate conditions to meet the research aims and to get answers to the research question. The study must also be rooted in the researcher's standpoint and paradigm. In this dissertation, I selected a qualitative research approach that uses a grounded theory methodology.

3.2.1 Qualitative research approach

I have followed a qualitative research approach by selecting research activities that would enable me, an embedded researcher in the world of the research participants, to "study things in their natural setting, attempting to make sense of, or interpret phenomena in terms of the meanings people bring to them" (Denzin & Lincoln, 2005, p. 3).

The main characteristic of qualitative research is to conduct research activities in the setting where the studied phenomenon naturally occurs. Qualitative research is a set of investigative tools to explore how and why phenomena occur in a certain context; it aims to provide a holistic account and understanding of the phenomenon under investigation by identifying factors affecting the phenomenon and their interaction within a certain context (Creswell, 2007). Qualitative research often provides a detailed understanding that can generate a theory and theoretical frameworks of the investigated phenomenon (Morse & Richards, 2007, pp. 27-28).

In this study, my research objective is to explain the interaction between the learning task and student's collaborative information behavior in a senior engineering design course. My epistemological position as described in the previous section is the constructivist approach, the core of this approach focuses on exploring the ways people make sense of their experiences in their life.

The selection of a qualitative research approach conforms to my standpoint but required me to select an applicable research methodology that could meet the constructivist tradition and inform me with the appropriate processes for data collection and analysis.

Given these considerations, I selected grounded theory as a research methodology for this study as originally introduced by Glaser and Strauss (1967), later developed by Strauss and Corbin (1990), and recently advanced and structured by Charmaz (2006) and Bryant and Charmaz (2011).

3.2.2 Grounded theory

Grounded theory is a qualitative research method developed by Barney Glaser and Anselm Strauss (1967) in their book *The Discovery of Grounded Theory: Strategies for qualitative research.* At that time, the work was revolutionary. It challenged the long held view against the quality of qualitative research and also endless critiques of the rigor of qualitative research when compared to quantitative research.

Grounded theory provided systematic and explicit analytic procedures and research strategies that did not exist before in qualitative research (Charmaz, 1995). It is an inductive methodology that allows the researcher to develop a theoretical explanation of the general features of a phenomenon under study while grounding the account in empirical observations or data at the same time (Glaser & Strauss, 1967). The grounded theory as a research methodology is a "general methodology for developing theory that is grounded in data systematically gathered and analyzed" (Strauss & Corbin, 1994, p. 273). The characteristic of grounded theory is that a theory develops and emerges out of data and not prior to data collection, which means that the emergent theory is grounded in the research data collection and analysis. In following such an approach, a grounded theory is discovered, developed, and provisionally verified through data collection and analysis of data pertaining to a particular phenomenon.

According to Charmaz (2011), the term grounded theory refers to the research methodology and its product; the product is a theory that is grounded in data. A theory can be defined as "a set of interrelated constructs (concepts), definitions, and propositions that present a systematic view of phenomena by specifying relations among variables, with the purpose of explaining and predicting the phenomena" (Kerlinger, 1973, p. 9). Glaser and Strauss accepted this definition when they developed grounded theory as a research methodology, but they described it further that a good theory should not only explain and predict but also be useful to be applied and developed. In their view, the functions of a theory are to "enable prediction and explanation of behavior; be useful in theoretical advance; be useful in practical applications, predictions, and explanations…to guide and provide a style for research on particular areas" (Glaser & Strauss, 1967, p. 3).

Grounded theory makes its greatest contribution in areas in which little research has been done. Little research has been conducted specifically into the interaction of the learning task and the collaborative information behavior of undergraduate students in a project-based course. Grounded theory was selected for this study as an appropriate methodology as it can develop a theory that can be used as a precursor for further investigation of the collaborative information behavior of undergraduate students.

Grounded theory as a research methodology has been used in some information behavior research, including some studies that resulted in acceptable conceptual models in this area. For example, Ellis' (1993) model of the information seeking pattern of academics resulted from grounded theory research, influenced the development of Kuhlthau's (2004) ISP model. Grounded theory has been also utilized in some recent studies on collaborative information behavior (e.g. Jentzsch & Prekop, 2002; Paul & Reddy, 2010; Prekop, 2002; Reddy & Jansen, 2008).

3.2.3 General characteristics of grounded theory

Grounded theory is an iterative, comparative, interactive, and abductive qualitative research methodology in which data collection and analysis reciprocally shape each other through an emergent iterative process. The strengths of grounded theory as a research methodology are regarded through its analytical strategies, such as coding processes, memo writing, constant comparative analysis, theoretical sampling, and theoretical saturation. These analytical strategies constitute an ongoing process of development, improvement, and incorporation of the emerging theory (Bryant & Charmaz, 2007; Charmaz, 1995, 2006; Glaser & Strauss, 1967; Strauss & Corbin, 1998).

In grounded theory research, the researcher has to constantly interact with the data, ask questions to verify and generate theory, and then relate concepts to make comparison and hypotheses to test ideas using selected analytic strategies. The researcher is immersed in the field of the research and acquires rich data through a process of theoretical sampling by selecting incidents for data collection that are guided by the emerging theory.

The researcher constructs analytic codes and categories from data and not from preconceived hypotheses. The researcher does so by using theoretical and systematic coding procedures to conceptualize how the substantive codes relate to each other. The researcher needs to continuously ask questions about the data that allow him or her to depict the complexity, variations, and nature of the relationship between the variables in the study.

Grounded theory researchers move back and forth between data collection and analysis as each informs the other (Charmaz, 2006; Charmaz & Henwood, 2008). Grounded theory relies on how the researcher interacts with data collection methods and analysis techniques; the degree of the researcher's interaction and how data are analyzed have resulted in variations of grounded theory approaches as described in the following section.

One of the main characteristics of this inductive approach in grounded theory research is that the categories and concepts emerge from data through these inductive analysis strategies rather than coding the data according to predefined categories (Charmaz, 2006; Creswell, 2007).

3.2.4 Variations in grounded theory

Glaser and Strauss, who originally developed grounded theory, have argued that its methodology needs to be developed further from its original 1967 proposal. Strauss teamed with Corbin (Strauss & Corbin, 1990) to develop alternate methods for generating theory. This resulted in a split of the methodology into two camps commonly known as: the Glaserian approach and the Straussian approach (Kelle, 2007, p. 192).

Although both approaches in grounded theory still share many of the principle elements of the methodology, they differ mainly in how grounded theory should be practiced as a research method (Charmaz, 2000, p. 510). The Straussian approach is mainly different from the Glaserian in:

1. Focus of the research: The Straussian approach focuses on verification and validation of the theory and not only on the discovery of theory.
2. Process of the research data: The Straussian approach generates a theory from coded data rather than from research raw data.
3. Role of the researcher: The Straussian approach confirms the researcher's active involvement in the research and does not accept the neutrality of the researcher.
4. Data analysis and coding: The Straussian approach suggests a structured method for incorporating data analysis using three levels of data coding: open coding, axial coding, and selective coding.

The more grounded theory has been used in research, the more it has been developed and altered to address new issues and to improve the methodology. Alternate forms of grounded theory have been developed from the Straussian approach such as Adele Clarke's (2005) situational analysis methodology and the constructivist grounded theory (Bryant & Charmaz, 2011; Charmaz, 2006); the latter is the selected methodology for this study.

3.2.5 Constructivist grounded theory

The constructivist grounded theory approach includes the core logics of grounded theory methodology as originally introduced by Glaser and Strauss but is built on the Straussian approach to grounded theory as described in the previous section. The common logics among all variations of grounded theory include the researcher's immersion in the field of study, acquisition of rich data, using coding techniques to create *codes* from fragmented empirical data, and then to raise significant codes to tentative *categories*. The researcher continuously compares these categories with existing and emerging codes during the study to create new categories. At the end of the research, major categories are treated as *concepts* and then compared with disciplinary concepts (Bryant & Charmaz, 2007; Charmaz, 2000, 2006, 2011; Charmaz & Henwood, 2008).

The comparative and interactive nature of grounded theory methodology requires the researcher's continuous interaction with research participants, data collection, coding strategies, data analysis, inducting categories and concepts, writing memos during data collections, and analysis and then following theoretical sampling of the emerged concepts with existing concepts in the field of the study to create an emerging grounded theory (Charmaz, 2006, 2008).

Charmaz (2011, p. 364) outlined that in all variations of grounded theories the researcher will have to:

1. Conduct data collection and analysis simultaneously in an iterative process.
2. Analyze actions and processes rather than themes and structure.
3. Use a comparative method.
4. Draw on data to develop new conceptual categories.
5. Develop inductive categories through systematic data analysis.
6. Emphasize theory construction rather than description or application of current theories.
7. Engage in theoretical sampling.
8. Search for variation in the studied categories or process.

9. Pursue developing a category rather than covering a specific empirical topic.

The main difference between the constructivist and objectivist grounded theory approaches lies in the influence of the researcher's tacit knowledge on the emerged grounded theory in research. Charmaz (2006, pp. 129-132) explained that the difference between objective and constructivist is drawn on the variance between the positivist and interpretative traditions in research. Within the constructivist grounded theory approach, the constructivist approach means more than looking at how individuals view their situations but how the emerging findings from the research could provide an interpretation of these data; that interpretation is based on the raw research data, analytic techniques, and most importantly is dependent on the researcher's view.

According to the interpretative paradigm in constructivist grounded theory, researchers act as social actors who "construct grounded theories based on prior experience and current concerns and interactions with people, perspectives, and research participants" (Bryant & Charmaz, 2011, p. 219). Therefore, researchers influence what data to collect and how they are analyzed. In constructivist grounded theory research, the researcher is an essential part of the research in a way that "shatters the notion of the neutral researcher removed from the world (Bryant & Charmaz, 2011, p. 223).

I have selected the constructivist grounded theory as a research methodology as it recognizes that both the data and products of the research are social constructions that reflect what their production entails (Bryant & Charmaz, 2007). The constructivist approach is aligned with my constructivist paradigm in this research as it fosters my reflexivity as the researcher about my own interpretations as well as those of the research participants, namely because this approach "views knowledge as located in time, space, and situation and takes into account the researcher's construction of emergent concepts" (Charmaz, 2011, p. 365).

Grounded theory is a generative inductive research methodology that enables researchers to develop a theoretical account of the general feature of a topic while simultaneously grounding the account in empirical data and not through predefined hypotheses. The advantage of grounded theory methodology lies in its flexibility (Glaser & Strauss, 1967) but it does not provide prescriptive ways to use. Instead, the grounded theory methodology provides a set of principles and practices that any researcher can apply in the context of particular research studies (Bryant & Charmaz, 2011; Charmaz, 2006)

I learned from many studies in grounded theory methodology that there is no endorsed form of the methodology that researchers have to follow. Grounded theory as a methodology provides flexible tools, rather than dogmatic methods, as recommendations for the research method.

3.3 Research method

The research method describes the forms of data collection, analysis, and interpretation during the research. Selected methods in this research were guided primarily by the recommendations from constructivist grounded theory (Charmaz, 2006). Grounded theory studies always follow an iterative and non-linear process that consists of overlapping phases of immersion in the field, sampling, data collection, data coding, memo writing, constant comparison, theory sampling, and theory construction. In the following sections I describe the main research stages as parts of the research method.

3.3.1 Research setting

The study was conducted at Queen’s University at Kingston in Canada. Established in 1841, it is one of the oldest universities in Canada. The engineering program at Queen’s University started in 1891 and is considered one of the most selective in Canada, it offers undergraduate and graduate degrees in 10 engineering disciplines (Queen's Engineering, 2011).

3.3.2 Sampling, recruitment and data collection

In grounded theory, sampling is initially purposive and becomes more theoretical as the theory is constructed (Glaser, 2007). Participants are recruited based on the knowledge they have about the phenomenon under investigation. As the data are analyzed and the theory develops, theoretical sampling may be used by the researcher to collect any additional data needed to enable full and complete construction of the theory. Additional data may be requested from participants already recruited to the study, or through the researcher’s observations from other sources such as documents or through his immersion in the field of the study.

In this research, I conducted two studies in two consecutive academic years. In the first academic year, I designed a web-based survey. This survey was sent to students from a final year engineering design course as they were near the end of a project that lasted for eight months. The purpose of the survey was twofold: to get responses from students about their experience in their projects regarding collaborative information behavior and to get their informed consent that I could use their deliverables as data for my research. The details of the web-based survey are available in Appendix A.

The survey included closed-ended questions that I have used as a pilot study to help me to define a conceptual framework for the study as the phenomenon under investigation is complex and I avoided using any predefined hypotheses as suggested by the grounded theory approach. The selection of a web-based survey at the end of the project was to be an *unobtrusive* method to avoid disrupting the phenomenon being studied (Case, 2007, p. 224). Unobtrusive methods aim not to alter the ways that individuals, the subject of study, behave if the purpose of the investigation was introduced to them at any stage of their assigned tasks. It was assumed that the survey is conducted at the end of the project to avoid any affect the outcome of the project and not to alter the ways students would consider in their collaborative information behavior. The main limitation of using the survey at the end of the project is that students' responses will be of self-reported nature based on memory recall which could affect the level of details students provide.

I also used the survey to get students' informed consent to use project documented materials from project groups. The collected documents included a variety of formats that described students' self-reported documents as groups in different project stages that occurred during the lifespan of the project that lasted for thirty two weeks. Examples of students' deliverables are available in Appendix D.

The documents varied from weekly team memos, weekly progress reports, brief reports, an interim report, and a final report and presentation. Deliverables were only collected for projects whose members collectively consented to participate in this research. Table 3.1 shows the description of these documents based on the course syllabus by the course structure. The design of Study 1 and the responses to the survey will be detailed in the next chapter.

Table 3.1: Description of used documents in Study 1

Deliverable	Description
Weekly team memos	A brief record of the team meetings and it focused on the internal workings of the group, what items were discussed, resolutions from the discussions and clarify each individuals responsibilities.
Progress reports	The progress report focused on the actual project, describing the issues resolved, new issues, and critical path items relating to the overall project's progress should be tracked. The progress report tracked *what* was done on the project while the Memo kept track of *how* the project was performed.
Project brief reports	Through the first term, project teams were required to submit 4 brief reports to summarize phases of the project as sections of a report.
Interim report	A formal in-class presentation of the project status and a formal report were due at the end of the first term.
Final report	At the end of the second term, final reports were submitted to the instruction team in addition to formal oral presentations in class.

Study 2 was conducted in the following academic year, I planned to recruit a cohort of 10 different students through a call for participation message that I sent to the course instructor. The course instructor was so supportive to my request that he added a few words to my original invitation, encouraging students to think about joining the research. He also confirmed to students that participation in this research was confidential and that he would not know who participated in the study. This was an advantage as many students avoid being a part of research that discusses their experience in a course they currently have. Eight students responded to the invitation to participate with their acceptance to be part of the study in its four interviews. I recruited the eight students who were four females and four males. The details of interviews' protocols are available in Appendix B.

I conducted four interviews with each student in a time-line approach. I started the first interviews in October 2010, the second interviews in December 2010, the third interviews in February 2011, and the fourth round of interviews near the end of April 2011 at the end of their courses. I gave each student a gift card valued $15 at the end of the first three interviews and a gift card valued $30 at the end of the fourth interview to acknowledge their participation in the four interviews.

The interviews were deliberately a mixture of semi-structured and unstructured ones to ensure in-depth interviewing. Semi-structured interviews were mainly used for the first two interviews as I needed to capture some of the data that I was not able to acquire in Study 1. In-depth interviewing techniques were used in the third and fourth interviews when students became more comfortable being interviewed: this enabled me to gain a detailed understanding of the students' subjective experience in information behavior during their group projects. During these in-depth interviews, participants were encouraged to tell their stories and reflect openly on their experiences.

The protocol of interviews was based on a set of questions that targeted both individual and collaborative information behavior according to students' experience in their projects. It was noticed during the first two interviews that students did not feel comfortable in disclosing their experiences in the course they are enrolled with and tried to give short answers as if they were expecting there was a right or wrong answer to the interview questions. Another thing I noticed during the first interviews that students' answers with respect to information were limited to library subscribed collections as they already knew me as the engineering librarian. At the third interview, I gave students an explanation that information in the interview questions is not limited only to library collections but includes any information used in their projects.

At the fourth interview, I have used a different interview protocol to make sure that participants did not omit any important information after their eight months' experience in their projects. I have used interview questions based on the questions I used in the survey of Study 1. I gave students the survey questions printed on paper and asked them to answer them while they think aloud about their selected answer and an explanation of what their answers mean. This was important to give students some time to think about their answers before they reflected on their experience and also to have another level verification for me of the results I got through Study 1 without the need to send the survey to all students in this course. The details of the protocol for the fourth interview are available in Appendix C.

I also gave students a timeline representing the months of project performance as printed on paper and asked them to reflect on their information behavior experience during these months in relationship to their assigned projects and also in relation to individual and collaborative information seeking, search, and use.

Near the end of the fourth interview, I used the information horizons interviewing technique (Sonnenwald, 2005; Sonnenwald, Wildemuth, & Harmon, 2001). The information horizons framework is an interviewing technique "during which study participants are asked to provide a graphical and verbal articulation of their information horizon in a particular context." (Sonnenwald, 2005, p. 191). Information horizon is a description of information channels and resources, including people and documents that an information user accesses when seeking information within specific situations. Students developed maps of their information horizons while they were verbally reflecting on their experience within their groups and with seeking information from people and documents.

At the outset of each interview, I explained to participants that I may refer to my list of questions from time to time and make brief notes of any issues that are raised during the interview so I can get back to it later during the interview. All interviews were audio recorded with each participant's permission in each interview.

3.3.3 Data preparation

Grounded theory methodology recommends researchers to collect rich data for analysis. In this research, I used different types of data that existed in different formats from survey results, documents, and interviews. The data preparation enabled the process of data coding and further analysis.

The responses to the survey in study 1 were collected through StudentVoice® (Studentvoice, 2012), a web-based surveying tool that is used in many universities. The responses were downloaded and prepared by removing any identifying information: I have used pseudonyms for the names of students. Students' deliverables were also prepared by removing all identifying information and by sorting them into groups: progress reports, memos, brief reports, interim reports, and final report. In Study 2, the thirty two interviews of eight students were transcribed and stored along with the original audio files.

The data were organized and then coded with the assistance of Nvivo 9® (QSR International, 2012), a Computer Assisted/Aided Qualitative Data Analysis (CAQDAS) package to assist me in managing, querying, and storing my research data. I used the software for coding and categorizing the emergent codes. The software did not replace my analytical skills as a researcher, but it supported them by providing me with a centralized location for different types of data, facilitating coding of different data sources, recording memos, and maintaining a study journal. Figure 3.1 shows the research data folders as data containers for the collected data during the research that included students' documents, interview audio files and their corresponding transcribed documents, and a dataset of the survey results.

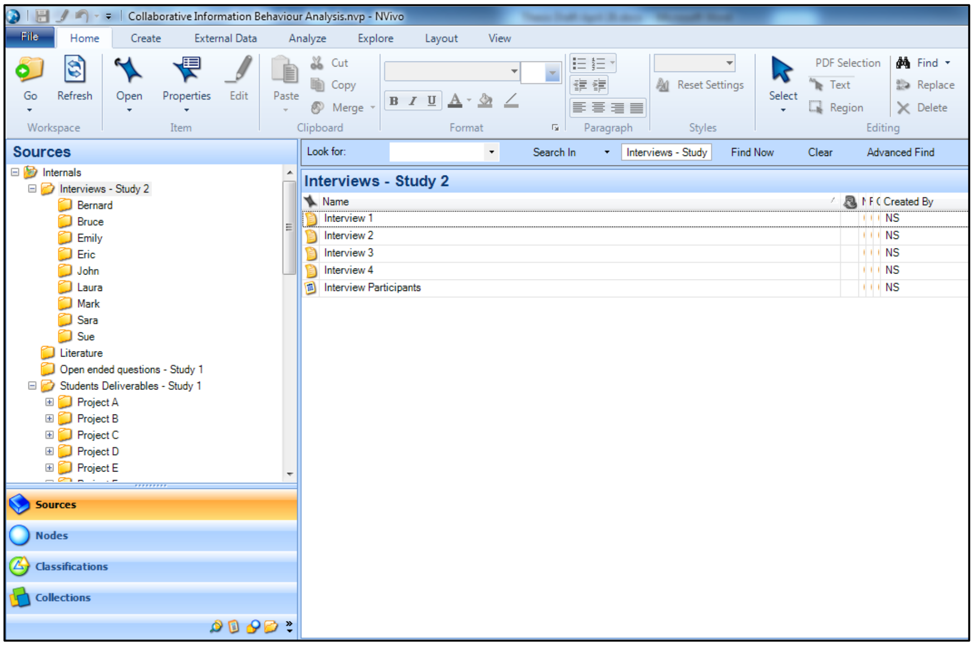


Figure 3.1: Structure of research data folders in Nvivo9.

3.3.4 Data coding

Coding is a common practice in qualitative research as a process of "categorizing segments of data with a short name that simultaneously summarizes and accounts for each piece of data" (Charmaz, 2006, p. 43). Coding is a way of organizing and indexing segments of text from multiple data records in a way that facilitates the development of categories and hence conceptualization (Bazeley, 2007, p. 66). In the process of coding, researchers select, separate, and sort the data to determine what the data is about and then assign labels as data representative codes (Charmaz, 2006, p. 45). Coding is the process of defining what the data are about and it may take the researcher to unforeseen areas that enable the construction of an emerging grounded theory.

Variations of grounded theory have recommended some methods for coding such as open, axial, and selective coding (Strauss & Corbin, 1998), theoretical coding (Glaser, 1978), and initial and focused coding (Charmaz, 2006). In grounded theory research, "coding generates the bones of the analysis and theoretical integration will assemble bones into a working skeleton" (Charmaz, 2006, p. 45).

3.3.5 Memo-writing

Memos are informal notes recorded by the researcher throughout the research process to enable the researcher's reflection on the analysis of data by recording ideas, discoveries, impressions, descriptions, and context (Morse & Richards, 2007, pp. 113-114). Memos can be seen as the theoretical notes about the data and the conceptual connections between categories and it is a parallel process with the coding and analysis to capture the researcher's emergent ideation of substantive and theoretical codes and categories (Holton, 2007, p. 281).

In grounded theory, Charmaz (2006, p. 85) added that writing memos is an ongoing process that helps researchers to analyze ideas about the codes, identify gaps in data collection, develop certain codes into categories and also to demonstrate relationships between emerging categories.

During this study, I used a notebook to write down my memos. I also took advantage of the qualitative data analysis software as a more efficient way to get back to my memos when needed during data analysis.

3.3.6 Constant comparative method

This is an analysis process during which the researcher constantly compares incident with incident and then incident with concepts. The use of constant comparative methods (Glaser & Strauss, 1967) is to establish analytic distinctions and then to make comparisons at each level of the analysis. The purpose of using this method is to generate more abstract concepts through inductive processes of comparison. In this research, I compared some interview statements and incidents within the same interview, and then compared them with other incidents and statements in other previous interviews for the same interviewee. The sequential comparison continued when new data were collected and new incidents were identified. Comparison of data had been an iterative process during the research: I followed a process approach when I conducted a time-line interviewing of participants so I needed to compare what happened in the most recent interview to the previous ones.

The grounded theory research depends on using constant comparative methods and the researcher's engagement (Charmaz, 2006, p. 178). Making continuous comparison between data, codes, and categories facilitated and enabled my conceptual understanding of the properties of the selected categories during this research.

3.3.7 Theoretical sensitivity

An important feature of grounded theory is theoretical sensitivity, which refers to a personal quality of the researcher and relates to understanding the meaning and refinement of data (Charmaz, 2006). Theoretical sensitivity has been described by

Glaser (1978) to be the process of developing the idea with which a researcher comes to the research situation. Grounded theory methodology suggests that any theoretical insight should be conceptual rather than concrete; it is often referred to as the creative aspect of grounded theory that involves the researcher working in a research area to obtain experience and expertise, and then to integrate the emerging concepts into a theory (Strauss & Corbin, 1990).

One of the main challenges in theoretical sampling is the use of previous literature in the substantive area of research. In the early forms of grounded theory, researchers were strongly advised to defer the literature review until they had collected and analyzed the first batch of research data, as the purpose of research in grounded theory is to discover and not to test hypotheses. This is a big challenge as the literature may create a preconceived bias on the part of the researcher (Glaser, 2007; Glaser & Strauss, 1967). Strauss and Corbin (1990) have agreed with that argument and advised researchers to use a theoretical framework that is generated from the initial data gathering as a starting point in their theory building processes and not to derive it from the reviewed literature. I have followed this approach by using a part of Study 1 as a pilot study to build a conceptual framework for this study.

This approach is similar to the situation of many researchers who conduct grounded theory research with knowledge of the research area. I have already reviewed the literature of collaborative information behavior that has motivated me to consider conducting this research, but I followed a *theoretical agnosticism* approach to avoid any bias towards existing theories or established hypotheses.

Henwood and Pidgeon (2003) introduced the concept of *theoretical agnosticism* as an approach that researchers in grounded theory need to consider at the early stage of the research by taking a critical stance toward earlier theories and models in the area of research to avoid the influence of any theoretical influences on the conducted study at its early stages.

In concluding the research design, I constructed an illustration (Figure 3.2) to present the main research plan and procedures of data preparation and analysis performed during this research.

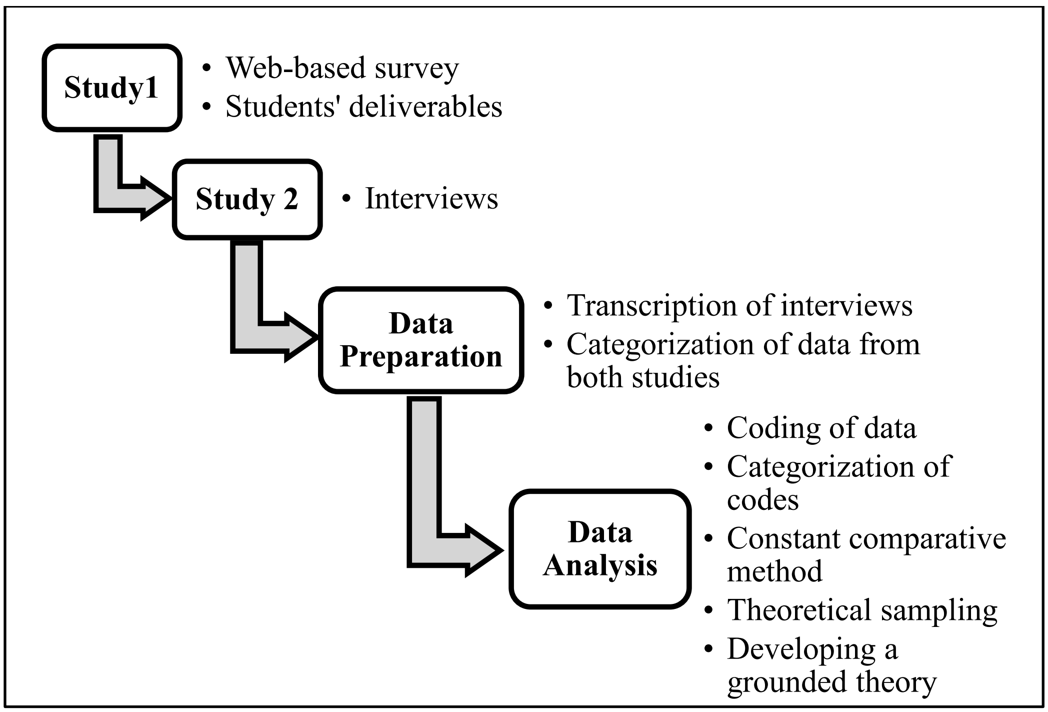


Figure 3.2: Research plan and procedures

3.4 Research considerations

There have been many considerations to address during this research in its different stages. These include the development of trustworthiness of the research to represent the rigor of this study and also ethical considerations in conducting the research and data work.

3.4.1 Trustworthiness

The criteria of rigor in qualitative research are different from those of quantitative research. Janesick (1994) noted that there has always been a constant obsession with what he described as "the trinity of validity, reliability, and generalization" (p. 215). Qualitative research uses *trustworthiness* (Guba & Lincoln, 1982) as the criteria to judge the rigor of the inquiry.

The aim of trustworthiness in a qualitative inquiry is to support the argument that the inquiry's findings are "worth paying attention to" (Lincoln & Guba, 1985, p. 290). This is quite different from the conventional experimental precedent of attempting to show validity, soundness, and significance.

In any qualitative research project, four trustworthiness criteria of qualitative research need to be considered: *credibility*, *transferability, dependability*, and *confirmability* (Lincoln & Guba, 1985, pp. 301-328). Bradley (1993) *has* provided examples of these four criteria representing the aspects of trustworthiness of qualitative research and they can be applied to the research in library and information science.

3.4.1.1 Credibility

Credibility is an evaluation of whether or not the research findings represent a credible conceptual interpretation of the data drawn from the participants' original data (Lincoln & Guba, 1985). It is about the value of conclusions and whether the represented research study is an authentic portrait of what the researcher was planning to look for throughout the study (Miles & Huberman, 1994).

Credibility in this research is demonstrated by the use of a prolonged approach in engagement with research participants and the research setting in two studies that lasted for two years. I also attained credibility for the study by carrying out the research in a natural setting during a real engineering course and not in laboratory-based experiments in which I have triangulated different types of collected data to gain multiple perspectives on collaborative information behavior in a variety of situations.

3.4.1.2 Transferability

Transferability is the degree to which the findings of this inquiry can apply or transfer beyond the bounds of the research. It is the extent to which the research can be transferred to other contexts or what can be described as fittingness (Miles & Huberman, 1994).

I have constructed the findings of this research in a way that they can be transferred to similar engineering courses or into other higher education settings where a group of students are involved in project-based or problem-based courses in any discipline and not necessarily in engineering, as I provided results and conclusions along with their corresponding descriptions, explanations, and arguments.

This dissertation also provides a detailed analysis of different data: a survey, students' deliverables, and longitudinal interviews to provide a holistic view to readers of and researchers in this field who may find the results useful for further investigation. Practitioners in engineering education can consider the application of some of this study's findings in their own contexts if there are sufficient similarities with the context of this study.

Transferability in constructivist research is totally different from generalization in positivist studies. This is an important aspect of qualitative research; as Dervin (1997) put it, "every context is by definition different, an intersection of a host of nameless factors. Because of this, research can only be particularized and generalization in the traditional scientific sense is impossible" (p.14).

3.4.1.3 Dependability

Dependability is an assessment of the quality of the integrated processes of data collection, data analysis, and theory generation. This can be seen as quality control, consistency and stability during the research. During this study, I have used a technique of *inquiry audit* as proposed by Lincoln and Guba (1985, p. 317) and an *audit trail* as suggested by Schwandt and Halpern (1988).

I have maintained all the original research data, documents, audio files of the interviews, transcriptions, and all developed memos from the two studies. I kept a journal throughout the study in which I recorded all methodological decisions and personal reflections. I also kept a variety of records including the signed consent forms, interview transcripts, field notes, memos and draft versions of this dissertation and the developed grounded theory.

3.4.1.4 Confirmability

Confirmability is a measure of how well the research's findings are supported by the data collected and how the research is reasonably free from unacknowledged researcher biases (Miles & Huberman, 1994). During the study, I ensured confirmability that all the findings are grounded in the data, research inferences are logical, and the category structure is clear and useful. I have also acknowledged any divergences and discrepancies in the data.

This research is following a constructive approach focusing on subjectivity and it is accepted, according to Charmaz (2006), that the knowledge and experience of the researcher have an impact on findings. It is important to mention that my tacit knowledge has not been transferred from me to the findings to such an extent that there was any modification in the meanings of students' reflection in their documents or during the interviews.

I have acknowledged my own arguments openly during the analysis. This approach should not be seen as a limitation of research but a technique of engagement and a source of insight that contributes to the understanding of a complex phenomenon, as argued by Sutton (1993). Acknowledged bias in this dissertation should be viewed as a benefit because of the researcher's rich understanding of the complexities of the various contexts within which the phenomena interact in the study.

Attitude toward bias, particularly as introduced by the researcher, is affected by the underlying epistemic assumptions of the research. Mellon (1990, p. 26) argued that objective researchers always try to eliminate bias while subjective researchers recognize and acknowledge it: the difference between the two research traditions is not that one has and one lacks objectivity, but qualitative researchers systematically acknowledge and document their biases rather than striving to rise above them.

3.4.2 Ethical considerations

As a researcher, I was not involved in the course where the interviews were conducted. All the research methods and procedures have been described in detail and in their sequence are available to all of the other researchers who read or review the results of this research. Although I have been involved in many design engineering courses at Queen's University, I was not involved in teaching for these courses under this study to avoid any possible influence on students' experience.

Ethics approval was arranged from the Ethics Review Board of the Faculty of Education at McGill University for the period of the research. A second ethics approval was arranged from the General Research Ethics Board (GREB) at Queen's University where research data were collected. The study followed the Tri-Council Policy Statement: Ethical Conduct for Research Involving Human Subjects and the code of ethics underlying research at both McGill University and Queen's University. The research was planned to respect human dignity and did not expose participants to any risk or harm.

The purpose of the study and its method was explained to research participants so that free and informed consent was obtained from students in both academic years in this study. Participants were clearly notified that participation in the study was voluntarily; their participation in the study had no effect on their course grade or project evaluation and that they were able to withdraw from the research at any point.

Students submitted their consent that their deliverables could be used as data sources for this study. Students had the choice to opt for their course deliverables to be used as research data at the end of the course. Students signed consent forms for the secondary use of data as the deliverables were a part of the course and were not designed as tools for research data collection. The letters of information and the consent forms for both case studies are attached as appendices to this thesis.

During data preparation, all original names were removed from students' documents and pseudonyms were selected. Names were chosen for students instead of using codes or numbers. Some data were manipulated such as the course name, course code and some company names, to avoid any possible identification of the study participants or the course under investigation.

4. RESEARCH FRAMEWORK

Researchers in grounded theory who use an inductive approach must try to avoid having a research framework in place before they collect and analyze their data. Charmaz (2006, p. 168) argued that when grounded-theory researchers approach data collection and analysis already knowing what their theoretical framework is going to be, they may harm their study by using deductive logic.

This was my biggest challenge when I started this research. I have already acquired knowledge about the field and research in the areas of information behavior, the learning sciences, and engineering education. I also have many years' professional experience planning, teaching and providing support to undergraduates enrolled in a number of different design-engineering courses. I have observed throughout my professional practice how students work together in groups at the library or in computer clusters using their individual computers and have noted how often they look and point to each other's computer screen when working on class assignments together.

To conduct research that investigates a complex phenomenon without formulating prior specific hypotheses was a considerable obstacle for me, however, especially given that I was required initially to present and defend my research objectives. With this in mind, I conducted part of Study 1 as a pilot study, as recommended by Strauss and Corbin (1998), to enable me to conceptualize a framework for the study according to my research objectives and also to collect some empirical data beyond my preliminary knowledge and observations. This would help me avoid coming to my research with any deduced or predefined hypotheses.

4.1 Study 1: Setting up the research stage

Study 1 was conducted in March 2010 to collect data on students' experience in ENG 495, a final year multidisciplinary design course at Queen's University. The main purpose of the user survey was to get students' reflections on information seeking, searching, and use through open ended questions and to get students' informed consent that I could use the their submitted documents during the course as data sources for my research.

In addition, I needed to conduct a pilot study to construct a conceptual framework for the research; the survey was designed in a way that resembled a conversational survey (Gobo, 2011) to include opinion questions, agreement questions using a Likert scale, and open-ended questions.

Although this is qualitative research, I used quantitative univariate analysis of data to frame the research outline. Strauss and Corbin (1990) described qualitative research as any type of research whose findings are not a product of any statistical process or some form of quantification; the research findings should be based on the interpretation of the data and not on their quantification. Qualitative researchers do not reject the use of statistical methods as long as the research findings are not direct results of quantified analysis (Maxwell, 2010).

The use of univariate analysis or descriptive statistical analysis (Finn, 1981) explores the characteristics of individual variables in isolation from all of the other variables in the study to describe the main features of a collection of data. Univariate analysis is considered very informative, allowing the researcher to fully understand the phenomenon under investigation before further inductive research, whether through inferential statistics or through interpretive analysis (Collier, 2010). Descriptive statistics were only used at the early stage of the research. This helped establish a structure or an outline of collaborative information behavior as the main phenomenon under investigation, in order to conceptualize the study framework.

4.1.1 Survey structure

I have sent an invitation to students enrolled in a final-year capstone design course to participate in a web-based survey that consisted of 33 questions near the end of the 2009/10 academic year and at the end of the projects. The survey was designed to obtain feedback about their experience of collaborative information behavior during the project. The selected class comprised 66 students divided into 20 project groups. The survey was available electronically to students for two weeks to respond; a reminder e-mail was sent after one week. The survey was designed to be completed by individual students.

The survey had two parts: the first part was about the project, and the second focused upon individual and collaborative information behavior from the students' point of view. Many questions were open ended to allow students to reflect upon their experience. The closed questions allowed students to indicate their level of agreement, using Likert scale, with 11 statements related to projects' characteristics and information behavior. The developed survey instrument is attached in Appendix A.

Students were asked to give an answer about their level of agreement on a scale from 1 to 5, where 1 is lowest (strongly disagree) and 5 is highest (strongly agree). For the purpose of data analysis, the level of agreement will be described as: SA, A, N, D, and SD, representing strongly agree, agree, neither agree/disagree, disagree, or strongly disagree respectively. To meet ethical research requirements the survey was designed to ensure anonymity of respondents, and it was not mandatory for students to answer all the survey questions.

The survey started with a number of statements about the characteristics of the project that were based on my original observation, my knowledge, and some aspects that were identified in recent and related literature on collaborative information behavior (Reddy et al., 2010). Relevant statements were used to examine both the dimensions of the project as a learning task and the information-related activities of individual students who are situated in groups. The statements served as a point of departure for the study, as the intention was to elaborate on them throughout the research rather than test them as hypotheses.

4.1.2 Profile of respondents

Of the 66 students enrolled in the course under investigation, 42 students responded, for an overall response rate of 66% representing all the 20 project groups in that course. There were no demographic questions about gender or age but students in this level represent an age group ranging from 20 to 24 years old according to the faculty's profile (Queen's Engineering, 2011).

The size of each project group varied from two to four students. The number of survey respondents who belonged to the same project group varied as well. Project numbers were first coded randomly with characters so that each project was assigned a character from A to T, and respondents were assigned numerical codes that represented their project. This identified respondents in combinations of letters and numbers such as A1, B3, or E4. Table 4.1.shows the number of survey respondents per group.

Table 4.1: Survey responses per project group

Project	No. of respondents per project	No. of groups	Subtotal of respondents
A, E, F	4	3	12
B, C, D, G	3	4	12
H, I, J, K, L,	2	5	10
M, N, O, P, Q, R, S, T	1	8	8
Total			N = 42

Respondents from different engineering departments worked together on a multidisciplinary project topic. Respondents were asked to identify their department in the second question. The majority of respondents (Table 4.2) were from Mechanical Engineering, followed by Chemical Engineering.

Table 4.2: Department affiliation of the survey respondents

Department	No. of respondents
Mechanical Engineering	19
Chemical Engineering	13
Engineering Physics	5
Applied Mathematics	2
Civil Engineering	2
Electrical Engineering	1
Total	42

A chi-square test of association for departmental affiliation was conducted on the data gathered by questions related to task assignment to determine the statistical significance, if any, of the linear relationship between the student's departmental affiliation and the answers given in response to the survey. None of the *P* values indicated a statistically significant ($P \leq 0.05$) association between a given response and the respondent's departmental affiliation. The results of the statistical significance analysis of department are described in the following section in its relationship to task assignment.

4.1.3 Task assignment

The first three survey statements were about students' interest in their selected projects, the project topic's clarity, and the students' prior topic knowledge at the beginning of the project. The course instructor provided a list of available projects at the beginning of the course and students ranked their preferred projects as a list of five projects.

The instructor assigned students to projects and groups based on their preferences and their department affiliation so each group would have representation from necessary engineering disciplines for each project. Projects were different in their scope and requirements and also had different industry partners from engineering companies or start-up businesses. Some projects were for government agencies, local municipality public work departments, or not-for-profit organizations.

The responses showed that most students had an interest in the project topic and that was why they were selected and assigned to it. Students' perceptions of their prior knowledge and the clarity of their assigned projects varied as shown in Table 4.3. Responses to the three statements on task assignment have been also used to construct a box plot (also known as a box-and-whisker plot) as a convenient way to display differences among responses (Figure 4.1). The results showed the variations among students who were assigned to diverse engineering design projects that had different objectives for many different project clients.

Table 4.3: Students' perceptions of task assignment

Statement	Respondents (frequency)					Mode	Mean	St. Dev.	95% CI	
	SA (5)	A (4)	N (3)	D (2)	SD (1)				*LL*	*UL*
S1 I had an interest in the project topic when I was assigned to it.	15	17	6	4	0	4	4.02	0.95	**3.74**	**4.31**
S2 At the beginning of the project, I felt that I had prior knowledge about the project topic	1	16	10	9	6	4	2.93	1.13	**2.59**	**3.27**
S3 At the beginning of the project, I felt that the project topic was clear to me and I could easily find the needed information.	2	18	9	9	4	4	3.12	1.11	**2.78**	**3.45**

Note. St. Dev.= standard deviation; CI= confidence interval; *LL*= lower limit; *UL*=upper limit.

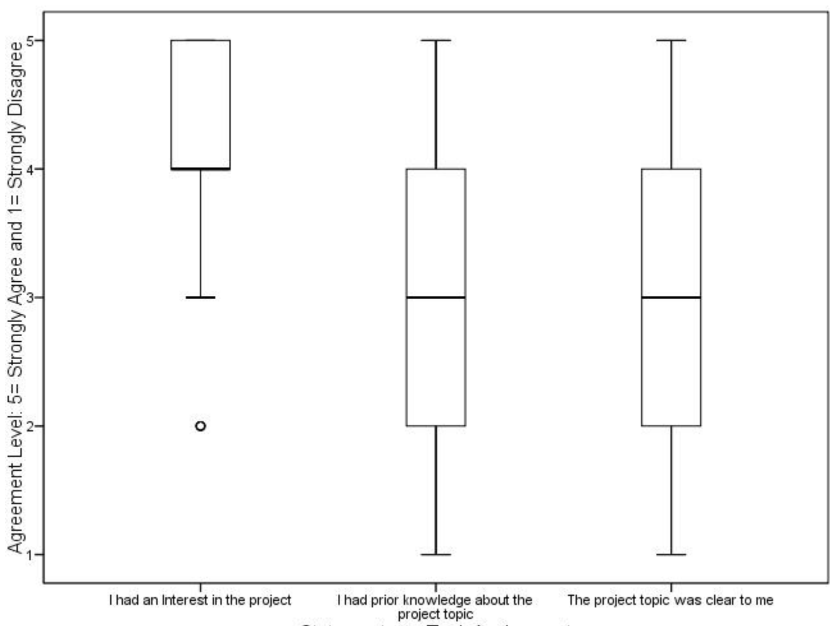


Figure 4.1: A box plot of students' perceptions of task assignment

The non-clarity of the project topic was purposefully a part of how the course was designed to provide students with ill-defined engineering problems. In these ill-defined projects, students were expected to further investigate their assigned project problem in order to identify the different constraints to their projects.

I wanted to find out if departmental affiliation had an impact on students' interest in the project or on their perception of essential prior knowledge. A bivariate analysis (Table 4.4) of the correlation between students' department affiliation and their interest in the project topic showed there is no statistical significance, with a very low Pearson's correlation (-0.20).

Table 4.4: Correlation of department affiliation with students' interest in assigned projects

	Value	*Df*	Sig. (2-sided)
Pearson Chi-Square	15.373	15	0.425
Likelihood Ratio	16.913	15	0.324
Linear-by-Linear Association	0.016	1	0.899
N of valid cases: 42			

Note. *df*= degree of freedom.

Another bivariate analysis (Table 4.5) was conducted on departmental affiliation and students' perceptions of their prior knowledge as related to their assigned projects, and it also showed that there is no significance with a very low Pearson's correlation (-.285).

Table 4.5: Correlation of department affiliation with students' interest in assigned projects

	Value	*Df*	Sig. (2-sided)
Pearson Chi-Square	15.373	15	0.425
Likelihood Ratio	16.913	15	0.324
Linear-by-Linear Association	.016	1	0.899
N of valid cases: 42			

Note. *df*= degree of freedom.

It is important to mention that the bivariate statistical analysis of department affiliation with both interest in the project and prior knowledge did not test any previous hypotheses but it was only intended to find out if there was any correlation between these concepts.

4.1.4 Finding information and task formulation

Students were then asked about how they perceived the process of finding relevant information for their projects and whether this process became easier as their understanding of their projects' requirements increased. Students had perceived finding information for their projects to be an easy process at the beginning of their projects, with a high levels of agreement that finding information was dependent on their understanding of the project's requirements.

Students also agreed that the nature of their projects required them to locate information through many different channels and from many different sources. The results showed that engineering design projects as learning tasks were information-intensive; information search and use was perceived to be an ongoing activity during the project and most students agreed that their understanding of their projects had a positive impact on their finding the information that they needed.

Students' agreed that information search and use was an ongoing activity and showed a high level of agreement that information related activities occurred during the entire project stages. Table 4.6 details students' responses to the three statements related to their projects' information requirement. A box plot (Figure 4.2) using these three statements shows a high level of agreement that information seeking and use is an ongoing activity that required them to look for information from different sources.

Table 4.6 Students' perceptions of learning task' information requirements

Statement	Respondents (frequency)					Mode	Mean	St. Dev.	95% CI	
	SA (5)	A (4)	N (3)	D (2)	SD (1)			.	*LL*	*UL*
S4. Finding and using information for my project was an ongoing activity.	23	18	1	0	0	5	4.52	0.55	**4.36**	**4.69**
S5. The project nature required me to look for relevant information from different sources	13	22	4	3	0	4	4.07	0.84	**3.82**	**4.32**
S6. Finding relevant information improved with my understanding of the project scope.	13	23	4	2	0	4	4.12	0.77	**3.89**	**4.35**

Note. St. Dev.= standard deviation; CI= confidence interval; *LL*= lower limit; *UL*=upper limit.

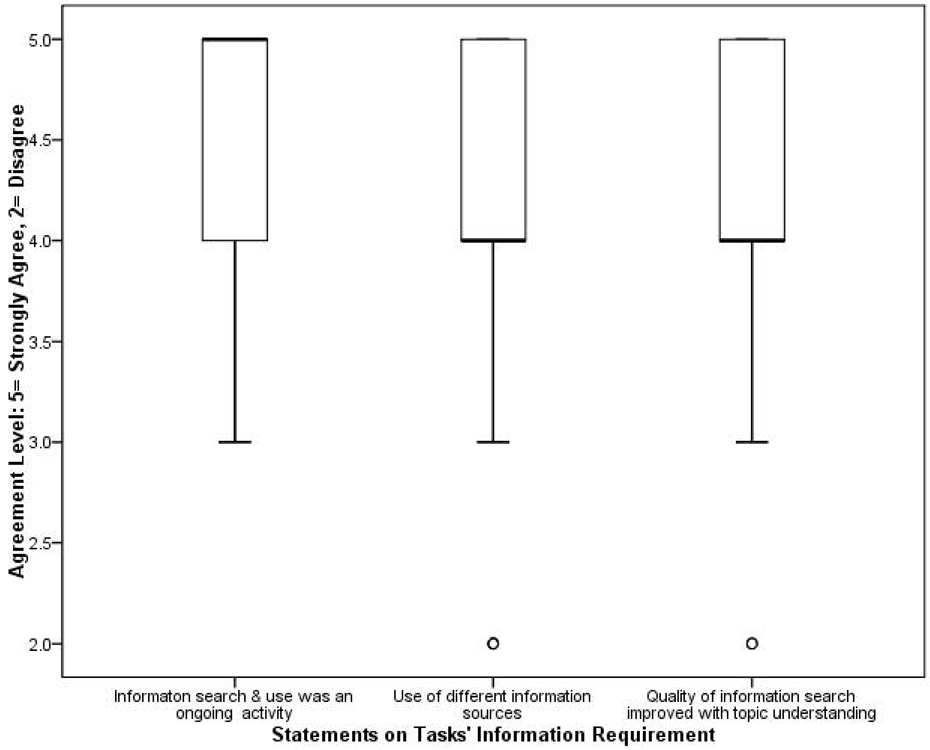


Figure 4.2: A box plot of students' perceptions of learning tasks' information requirements.

4.1.5 Types of information sources

Students were asked to identify the format and types of information sources they used for their projects. Forty-two students (100%) used electronic resources, 29 students (69%) used print resources, and seven students (17%) used multimedia resources; students defined multimedia by using online videos.

Students were then asked about the information sources used for their projects. Different types of information sources from different channels were used. This confirms that engineering design projects are information-intensive tasks that require students to find and use information that may exist in different types not necessarily available through one specific channel. The results

(Figure 4.3) show the variety of information sources that students used during their projects. "Other" information sources, as indicated in the figure, included: asking experts, help from the course instructor, and phone calls with the project client.

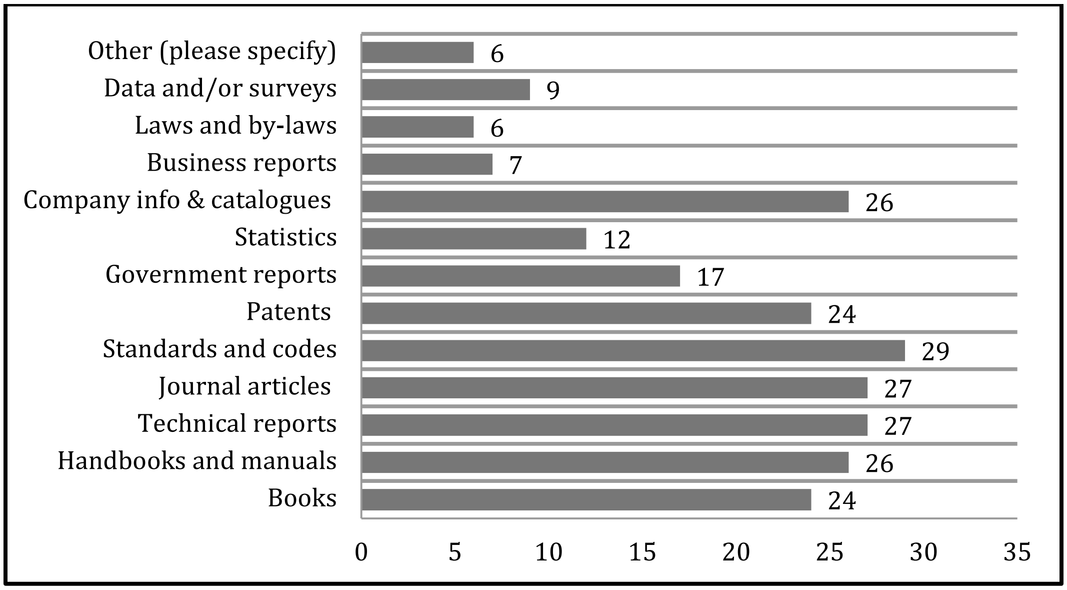


Figure 4.3: Types of students' used information sources.

It is important to mention that each of these information sources may represent different information content. For example, standards and codes describe technical requirement needs that had to be met during the design process; patents represent documents giving the intellectual properties of new design ideas; and handbooks provide background information and subject specific facts.

4.1.6 People as information channels

One of the common findings about the information behavior of engineers as described in Chapter 2 is that engineers often prefer to get information from other people such as their work colleagues. The reasons behind these tendencies were detailed in section 2.4 of this dissertation. Students were asked if they had approached people to get information for their projects; 36 students (85%) replied that they had asked for help in getting information (see Table 4.7).

Table 4.7: People as information channels

Number of responses (percentage)	People as information channels (with number of particular responses)
31 (89%)	The project client representative
27 (77%)	Course instructor
24 (69%)	Teaching assistants
9 (25%)	Librarian
5 (14%)	Library reference desk
4 (11.5%)	Students in other courses
9 (25%)	Other people at the university: professors (4), lab technicians (5)
11 (31.5%)	Other people outside the university: vendors and suppliers (10), people who work in similar business (5), surveying potential users of the developed product (4), father (2)

The project client was an important information channel for students as they needed to get more information about the project scope and about how the proposed design should meet the client's requirements. The course instructor and teaching assistants were also important channels of information, given that all groups had a weekly meeting with the instruction team, course instructor and the teaching assistants to discuss their progress. Librarians and library services were approached when students were not able to find a specific information source or when students sent requests asking if the library would acquire an information source such as a book or technical standard.

4.1.7 Collaborative information seeking activities

Students were then asked if they sought and searched for information as individuals or as a group. All respondents reported that they sought information individually, while 34 students (80%) indicated that they performed collaborative activities in information seeking through their groups during the project.

Students were asked about the reason to look for information collaboratively, using five statements that describe different contextual factors. These factors were identified in a recent grounded theory study as triggers for collaborative information behavior in a group setting (Reddy & Jansen, 2008): the setting of the group, complexity of needed information, unavailability of information, easiness of seeking information as a group, and the necessary searching expertise to find the information.

Table 4.8 shows that students considered the complexity of needed information to be the major reason for them to collaboratively seek information, followed by the project-design requirement that all of the work be done by students in groups. Availability and accessibility of information were not viewed by students to be important factors requiring them to seek and search for information collaboratively during their projects. A box plot (Figure 4.4) was constructed to present students' responses with respect to triggers of collaborative information seeking activities.

Table 4.8: Students' perceptions of collaborative information activities

Statement (We worked together in a group to look for information because)	Respondents (frequency) SA (5)	A (4)	N (3)	D (2)	SD (1)	Mode	Mean	St. Dev.	95% CI LL	UL
S7. It is a requirement for this course to work as a team	12	9	14	3	4	3	3.52	1.25	**3.14**	**3.90**
S8. The information needed for the project is complex	7	18	10	6	1	4	3.57	1.02	**3.26**	**3.88**
S9. It is easier to look for information as a group rather than as an individual	4	12	15	10	1	3	3.19	0.99	**2.89**	**3.49**
S10. The needed information requires searching expertise that I do not have as an individual	2	8	13	11	8	3	2.48	1.14	**2.30**	**2.99**
S11. The needed information was not available to any of us as individuals	0	6	15	14	7	3	2.64	0.94	**2.19**	**2.76**

Note. St. Dev.= standard deviation; CI= confidence interval; *LL*= lower limit; *UL*=upper limit.

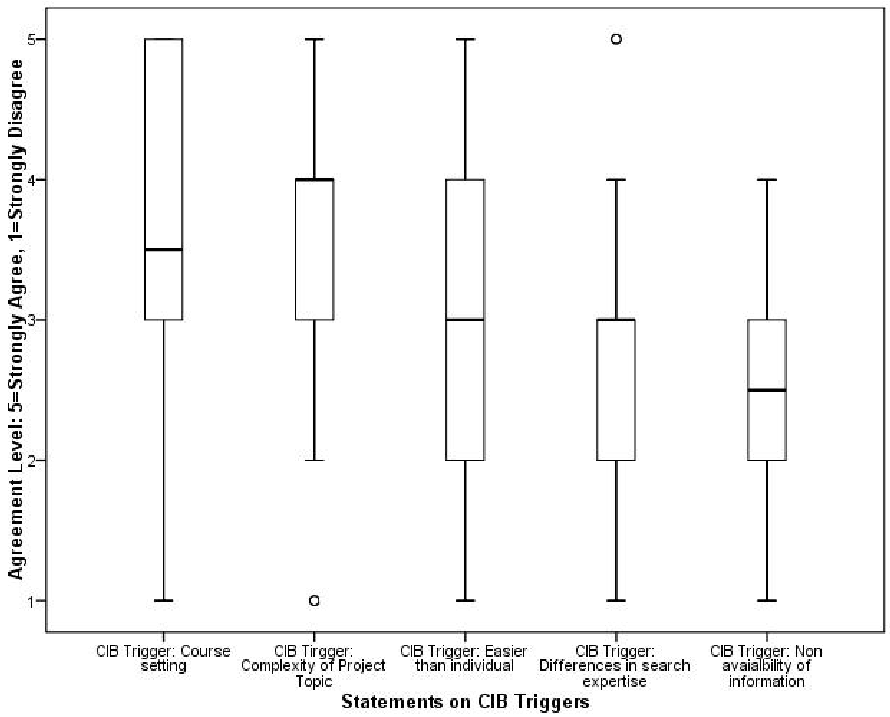


Figure 4.4: A box plot of Students' perceptions of reasons for collaborative information activities.

Students were then asked about the outcomes of their collaborative information activities and how often they were able to find the information collaboratively as a group. Most students agreed that the outcomes of collaborative activities were positive: five students (12%) replied "always", 23 students (55%) replied "often", 13 students (31%) replied "occasionally", and one student (2%) replied "rarely.

Students were also asked about the tools that they used for information sharing during their collaborative information-related activities. All students (100%) used email and face-to-face meetings, and file sharing tools including Google Docs or DropBox®, 31 students (74%) used phone calls, eight students (19%) used instant messaging tools, and two students (5%) used social networking sites such as Facebook.

In an open ended question, 38 students (90%) said that in addition to using collaborative technical tools, they shared information all the time during their weekly in-person meetings to discuss how the information could be relevant and how it could be used for their projects.

4.1.8 Critical stages in the project

An open ended question asked the students to describe a critical stage in their project when there was a high need for information. Twenty-nine students (48%) chose the beginning of the project, that point when they collaboratively identified the information needed to start the project. This required them to meet and assign tasks with regard to seeking background information. In contrast, 17 students (40%) described the selection of the solution to be the most critical part, a time when they experienced more collaborative activity in order to evaluate the relevance of available methods and solutions, and to decide which solution to select. Five students (12%) described understanding the subject of the project as the most complex task requiring them to engage in more collaborative activities. Specifically they needed to work together to define the information they would need because their engineering program to date had not provided them with the necessary knowledge of the subject pertaining to their projects.

4.2 The research conceptual framework

Previous descriptive statistical analysis of the closed ended questions of the survey provided preliminary insights that helped me to construct a conceptual framework for the research to guide the interpretative analysis of responses to open-ended questions, students' deliverables, and interviews in Study 2. Findings at this stage of the research included the fact that collaborative information behavior had occurred during these projects, and that these activities varied in different stages of their projects. How students perceived these activities varied, and this is reflected in the responses to the survey.

The findings also described the nature of engineering projects as information intensive tasks in which students had to acquire information in many types and formats. Students approached people as information channels in addition to using documentary information channels to search for documents.

As this study covers a complex phenomenon that has many dimensions, it has been critical for me to outline these dimensions at this stage of the dissertation. The dimensions identified with respect to the research objective and according to my research paradigm, to investigate the effect of the learning task on students' collaborative information behavior, are:

1- The learning task characteristics: This dimension represents the learning task's characteristics associated with engineering design projects in their relationship to information behavior.

2- The learner knowledge: This dimension represents constituents of students' knowledge as related mainly to information seeking, searching, and use.

3- The activity and interaction: This dimension represents active information related activities that students were engaged with during their assigned learning tasks.

4- The information objects: This dimension represents the information sources that students used during their learning tasks.

A conceptual framework (Figure 4.5), based on these four main dimensions identified in this pilot study, was developed to describe the relationships between these dimensions as constituents of students' collaborative information behavior.

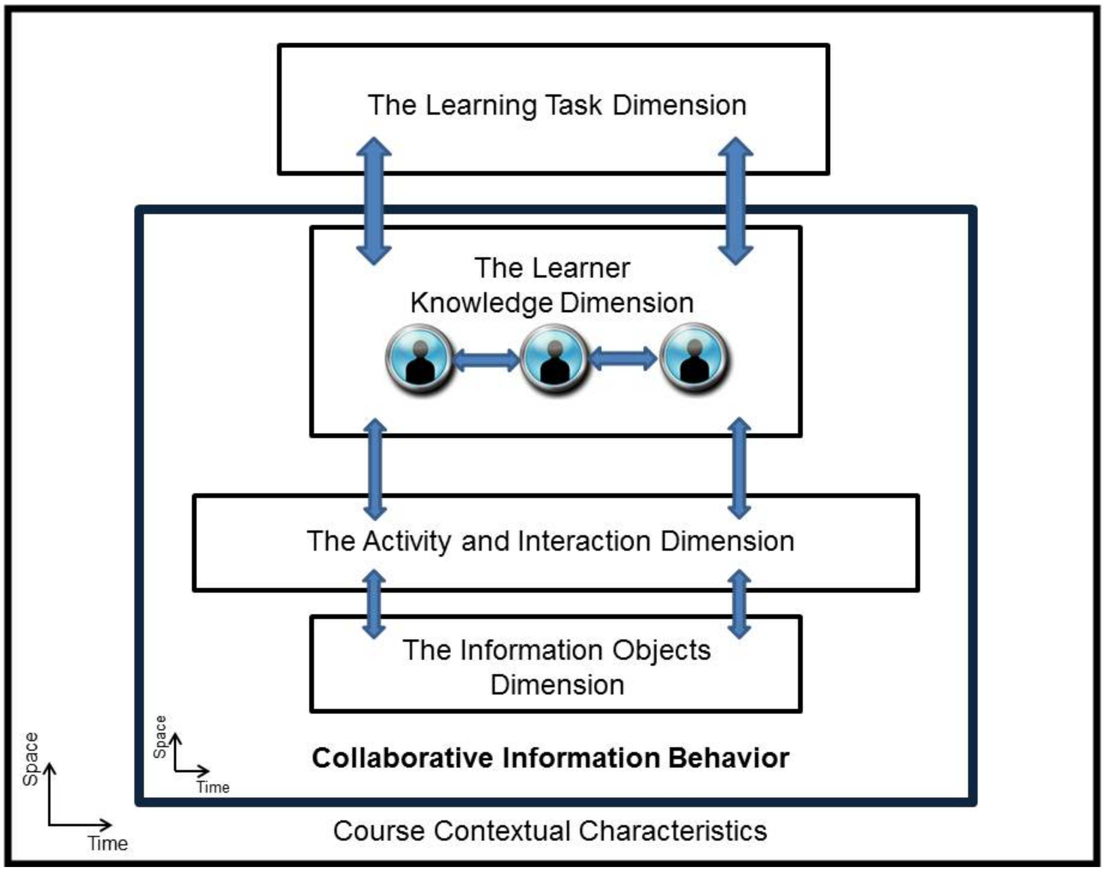


Figure 4.5: The research conceptual framework

In the context of the engineering course, students are assigned to different projects. The project is the learning task that has objective characteristics as designed by the course instructor. These objective characteristics are perceived by students who are situated in different project groups. The arrows of time and space represent the dynamic nature of both the collaborative information behavior and the engineering course.

The collaborative information behavior in this developed conceptual framework includes three dimensions: (1) the learner knowledge dimension, (2) the activity and interaction dimension, and (3) the information objects dimension. The arrows in the figure depict the relationship between these dimensions. The arrows between different dimensions represent relationships that will be investigated further in this thesis.

The three dimensions of collaborative information behavior and the learning task dimension are all embedded within the course contextual characteristics. The course contextual characteristics were not studied separately; they were included throughout for their effects on the learning task characteristics.

5. THE LEARNING TASK DIMENSION

This chapter presents my findings as to the learning task dimension, the first component of the study's conceptual framework. By way of this dimension, engineering design projects assigned as learning tasks were analyzed according to objective task characteristics, task stages and key components found to contribute to the objective task complexity. The learning task dimension only represents the findings on objective characteristics related to the task's information requirements found to affect task performers' information behavior.

5.1 Learning task stages

Engineering design projects as learning tasks were found to include many consecutive and interrelated stages. These stages have corresponding phases that are structured according to the information requirements of the project.

Learning task stages were found to be akin to the associated stages of problem solving (Newell & Simon, 1972) as: (1) problem definition, (2) identification of possible solutions to the problem, (3) selection of a solution, and (4) the development of this selected solution. Each stage within the learning task was found to have corresponding subtasks representing different project phases. The learning task stages were found to be: (1) task initiation, (2) task formulation, and (3) task completion.

5.1.1 Task initiation stage

In the first stage of the learning task, students were assigned to groups and given a brief outline as a summary of the project objectives. The project outline provided an overview of the project background, the project scope, the project client's needs, and the client's expectations with regard to the project outcomes. One group received a project description outlining the needs of a general hospital (the client):

> The hospital is looking at the possibility of an ice production plant (or other cooling source) where ice or other chilled material would be produced in the evenings and overnight when electricity costs are lowest, and then, during the day, chilled water would be created from this cold mass to provide the cooling that is needed to the hospital and supplemented by our existing cooling plant. The project would require a thorough analysis to determine size, cost, and economic benefit of chilled water production using this method, as well as an investigation and optimization of what material should be used for the chilled mass. Ice is one obvious solution, but there may be others. The students will provide full rational for their choices and design the layout and equipment required for their solution.

This project description presented the hospital's design need (an ice production plant) and some constraints (hours of operation, the new design is supplementary to the hospital's existing cooling plant). It also provides the expectation that the project will include a variety of design aspects relating to the proposed solution (e.g., cost, selected materials, and selected equipment).

At this stage, it was found that there are three corresponding phases related to task initiation: (1) project preparation, (2) problem comprehension, and (3) project background research.

5.1.1.1 Project preparation phase

This first project phase occurred during the first week of the project. During this phase, students started to get to know each other. They discussed their schedules and their availability to work on the project, as they had different schedules based on the courses they were taking during the academic semester. Students had to develop a time schedule for the group comprising weekly meetings and also a weekly meeting with the instruction team (the course instructor, and the group's assigned teaching assistant).

Some groups mentioned in their first progress report that they created a generic email address for the project group as a more convenient and professional communication tool to be used for correspondence with the project client and the instruction team. Some groups clearly mentioned that this email address was set up to automatically forward all received messages to group members' individual email addresses.

As required by the course structure, students had to delegate and assign administrative roles for each group member to be responsible for one or more administrative parts of the project. Administrative roles included: (1) a client contact person who was responsible for setting up all client meetings, (2) an instruction-team contact person responsible for setting up meetings with instructors and teaching assistants and also for correspondence if they had any questions regarding their project, and (3) a treasurer in charge of all cost reimbursements and other financial matters throughout the course of the project.

Afterwards, each group had to contact their project client, who had already assigned a dedicated employee to be the contact person during the lifespan of the project. Initial contact with the client took different forms depending on the geographical location of the client and also on the availability of the project client to meet in person. Initial contact with the client representative occurred through face-to-face meetings, by exchanging emails, or by arranging a conference phone call with the project group members.

5.1.1.2 Project problem analysis phase

During this phase students had to clearly define and detail the problem posed by their project based on the information they had from the project description and from their initial contact with the client representative. Each group had to come up with a defined problem statement and to send it to the instruction team and the client representative for review before the end of the second week of the project.

The problem statement developed by each group had to be reviewed and approved by the instruction team and the project client. After each group received approval, students developed a list of all planned future activities and work tasks for the project and the time needed for each activity. Some groups categorized all project tasks and developed a work breakdown structure (WBS) to list all project activities. As required by the course structure, each group had to develop a spatial representation of the tasks' schedule and their planned deadlines. One of the commonly used spatial representations in engineering projects is a *Gantt Chart*, a bar chart developed by Henry Gantt in the 1910s to illustrate a project schedule from start to end by showing dependency relationships between work activities

(Wilson, 2003). Gantt charts are commonly used in engineering projects. Students in this course were familiar with this tool because they had already used it in previous courses.

5.1.1.3 Project background research phase

During this phase students had to conduct initial background research as a course requirement. Although the extent and details of background research in this phase depended on the nature of each project, all groups conducted research about their project clients. This information included the client's current customers or users of service, their existing market, and their future potential markets. The background research also included an identification of some of the client's major competitors and their market share. Some groups conducted site visits to learn more about their project and to meet with other employees of the client company who might provide students with further needed information.

More background research was conducted to gain more knowledge about the domain of the project topic. The domain of the project refers to subject-related knowledge related to each project problem and its required solution as described in the project problem statement.

All groups conducted this background research as they had to produce two required course deliverables in the form of project brief reports: (1) a project brief report due at the end of the third week of the project to state the defined problem statement and the background research, and (2) a second project brief due at the end of the fifth week of the project to report on the user and market research of the project's client products or services.

5.1.2 Task formulation stage

This stage started by the sixth week of the project as stipulated by the course structure. However, during the interviews in Study 2, some students mentioned that they started some activities related to this stage earlier or a week later than expected. The task formulation stage resulted in a design solution to the project. This stage consisted of three phases: (1) design ideas generation, (2) design ideas evaluation, and (3) design idea selection.

5.1.2.1 Design ideas generation phase

In this phase, students brainstormed ideas for suitable possible designs that might meet the project requirements. Students' deliverables showed that all groups were able to generate at least three different ideas for their project solution. Within most project groups, each member was able to come up with a different design idea. By contrast, very few groups have mentioned that they generated these different ideas as a group.

All groups had to present their developed morphological charts along with detailed descriptions of each generated design idea in a project brief report that was due in the seventh week of the project.

5.1.2.2 Design ideas evaluation phase

In this phase, students had to identify advantages and disadvantages of each generated idea for their design solutions by developing their own evaluation criteria. Evaluation criteria varied among different project groups to include, for example, safety, reliability, manufacture ease, installation, and durability.

Students had to report the process of evaluating different design ideas and a justification for the selected design idea in a project brief report that was due in the ninth week of the project.

5.1.2.3 Design decision making phase

In this phase, students had to provide more details of their selected solution and its related monetary and technical specifications. Students developed some detailed sketches of the proposed design solution and shared them with the project client representative for review and feedback. All project groups had to get approval for their selected design idea from the course instruction team and then from their project' client that the design solution was feasible enough to meet the client's needs.

At the end of this phase, students had to compile their work on the project into one interim report that included their previous brief project reports along with detailed descriptions of the process they followed in selecting one design solution. The interim report was due in the twelfth week of the project, and each group had also to present their findings through an in-class presentation to the course instruction team and other student groups for feedback and suggestions.

5.1.3 Task completion stage

This stage started in the thirteenth week of the project after each group had agreed upon a design solution and got the necessary approval from their project client. The main difference between this stage and the former two stages is that there were no required project brief reports from students. The task completion stage included three phases: (1) design solution refinement, (2) design prototyping and testing, and (3) project closing.

5.1.3.1 Design solution refinement phase

In this phase, students had to further develop their selected design solution by choosing appropriate materials and parts that constituted the components of the design solution. During this phase, students also had to contact different suppliers to get price quotations for any materials and parts. Each group evaluated these different price quotations to select the best supplier to provide the materials based on the available project budget. Subsequently students needed to get approval for procurement from the project client representative before buying any materials or parts.

Students had also to develop drawings and technical specifications that included all the design and operational requirements for the developed design solution.

5.1.3.2 Design prototyping and testing phase

A design prototype is a physical or virtual representation that is often built early to model an engineering design. A design prototype acts as an objective artifact used to test a new design and also to learn how the design can be developed further (Eggert, 2005).

Students developed their design prototypes using different techniques. Some groups had to purchase parts and materials for the product prototyping while others developed virtual prototypes using design simulation software packages such as Solid Edge® (Siemens, 2012). Some groups preferred to build both virtual and physical prototypes for their products; following the specifications of a virtual model of the design product, they would then create a physical prototype using a three dimensional printer.

During this phase, students also had to test the prototype based on the planned operational limits. They also needed to update, when necessary, the design from the previous phases if there were additional findings from this performed test that should be incorporated in the design solution. Students had to make any necessary changes to the design based on the findings from the testing process and then finalize the documentation to include the method of manufacturing and the product operational specifications.

5.1.3.3 Project closure phase

As the last phase of the project, students had to prepare a final report that incorporated all the design processes they had used and their justification of their selected design solution. Students presented their final report to the project client and the course instruction team in the 23rd week of the project. Students had also to make any necessary changes based on the feedback and recommendations from the client. At the end of the project, students had to deliver all of their project work on compact discs to both the project client and the course instruction team.

5.1.4 Recurring subtasks in all project stages

In addition to the previous three stages and their corresponding phases, there were other recurring subtasks that students had to perform in these project stages. Students had weekly meetings with the course instruction team for updates and review of the project progress. Also, students had to maintain contact with the project client representative, either through site visits if possible or periodic conference calls to ask questions and update team progress. Students had to update the project time schedule with the accomplished tasks and make any changes to it when needed. They also had to monitor and update the allocated project budget with their expenditures on any required materials or parts for the prototype construction.

5.1.5 Conceptualization of learning task stages

The learning task was characterized by its main three stages with their associated phases. The learning task was found to be a process that had different work related activities that students performed based on the nature of their assigned engineering design project. These stages and phases were sequential during the lifespan of the project; each stage or phase was dependent on its previous one and could not be initiated before the completion of its precedents. The timeliness of project phases was guided by the course structure that required students to finalize task initiation and formulation stages during the first academic term, and to perform the task completion stage within the second term. Figure 5.1 represents a conceptualization of the learning task stages and its phases. The phases of the task completion stages were highly interrelated and iterative in nature.

<table>
<tr><td></td><td colspan="12">Fall Term
September to December</td><td colspan="5">Winter Term
January to April</td></tr>
<tr><td>Week</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>8</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>…</td><td>25</td><td>26</td></tr>
<tr><td>Stages</td><td colspan="5">(1) Task Initiation</td><td colspan="7">(2) Task Formulation</td><td colspan="5">(3) Task Completion</td></tr>
<tr><td rowspan="3">Phases</td><td colspan="5">Project preparation
(ends at week 1)</td><td colspan="7">Design ideas generation
(ends at week 7)</td><td colspan="5">Design solution refinement</td></tr>
<tr><td colspan="5">Project problem analysis
(ends at week 2)</td><td colspan="7">Design ideas evaluation
(ends at week 10)</td><td colspan="5">Design prototyping and testing</td></tr>
<tr><td colspan="5">Project background research
(ends at week 5)</td><td colspan="7">Design decision making
(ends at week 12)</td><td colspan="5">Project closure
(ends at week 24)</td></tr>
<tr><td>Recurring Subtasks</td><td colspan="16">• Contact with the project client
• Contact with the course instruction team
• Weekly group meetings
• Update of both the project time and the project budget.</td></tr>
</table>

Figure 5.1: A conceptualization of the learning task stages

5.2 Learning task complexity

In this dissertation, task complexity was approached from two perspectives: (1) objective task complexity, and (2) subjective task complexity. In the former approach, task complexity is determined independent of the task performers; components and variables of the task itself are examined irrespective of who would perform the task. In the latter, task complexity is determined based on the subjective interaction between the task and its performers; perceived task complexity is examined through the ways task performers perceived the task requirements.

The first perspective, presented in this section, is the objective approach, which determines task complexity by way of the characteristics of the task's components and variables. The second perspective, the perceived task complexity, will be discussed in the following chapter as part of the learner's knowledge dimension.

Task complexity, defined in this section through its objective characteristics, has six related traits: (1) the course learning objectives, (2) the learning task objectives, (3) the learning task requirements, (4) the interdependence of the learning task components, (5) the learning task subject-specific skills demands, and (6) the learning task cognitive demands.

5.2.1 The course learning objectives

The learning objectives for the course were designed around project-based learning as a comprehensive approach, supplementary to classroom teaching and learning, in which students engage in the investigation and solving of authentic engineering problems. The course extended students' knowledge, acquired in previous academic courses, to include real-world engineering situations. The summary description of the course learning objectives stated:

> Building on the design engineering fundamentals learned in prerequisite courses, the objective of this course is to further develop the student's design, innovation, and professional skills. Working in multi-disciplinary teams, students will engage in real-world design projects typically offered

> by industry based clients. While designing a product, process, or system, design processes will be applied from problem definition through validation of physical prototypes or digital/mathematical models. Accompanying lectures, exercises, tutorials, and guest speakers will augment the projects

The overall course learning-objective included components of the objective task complexity. The newness of the situation resided in the fact that students did not have prior experience working on a real engineering project with industry based clients. Students were expected to bring their accumulated knowledge and skills in engineering problem solving and design, acquired in previous years of study, to this new course, a compulsory capstone course needed for graduation.

The course learning objectives also identify task complexity in its requirement that, in addition to receiving guidance through lectures, exercises, and guest lectures, students engage in self-regulated learning. In self-regulated learning, students are expected to experience personal control over the planning of their learning, and also the management of their learning experience. Self-regulated learning was found not to be that common in comparison with other undergraduate courses in which teaching and learning occurred by way of lectures, workshops or laboratory sessions. The course description presents this unfamiliar and complex situation to students as a new and invaluable learning opportunity:

> The overall objective of this course is to provide you with an opportunity to enhance and practice your engineering design and professional skills learned, while continuing to learn more advanced design techniques and practical engineering skills. Working in multidisciplinary teams, you will

> tackle a real industry-based design project. Both faculty supervisors and industry mentors will be provided, giving you the opportunity to work first-hand with the industry sponsor. This experience will be an invaluable learning opportunity for your career in industry, building the design, technical and professional skills necessary for a practicing engineer.

The course learning objectives were achieved through a number of projects assigned to different groups whose size ranged from a minimum of two students to a maximum of four students per group. Although each project was unique in context and nature, as guided by the client's needs, all projects had to meet the overall course objectives.

All projects in this course were presented to students in a brief description of the client's request and problems. During the following phases of these projects, students had to identify the main problem and then engage in a number of activities resulting in a series of artifacts or products that concluded in a final product that addressed the driving goal of the project. During these project activities, students had full responsibility for the creation of both the problem statement and the corresponding activities to solve their project problem. Students also had to provide full documentation for the developed artifacts in their projects.

5.2.2 The learning task objectives

Learning task objectives were contained in the project descriptions given to students at the beginning of the course. All projects described varying degrees of objective complexity by which students could attempt to plan and manage their actions. In the task initiation stage, students learned what they were expected to do in order to meet their project's objectives. The objective complexity of the learning task could be assessed based on the number and characteristics of the various connected parts described in the project objectives.

Project descriptions defined the objectives of each project and the overall project client's expectations in a few sentences in one or two short paragraphs. The following is a project description to develop a solar energy solution:

> Solar Technologies, a Canadian company located in Toronto, has asked us to design a new solar rack/solar rack mounting system that incorporates some specific features. The solar rack design needs to be lightweight and easy to use/install while still having high durability. The design must meet all standards and codes and must be manufactured in a cost-efficient manner. It is encouraged that the design be modular and also be able to adapt to seasonal sun positions.

The technical scope of this project involves creating a specification that leads to a design for a product to meet the client's needs. The interconnected components in the project topic come together to address the needs of a solar technologies company, specifically a solar panel rack mounting system able to be used for a variety of applications through different constraints in manufacturing and installation. The design as described should also meet some preferred features with respect to the product's overall weight and durability. Project complexity is further seen in the requirement that the design product meet not only the client's preferences but also engineering and government standards regulating the development and use of these products.

The final design product also needed to be modular, i.e., consisting of a number of modules or components that needed to be manufactured separately and assembled to work together. Adding to the objective complexity of this project were the manufacturing cost and the marketability of the product within the price range of similar products sold.

In addition to the technical knowledge and skills they needed to solve the engineering problem, students working on this project had to gain knowledge in such non-technical subject areas as weather conditions in Canada and seasonal sun positions, to select the best materials and calculate the optimal positioning angles of the rack mount.

Another complicated project called for an energy efficiency retrofit at regional long-term care home in Ontario:

> The project objective is to analyze the energy usage at Green Manor and suggest solutions to elements of the building where the current needs of the residents remain satisfied while the energy consumption is significantly reduced. Such elements would include HVAC, heating, cooling, lighting, domestic hot water, and domestic cold water. A thorough energy analysis of the current situation at Green Manor will help define the critical areas of focus. All possible solutions should be assessed to ensure they meet the standards and regulations for Long Term Care facilities, as well as any other governmental laws. The sustainability and suitability of each solution should be evaluated in order to determine the most appropriate changes for Green Manor.

The project objectives here described similar constraints to the previous project, in the large number of components that would have to be addressed in any design solution. In this case the constraints included a number of technologies (mechanical, hydraulic, and electrical) and the existing energy usage in the building. Similar to the previous project description, this project required students to design a solution based on existing efficiency and safety standards and government regulations.

Objective task complexity is further increased when students realize that their project must meet not only the objectives of the course but those of the overall engineering program. The engineering program objectives are outlined in the twelve graduate attributes established by the Canadian Engineering Accreditation Board (CEAB, 2011). This particular engineering design course was designed to meet many of these accreditation criteria, particularly the four graduating attributes of: (1) design, (2) use of engineering tools, (3) problem analysis, and (4) investigation.

The first CEAB graduate attribute is *design*, a core objective of learning tasks investigated in this dissertation,:

> Design: An ability to design solutions for *complex* [emphasis added], open-ended engineering problems and to design systems components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, economic, environmental, cultural and societal considerations (CEAB, 2011, p. 12)

Design, as a CEAB graduate attribute, states that engineering students need to develop design solutions to real-world, complex engineering problems and to take into consideration the many related dimensions that could affect any proposed solution, including such non-technical dimensions as health, safety, environmental, and societal considerations. Design can be generally viewed as a complex process requiring the development of a solution within many constraints.

The second CEAB graduate attribute, *use of engineering tools,* a demonstrated engineering skill necessary to any engineering task, is described as:

> an ability to create, select, apply, adapt, and extend appropriate techniques resources, and modern engineering tools to a range of engineering activities, from simple to *complex* [emphasis added], with an understanding of the associated limitations (CEAB, 2011, p. 13).

This CEAB graduate attribute describes the number of possible engineering tools and techniques that students need to use, although it does not describe the nature or the characteristics of these possible tools. The appropriateness of using any engineering tool in learning tasks was found to be dependent on both the task at hand and students' knowledge of these tools. Objective task complexity in this case depended on the number of possible engineering tools used, the purpose of using them, and the different ways students would use these tools during their learning tasks.

The third CEAB graduate attribute is *problem analysis*:

> an ability to use appropriate knowledge and principles to identify, formulate, analyze, and solve *complex* [emphasis added] engineering problems in order to reach substantiated conclusions (CEAB, 2011, p. 12)

Learning task complexity with regard to this attribute is calculated according to the different problem solving skills students have learned in their prior courses and their ability to transfer them to this senior design course. However, the nature and the context of the engineering problems encountered in this course were different from the projects students had previously experienced, as they were now dealing with real-world engineering problems for real industry or community partners. The problems in this course had different characteristics than the problems students had to solve in other courses.

Another dimension to task complexity involved the possible problem solving techniques that students practiced in their previous courses and how they practiced them. The selection of an appropriate problem solving technique from many possible and available techniques would add to the task complexity.

The fourth CEAB graduate attribute related to learning task objectives in this research is investigation. Investigation, as an engineering graduate attribute, is the only attribute within the twelve CEAB graduate attributes that explicitly mentions *information*:

> Investigation**:** An ability to conduct investigations of *complex* [emphasis added] problems by methods that include appropriate experiments, analysis and interpretation of data and *synthesis of information* [emphasis added] in order to reach valid conclusions (CEAB, 2011, p. 12)

The need for data and information to develop any engineering solution adds to task complexity. Information pertains to the learning task itself or any possible constraint that might impact the selected solution.

The CEAB graduate attribute of *investigation* includes appropriate analysis and interpretation of data and synthesis of information but does not define what appropriate techniques might be. Compared to the rigor with which they were taught in their previous courses to use engineering tools, the students in this study were not taught in a formal way to synthesize information.

5.2.3 Learning task requirements

In the learning task stages, project tasks and phases were closely associated with required deliverables for the course. The deliverables were the reports students had to write describing their project's progress and their activities during the learning task performance.

All project groups had to develop weekly reports on the progress of the project activities, and to identify any new issues that occurred during that week. Weekly project progress reports included activities planned for the following week. In addition, students had to submit a weekly group memo to the course instruction team as a self-report on what each group member did during that week. Every student group discussed their weekly reports in their weekly meeting with the instruction team to get any necessary feedback. Examples of weekly memos and progress reports are attached in Appendix 3.

Project groups were also required to submit other documents: a time schedule for the project, four brief project reports, an interim report, and a final report. All project deliverables, describing each project phase, were used to construct the final design report of what had been achieved over the lifespan of the project.

The findings in the learning task stages in section 5.1 demonstrated that project phases were time-bound with a required course deliverable that students had to develop at the end of each project phase as shown in Figure 5.2. The number and sequential nature of these learning task deliverables tended to increase objective task complexity.

<table>
<tr><th></th><th colspan="12">Fall Term
September to December</th><th colspan="5">Winter Term
January to April</th></tr>
<tr><td>Week</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>8</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>…</td><td>25</td><td>26</td></tr>
<tr><td>Stages</td><td colspan="5">(1) Task Initiation</td><td colspan="7">(2) Task Formulation</td><td colspan="5">(3) Task Completion</td></tr>
<tr><td rowspan="3">Learning Task Deliverables</td><td colspan="5">W2: Project time schedule</td><td colspan="7">W7: Project brief report #3: Idea generation.</td><td colspan="5">W23: Initial final report</td></tr>
<tr><td colspan="5">W3: Project brief report #1: Problem definition and background research.</td><td colspan="7">W9: Project brief report #4: Design selection</td><td colspan="5">W24: Final project presentation</td></tr>
<tr><td colspan="5">W5: Project brief report #2: Market and user analysis</td><td colspan="7">W12: Interim report & presentation</td><td colspan="5">W26: Final report</td></tr>
<tr><td>Recurring Deliverables</td><td colspan="17">Weekly group memos (W1 to W23)
Weekly project progress reports (W1 to W23)</td></tr>
</table>

Figure 5.2: Learning task requirements

5.2.4 Interdependence of learning task components

Many independent but interrelated components constitute the learning task. These components represent activities that are time-bound to task requirements and interdependent with respect to the objective goals of the task. The selection and implementation of a design solution for a product, for example, was dependent on identified possible ideas for the product, in turn based on information about the product, the company, the user and the market.

Learning task complexity is a product of the linkage and interdependence of its multiple components. Each component of the learning task depends on a single precedent or many previous components. Task components include one or more activities that have occurred in different phases of the project and have adhered to the tasks' sequential requirements. The completion of these several project components acted as inputs to the completion of the learning task.

The interdependence of learning task components also impacted the complexity of information exchange among task performers, in that it affected "the degree to which group members have to exchange information and/or means for the completion of the group task." (van Vijfeijken, Kleingeld, Tuijl, Algera, & Thierry, 2002, p. 366).

In situations of high task interdependence such as the generation of design ideas and development of a design solution, group members were expected to coordinate actions and develop task strategies. My research found that in situations of high task interdependence groups felt a greater need to coordinate their activities and collaborate in executing both individual and group tasks. This relationship between task component interdependence and students' collaborative activities in information seeking, search, and use will be further discussed in the chapter on activities and the interaction dimension.

5.2.5 Learning task domain-specific skills demands

Design in this research describes both the process of making things (designing) and the product of this process (a design). The activity of designing is a user-centered, problem-solving process that requires particular skills that require formal education and training (Best, 2006). In engineering-design learning tasks, students are expected to use multiple skills acquired during design-based courses and from their experience generally in the engineering program. In addition to their knowledge of engineering design, students in this study had to apply such project management skills as project needs analysis, market research, budgeting, time scheduling and management, risk analysis, and human resources management to their learning tasks.

Learning tasks had different objectives and requirements that drew upon a range of design techniques to solve the design problem and to provide a solution that met the needs of the project client. A variety of engineering design techniques was commonly used in many projects. The design skills outlined in this section are examples of those commonly used in the learning tasks that were investigated in this research.

During the project problem analysis phase at the task initiation stage, students needed to use adequate problem-solving techniques. One such commonly used technique in engineering design is *TRIZ.* G.S. Altshuller and his colleagues developed the TRIZ method between 1946 and 1985; TRIZ is a Russian acronym that stands for *Teoriya Resheniya Izobreatatelskikh Zadatch,* which, translated into English, approximates to the *Theory of Inventive Problem Solving* (Altshuller, 2004). TRIZ is a problem-solving methodology based on logic, data, and research and is specifically designed to solve engineering problems (Jugulum & Samuel, 2008).

The logic behind TRIZ is that engineers should be aware that "somebody someplace has already solved that problem…or one very similar to it" (Altshuller, 2004, p. 26). Accordingly, because the same engineering problems and solutions appear again and again across different industries, there should be no need for engineering to re-invent the wheel to provide a totally original solution, but rather be creative in a way: (1) to identify possible solutions for the problem, (2) to select the most appropriate solution, and (3) to adapt this selected solution to the particular design problem.

In adopting TRIZ as a design problem solving technique (Figure 5.3), designers start first with a specific engineering problem, compare this problem against already defined similar problems in that engineering area, analyze solutions that were implemented to solve similar problems, and then select the most appropriate solution to the design problem at hand. Designers adapt this generic solution within such constraints as availability of resources and cost of materials to meet their project objectives.

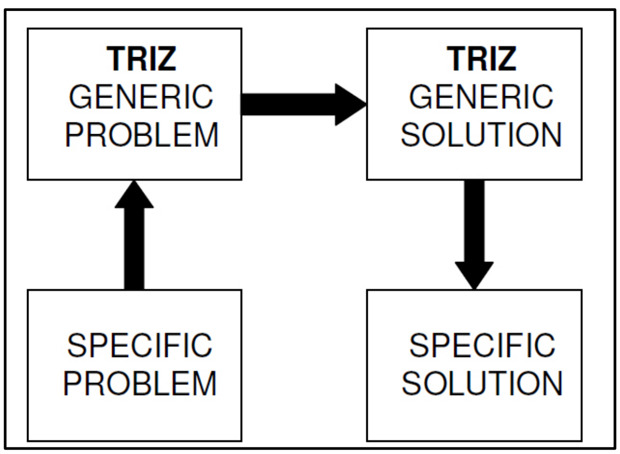


Figure 5.3: The TRIZ problem solving method

During the *design ideas generation* phase of the *learning task formulation* stage of this study, students employed a number of engineering techniques to generate and compare design ideas. One such technique is the development of a *Morphological Chart,* a design technique used to generate ideas in an analytical and systematic manner (Roozenburg & Eekels, 1995). Morphological charts represent possible design solutions that the design group can identify and possibly implement according to their project objectives.

A morphological chart for the design of a corkscrew (Figure 5.4) shows seven possible design concepts selected by one design group and categorized in a matrix according to (1) the possible ways a corkscrew would connect with the bottle cork, and (2) the projected force amplification in uncorking a bottle in each of the developed solution ideas (Pahl, Beitz, & Wallace, 1996).

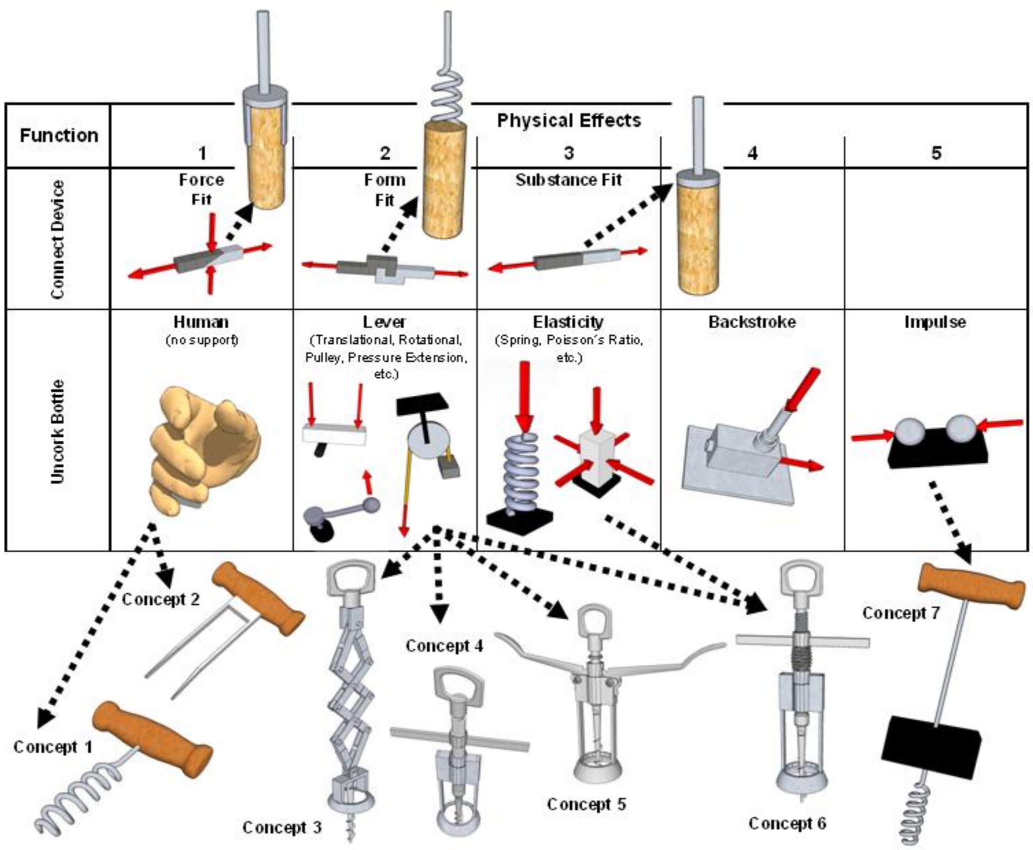


Figure 5.4: An example of a morphological chart for corkscrew design.

Morphological charts always provide a spatial representation of possible design ideas. Designers evaluate the choices based on definite selected criteria in order to select the most appropriate design idea for the design solution.

Beforehand, designers should develop evaluation criteria as references for the selection of one design idea from all the identified ones. Identification of design evaluation criteria is mainly based on the design objectives in relation to all design constraints. Designers define the evaluation criteria according to two categories: mandatory and desirable criteria (Pahl et al., 1996). Mandatory criteria are the requirements that must be satisfied for a design idea to be considered feasible. On the other hand, the desirable criteria are the requirements that would be met to some degree to provide some additional benefits to the design solution.

The evaluation of design ideas requires the use of different engineering design techniques such as a *Weighted Evaluation Matrix* (WEM), a constructed table used to calculate weighted ratings of each design idea based on selected design evaluation criteria (Best, 2006). The WEM evaluates both design and function, producing a score for each suggested design idea.

This evaluation matrix assigns importance weights to each evaluation criterion based on the designers' decision; designers should report and explain how they identified evaluation criteria and their corresponding importance weights. Each design idea is then rated against each criteria and a score of 0 to 4 is given: the lowest score implies an unsatisfactory while the highest score implies a very good performance. Each of these scores is multiplied by the weighting factor and the scores are summed. The highest weighting score for a design idea is an indication of the best design idea that met the evaluation criteria. Table 5.1 shows an example of a weighted evaluation matrix for two design ideas based on selected criteria in which the first design idea was found to be of a higher calculated weighted rating than the second one. The design idea with the highest weighted rating is then selected as the proposed design idea to be developed further.

Table 5.1: An example of a weighted evaluation matrix

		Design Ideas			
		Design Idea 1		Design Idea 2	
Criteria	Importance Weight (%)	Rating	Weighted Rating	Rating	Weighted Rating
Cost	30	4	1.20	2	0.60
Durability	25	4	1.00	3	0.75
Safety	20	4	0.80	3	0.60
Ease of use	15	2	0.30	4	0.60
Efficiency	10	2	0.20	4	0.40
Total	100		3.50		2.95

New engineering products or systems designed to be on the market are often examined through a *Failure Modes and Effects Analysis* to determine the limitations of the designed product. Failure modes and effects analysis (FMEA) are a design control method of investigation for determining how a product or a system might fail and the likely effects of particular modes of failure (Ruggeri, Kenett, & Faltin, 2007, p. 656). Designers conduct FMEA as a design technique to "define, identify, and eliminate known errors or potential problems from the design solution before it reaches the client" (Omdahl, 1988, p. 91). It is a commonly used technique in product development to: (1) identify and recognize potential failures including their causes and effects, (2) evaluate and prioritize identified failure modes, and (3) identify and suggest actions that can eliminate or reduce the chance of the potential failures from occurring (Ben-Daya, 2009, pp. 76-77).

For example, in a project that examines the development of an electrical system for an electrical vehicle tractor, designers would perform the FMEA analysis to test the conditions within which the electrical system of the tractor can work properly in order to define the limits of operation. FMEA helps designers assess the possible ways failures might occur during tractor operation, and the magnitude of those failure effects, in order to uncover the possible causes of failure.

There are different approaches in FMEA with recommended guidelines and recommendations on how to perform such an analysis for different engineering design projects (Stamatis, 2003). There is no standardized way as to how FMEA should be performed, but there are best practices that require designers to report how any failure modes were identified, assessed, and measured during the product design process (Ben-Daya, 2009). FMEA includes many logical and mathematical approaches to identify possible failure modes that could affect the designed product. In general, designers identify and then rank the criteria of any detected failure, as shown in Table 5.2, based on a scale from 1 to 10: the number 1 implies the highest rank of a failure occurrence, i.e., a certain failure, while 10 implies the lowest rank, indicating failure to be an uncertain or improbable occurrence in the developed product (Breiing, Engelmann, & Gutowski, 2009).

Table 5.2: Evaluation criteria and ranking system in a design FMEA

Detection	Criteria (likelihood of detection by design control)	Rank
Absolute uncertainty	Design control does not detect a potential cause of failure or subsequent failure mode; or there is no design control	10
Very remote	Very remote chance the design control will detect a potential cause of failure or subsequent failure mode	9
Remote	Remote chance the design control will detect a potential cause of failure or subsequent failure mode	8
Very low	Very low chance the design control will detect a potential cause of failure or subsequent failure mode	7
Low	Low chance the design control will detect a potential cause of failure or subsequent failure mode	6
Moderate	Moderate chance the design control will detect a potential cause of failure or subsequent failure mode	5
Moderately high	Moderately high chance the design control will detect a potential cause of failure or subsequent failure mode	4
High	High chance the design control will detect a potential cause of failure or subsequent failure mode	3
Very high	Very high chance the design control will detect a potential cause of failure or subsequent failure mode	2
Almost certain	Design control will almost certainly detect a potential cause of failure or subsequent failure mode	1

Note. Adapted from "Reprioritization of Failures in a Silane Supply System Using an Intuitionistic Fuzzy Set Ranking Technique," by K.-H. Chang, C.-H. Cheng, and Y.-C. Chang, 2010, Soft Computing - A Fusion of Foundations, Methodologies and Applications, 14, 3, p. 286. Copyright 2010 by Springer-Verlag.

The results from FMEA identify corrective actions required to prevent failures from reaching the product users, thereby enabling designers to understand what design changes are needed to prevent such failures or to mitigate the likelihood of their occurring if they are not avoidable (Eggert, 2005; Roozenburg & Eekels, 1995).

Finally, prototyping is also a required engineering skill commonly used in engineering projects to represent the resultant creation of an original model in a way that is suitable for evaluation and testing. Prototyping is utilized as a basis for production of current and future models (Kaplan, 2004, p. 609). These original models are called prototypes whether they are developed as physical models or virtual ones using computer aided design.

Prototypes depend on the nature of the project. Design prototypes in this research were found to be one of the following categories (Walker, 1998):

1. Proof of principle prototype: This model acts as a proof of the design concept without attempting to simulate the visual appearance or the selected materials.
2. Visual prototype: This model captures all intended design aesthetic and simulates the appearance, color, and surface textures of the intended design product.
3. Form study prototype: This model allows designers to explore the basic size, look, and feel of the design product without simulating the actual function or visual appearance of the product.
4. User experience prototype: This model represents the overall size, proportions, interfaces, and articulation of the design solution in order to define possible use scenarios and to understand how a potential user would interact with this developed solution.
5. Functional prototype: This represents a working model of the design solution, usually a scaled down prototype from the objective size of

the design product, to simulate the functionality of the proposed design.

The previous examples of engineering skills demanded for the performance of the learning tasks add an important dimension to the objective learning task complexity. They require students' (1) awareness of these engineering design techniques, (2) knowledge of the use of these techniques, (3) selection of appropriate design techniques, and (4) awareness of the interdependence of these engineering skills and techniques during the project performance.

5.2.6 Learning task cognitive demands

Finally, I looked at learning task complexity by way of its cognitive demands. In addition to the engineering-skill demands described in the previous section, my research found that engineering projects as learning tasks required high levels of cognition in the performance of the learning task in its different stages. In order to analyze a learning task's cognitive demands independent of its performers, I referred to Bloom's taxonomy of educational objectives (Bloom, Engelhart, Furst, & Krathwohl, 1956). Bloom's taxonomy, a well-established scheme for classifying educational objectives, describes the associated cognitive processes learners undergo while they learn. Bloom's taxonomy identified six levels within the cognitive domain (Figure 5.5), from the simple recall or recognition of facts as the lowest level, through increasingly more complex and abstract mental levels, to the highest order, which was classified as evaluation. The identified structured components of Bloom's taxonomy, from the lowest cognitive level to the highest, were: knowledge, comprehension, application, analysis, synthesis, and evaluation.

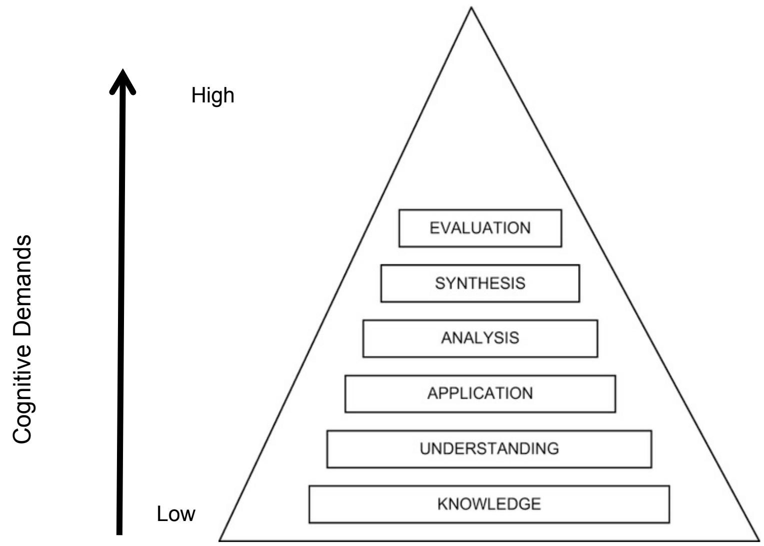


Figure 5.5: Bloom's taxonomy of the cognitive domain.

Bloom's taxonomy was revised by Krathwohl (2002) and Anderson and Krathwohl (2001), taking it from one dimension to two to represent both the knowledge and the cognitive-process dimension (Krathwohl, 2002, p. 213). The main difference between Bloom's original taxonomy and its revised version is that knowledge becomes a standalone dimension affecting the other aspects of the taxonomy. In the revised taxonomy, the cognitive process dimension (Figure 5.6) is represented by six cognitive categories with their associated processes.

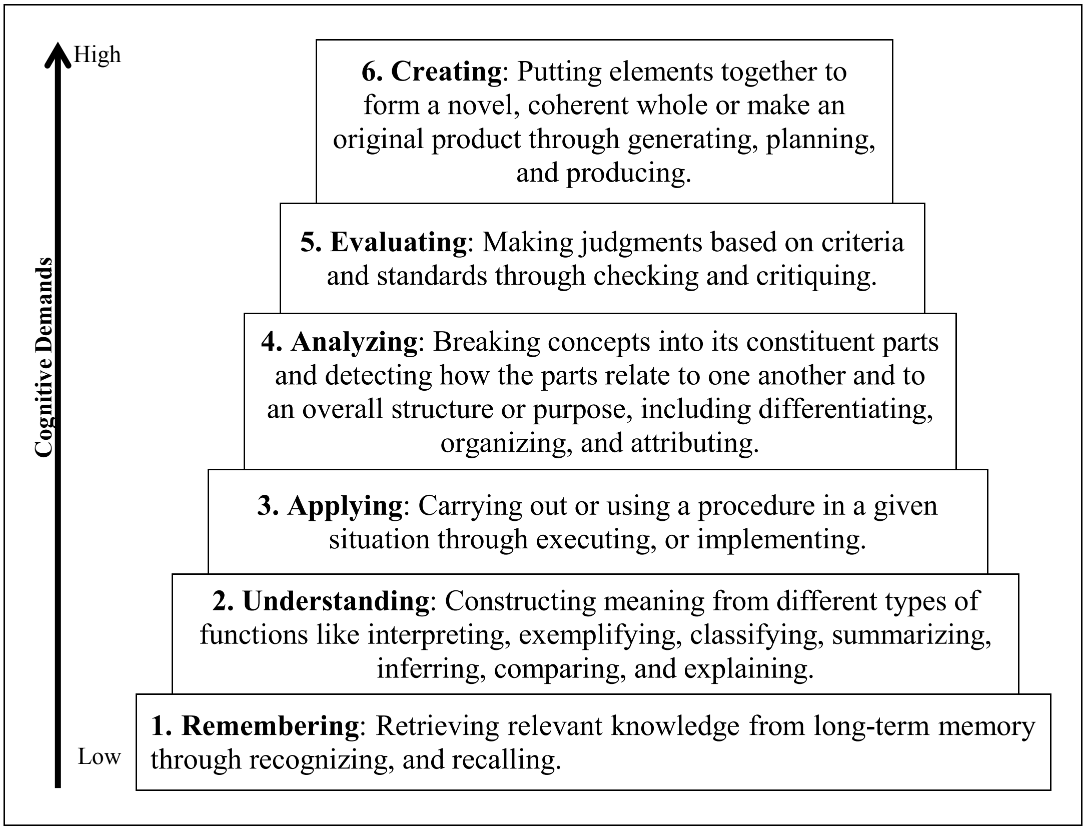


Figure 5.6: The cognitive process dimension (Anderson & Krathwohl, 2011).

The knowledge category in Bloom's taxonomy became *Remembering* to describe retrieval of relevant knowledge from long-term memory, and the two highest cognitive categories in the original taxonomy, synthesis and evaluation, were interchanged in the revised model so that synthesis became related to creation as the highest level of cognitive demand.

The cognitive demands of learning tasks were viewed here as parts of the objective learning task complexity. That is to say, the learning task complexity was analyzed objectively through the cognitive demands of the learning task, demands that may vary dynamically during the different stages and phases of the learning task.

Task complexity was analyzed here based on the types and levels of task components' cognitive process demands. Given that learning tasks in the course under investigation had different objectives, learning task cognitive demands were identified through the analysis of the course learning objectives, the learning task objectives, and the learning task subject-specific skills demands.

The cognitive demands of engineering design projects as learning tasks were defined using the common objectives of the design project and according to the cognitive process dimension of educational objectives. Analysis of cognitive demands was based mainly on their relationship to information behavior, the phenomenon under investigation in this research.

The findings showed that engineering design projects required high levels of cognitive demand in the different learning task stages, particularly with respect to the design and creation of a new product, identified as the highest level of cognitive demand within the cognitive process dimension of educational objectives. A summary of the identified cognitive demands (Table 5.3) describes and ranks the main cognitive demands of those engineering design projects associated with the learning task from lowest to highest.

Table 5.3: The cognitive process dimension of engineering design projects

Cognitive process dimension	Learning task educational objectives
Remembering	• Locating information in long-term memory that is consistent with the objectives of the engineering design project • Recalling and retrieving relevant technical and non-technical information that is related to the engineering design project
Understanding	• Abstracting a design problem statement based on the information of the given engineering design problem • Predicting the required information and resources that are needed for the given engineering design project • Comparing possible design solutions for the given engineering problem • Detecting correspondence and connections between the components of the developed design solution
Applying	• Applying engineering procedures and techniques to a range of engineering activities to solve the given engineering design problem • Using appropriate engineering knowledge and principles to solve complex engineering problems to reach substantiated conclusions
Analyzing	• Deconstructing the engineering design components into activities within time and resources constraints • Determining the available information and select the most relevant information to the given engineering design project • Distinguishing relevant and appropriate engineering knowledge to solve the engineering design problem in order to reach substantiated conclusions • Integrating both engineering and non-engineering knowledge to determine the most appropriate solution to the given problem • Interpreting data in order to make accurate calculations and specifications

Cognitive process dimension	Learning task educational objectives
Evaluating	• Detecting inconsistencies within a process or product that is a part of the given engineering design problem • Synthesizing information to develop a solution for the given engineering design problem • Evaluating all possible developed solutions based on both external and self-identified criteria • Judging the appropriateness of the selected solution to meet the project client needs • Testing the new developed solution or a product to measure the effectiveness of the design
Creating	• Generating alternative possible hypotheses for design solutions to the given engineering design problem • Designing procedures for accomplishing the objectives of the engineering design project • Creating appropriate techniques, resources, and engineering tools to achieve the engineering design objectives • Inventing a new product and solution that meets the specified needs and requirements of the engineering design project

The findings showed that the objectives and the requirements of the learning task resulted in different levels of cognitive demand occurring during different stages and phases of the learning task. These findings relate objective task complexity to the predicted levels of cognitive demands in the learning task, the interrelation between these cognitive demands during the performance of the learning tasks, and the interdependence of these cognitive processes towards the accomplishment of the learning task goals.

Design as a process is highly cognitive and requires not only an understanding of a current engineering problem but also analysis of the problem components, the available information regarding the problem and its requirements, application of different techniques and previous engineering knowledge to reach possible solutions, evaluation of possible solutions based on specific criteria, and finally the creation of an original product or solution that meets existing standards, codes and the project client's requirements.

The high cognitive demands of engineering design projects are related mainly to the creation aspect in the design process. Creating was defined as the highest cognitive process in both the original and reviewed versions of Bloom's taxonomy of education objectives (Anderson & Krathwohl, 2001, pp. 84-85).

Engineering design literature (e.g., Dym & Little, 2008; Eggert, 2005) relates the high cognitive demand in a design project to the *creativity* required in the design process. Different definitions of creativity as a cognitive demand in engineering design have been proposed. Creativity is the cognitive ability "to produce work that is both novel…and appropriate" (Sternberg & Lubart, 1999, p. 3). Creativity is the cognitive ability to produce new and original work that is appropriate to the task constraints. Creativity as a cognitive ability is not only a personality trait; it is also affected by situational factors, such as task characteristics, or expected goals or motivational variables (Förster, Friedman, & Liberman, 2004).

5.3 Conceptualization of the learning task dimension

In the learning task dimension, the objective characteristics of the learning task can be seen in the various learning task stages and in each learning task's complexity. Each learning task stage can be broken down into different phases constituting all the subtasks of the engineering design project from its initiation to its completion. Each phase has its own outcome requiring particular types of information to support the performed subtask.

The learning task stages and phases are akin to the stages of engineering design projects: definition of the design problem, identification of possible solution, selection of a solution, and the development and creation of the selected design solution. The learning task stages were time-bound with project milestones imposed by the engineering course structure.

A high level of objective task complexity was evidenced in the number and interrelationship of learning task components and variables. It was also found that learning tasks were purposefully intended as complex tasks, according to the objectives of both the course and the learning task, with as many constraints as possible as an influencing factor on the types and nature of activities that students would experience during their projects.

The learning task dimension as presented in this chapter describes the general objective characteristics of tasks irrespective of task performers. A general conceptual description of the learning task dimension (Figure 5.7) presents those aspects of the learning task that affect task performers' activities and interaction.

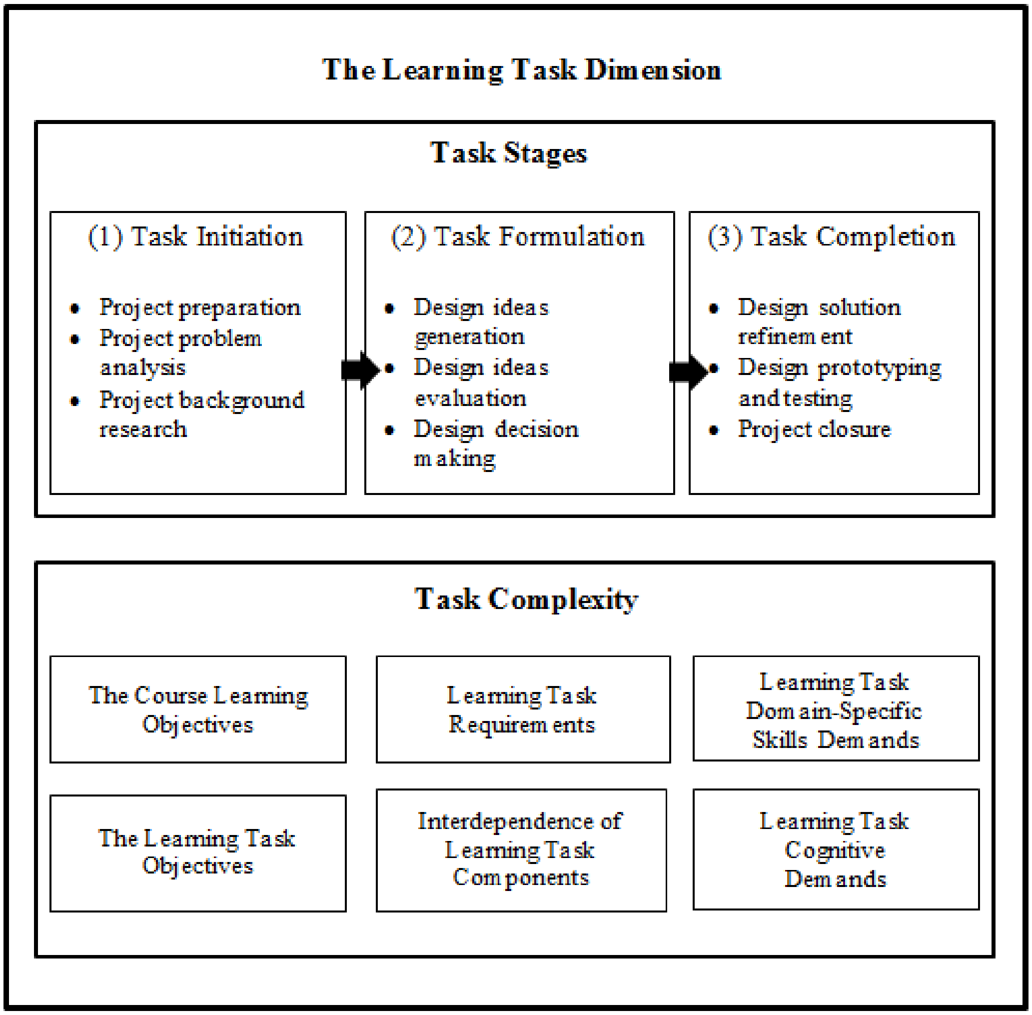


Figure 5.7: A conceptualization of the learning task dimension

The learning task dimension has been described through the different tasks and aspects that constitute objective task complexity. It was found that learning tasks were designed to follow what Jerome Bruner termed discovery learning and learning-by-doing (Bruner, 1990). The learning task as designed within the engineering course created a learning environment in which students were free to choose what to do and what tools and activities to use individually or collaboratively in their project groups. In such learning environments, students were expected to carry out many activities, both cognitive and physical, to meet the learning task objectives; students were expected to execute higher levels of cognitive activities in analyzing the design problem, identifying possible solutions, and selecting and implementing a particular solution to solve the given design problem. Students' cognitive activities are dependent on students' knowledge when they perform their learning tasks. Thus, the following chapter will describe the learner's knowledge dimension in relationship to both their information behavior and the learning task characteristics.

6. THE LEARNER’S KNOWLEDGE DIMENSION

This chapter represents my findings with respect to types and characteristics of learners’ knowledge as they relate to their information behavior. Anderson and Krathwohl (2001) argued that the problem of defining and characterizing how individuals represent their knowledge is so complex that it remains a “classic and enduring question” (p. 40).

The literature identifies many different types of any individual’s knowledge and uses many terms to describe them: prior knowledge, declarative knowledge, domain knowledge, conceptual knowledge, content knowledge, explicit knowledge, procedural knowledge, semantic knowledge, situational knowledge, tacit knowledge, factual knowledge, strategic knowledge, and metacognitive knowledge (see, Alexander, Schallert, & Hare, 1991; de Jong & Ferguson-Hessler, 1996). The variety of knowledge types identified in previous research demonstrates the different ways knowledge can be described, constructed, developed, and represented by individuals.

Given the lack of agreement among scholars as to what constitutes the knowledge dimension of learners in complex tasks, I found that investigating this dimension, by way of these aforementioned knowledge types and through analysis of my research’s empirical data, was a complex process. In considering these multiple constraints, I based the components of my study’s learner’s knowledge dimension on a constructivist approach that maintains that knowledge is domain specific and contextualized. Following this approach, I found that an individual’s knowledge type is a construct of domain specificity, context and experience (Bransford, 2000). The following sections describe the components of students' knowledge that I identified, as they related to their information behavior: information seeking, search, and use as integrated and embedded activities in learning tasks.

6.1 The knowledge dimension in learning

The original Bloom's taxonomy of educational objectives has described knowledge as the first category in the developed model. This category includes three types of knowledge, with corresponding subtypes: (1) knowledge of specifies, (2) knowledge of ways and means of dealing with specifies, and (3) knowledge of universals and abstractions in a field (Bloom et al., 1956). The revised Bloom's taxonomy (Anderson & Krathwohl, 2001) created a newer version as a framework called "the taxonomy table" (P. 27). In this reviewed framework, Bloom's knowledge dimension became a separate dimension to describe his three types of knowledge: Factual, Conceptual, and Procedural, in addition to a new category identified as *Metacognitive Knowledge*. The developed framework mapped the cognitive process dimensions to these four types of knowledge and the objectives of learning activities to both the cognitive-process and the knowledge dimensions; I have developed a representation (Figure 6.1) to map learner's cognitive processes against different types of knowledge through the learning task objectives.

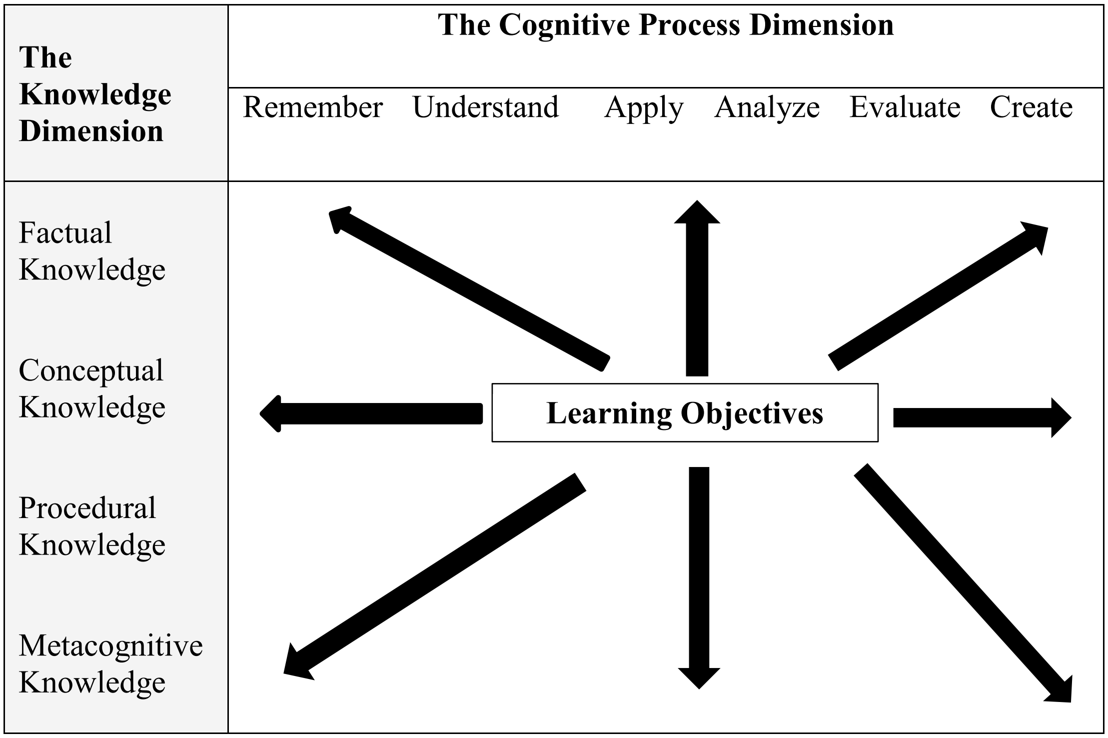


Figure 6.1: The taxonomy table with learning objectives.

Categorizing cognitive processes according to types of knowledge was intended to classify those learning objectives that have a cognitive emphasis and to connect them to both corresponding types of knowledge and targeted cognitive processes. In developing this revised taxonomy, Anderson and Krathwohl (2001) stated that "given the many different terms and the lack of agreement about the many aspects of the knowledge dimension, it is a difficult task to develop a taxonomy of knowledge that captures the complexity and comprehensiveness of our knowledge base" (p. 41). Table 6.1 presents the four types of learners' knowledge with their definitions according to Anderson and Krathwohl (2001, p. 29).

Table 6.1: Types of students' knowledge dimension

Type of Knowledge	Definition
Factual Knowledge	The basic elements students must know to be acquainted with a discipline or solve problems in it including: • Knowledge of terminology • Knowledge of specific details and elements
Conceptual Knowledge	The interrelationships among the basic elements within a larger structure that enable them to function together including: • Knowledge of classifications and categories • Knowledge of principles and generalizations • Knowledge of theories, models, and structures
Procedural Knowledge	How to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods including: • Knowledge of subject-specific skills and algorithms • Knowledge of subject-specific techniques and methods • Knowledge of criteria for determining when to use appropriate procedures
Metacognitive knowledge	Knowledge of cognition in general as well as awareness and knowledge of one's own cognition including: • Strategic knowledge • Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge • Self-knowledge

Metacognitive knowledge was included in the revised taxonomy because new educational research has found that students' understanding of their own cognition along with a sense of control over that cognition are an important part of both the learning experience and the development of their knowledge (e.g., Bransford, 2000; Zimmerman, Bonner, & Kovach, 1996). The following sections present my findings with respect to the learner's knowledge dimension, categorized within the identified four types of the knowledge and further defined as it relates to the phenomenon of collaborative information behavior.

6.1.1 Factual knowledge

Factual knowledge represents the basic elements of technical and non-technical knowledge that engineering students must have at the level of the fourth year course. It represents the knowledge of engineering technical vocabulary and terminology such as project management, budgeting, prototyping, time scheduling, lead time, or units of measurement. Factual knowledge also includes the knowledge of specific details and elements such as data specifications of materials, technical standards in specific subjects, and also what is considered to be a reliable source of engineering information.

6.1.2 Conceptual knowledge

Conceptual knowledge for engineering students includes knowledge of principles and theories in the engineering domain. This type of knowledge is commonly described as the disciplinary knowledge of experts who belong to a particular field when they think about a phenomenon in their subject area (Anderson & Krathwohl, 2001, p. 48). Engineering students' conceptual knowledge includes their knowledge of such principles and theories in science and engineering as: Newton's three laws of motion, the four laws of thermodynamics, Ohm's and

Kirchhoff's laws in electrical circuits, or nitration and oxidation in chemical engineering processes.

Conceptual knowledge is a foundational knowledge in engineering, as it provides the concepts and theories used in solving engineering problems. Students develop a conceptual knowledge through their formal education in primary and secondary school and develop it further through their engineering educational program. Conceptual knowledge is founded on and constructed from the factual knowledge that students have; students know force, mass, and acceleration of a moving object as facts, but the relationship between these three facts is represented by students' knowledge of Newton's second law of motion, that force is directly proportional to acceleration and represented in a formula that force equals mass multiplied by acceleration.

To illustrate how an engineering student's conceptual knowledge would be constructed, I refer to concepts in the domain of thermodynamics. Important thermodynamics concepts that students must understand in thermal-related engineering projects include the differences of: heat versus energy, temperature versus energy, and steady-state versus equilibrium processes. These three conceptual distinctions were found to be important in those projects the topics of which related to heat transfer and energy storage. Heat versus energy and temperature versus energy were found to be distinctions that, if not understood, could easily lead students to believe that heat and temperature are equivalent and that temperature determines how cool or warm a body feels. In the same subject, conceptual knowledge of steady-state versus thermal-equilibrium processes is important because it explains how heat can be transferred between bodies and how energy transfer is related to temperature changes. These three concepts are commonly referenced in engineering-education literature as examples of conceptual knowledge, as examples of how these concepts are introduced to students, and as examples of how they can be learned and then applied in different engineering problems (see, Streveler, Litzinger, Miller, & Steif, 2008).

When students were able to understand the main concepts of thermodynamics, they could generate the law that states that the amount of heat transferred to or from a body is determined by changes in the surrounding temperature. The thermodynamic law describes that the amount of heat of a substance will absorb or release is related to both the mass of the substance and also to the temperature change.

This law is represented through a formula that describes the relationship using commonly agreed symbols (factual representations) in thermal engineering. The capital letter Q represents heat that is measured in Joules (a metric unit of energy measurement), the lowercase letter m symbolizes the mass of the substance that is measured in grams, the combination of two symbols △T meaning the temperature change measured in Celsius degrees, and the lowercase letter c to symbolize the specific heat capacity of a substance. The relationship between these three concepts is represented as a mathematical formula: $Q=m*c*\Delta T$.

This law governs the conceptual knowledge necessary in a student engineering project the goal of which was to design a hot water tank attached to an energy storage system. In this project students calculated how much heat would be absorbed by water in a full tank when the temperature changed within a specific range. In this situation students used the formula to calculate heat absorption based on the capacity of the tank and a range of temperature changes. Students had to either know or discover that the specific heat capacity of water is of constant value, 4.19 J/g*^{o}C (Yaws, 2009, p. 43). This essential fact would be available in such basic information sources as a course textbook or an engineering handbook.

A student's conceptual knowledge would have been developed in previous courses in a specific subject area or it might need to be acquired during the task at hand. Components of conceptual knowledge were found to be dependent on the discipline of the engineering program. Students would have learned the previous example, the laws of thermodynamics, in a compulsory first-year engineering course. In the second year of the undergraduate degree, students are assigned to different programs representing disciplines of engineering. Within these disciplines students develop conceptual knowledge pertinent to their subject area; for example, the laws of thermodynamics would be used and applied in mechanical engineering or chemical engineering more than in electrical engineering or mining engineering.

Familiarity with and automaticity of applying conceptual knowledge is crucial to students' learning experience when they work to solve an engineering problem. The following quotation, from Bruce, an interviewee in this study, illustrates one student's perception of just how important conceptual knowledge is to the project at hand and to problems as yet undefined:

> In our project to design solar panels, we needed the maximum one in fifty years snow and wind loads for Kingston. We are a group of three and we are all in Mechanical Engineering. We did not know where and how to get this information. However, we got help in getting this information but we did not know what to do with all of these tables and numbers. We looked for these theories and models that may help us to work through a series of equations to figure out the worst case combination; well, we learned something new here even though it was difficult for us at the beginning but we felt that these equations can be helpful for other works we may do.

In this case, students did not know where to look for the historical environmental data they needed. After seeking help, they were able to get the required information, which they found represented in tables. In this situation they looked to acquire the conceptual knowledge they would need before these numbers could be related and before they could make the necessary calculations for their design.

Whether it is categorized as existing, enhanced, or recently acquired, conceptual knowledge is important to solving engineering problems. Students' approaches to the acquisition of conceptual knowledge will be further detailed in Chapter 7 dealing with the learner's activity and interaction dimension.

6.1.3 Procedural knowledge

Procedural knowledge is the *how to do* knowledge that translates an engineer's conceptual knowledge into applied products and solutions. Procedural knowledge represents students' knowledge of methods, techniques, and skills needed to solve the given problem in an assigned task. Examples of procedural knowledge, as seen in the engineering skills needed in the learning tasks presented in section 5.2.5, include project management skills and such engineering-specific techniques as TRIZ, FMEA, and WEM. Procedural knowledge also includes the knowledge of criteria for determining when to use appropriate techniques and to judge the effectiveness of using a particular method to solve identified problems.

Procedural knowledge can be illustrated using the previous example of the calculation of the absorbed heat of water in an energy storage system. The example hinges on the use of conceptual knowledge, in this case the law of thermodynamics. Students were not told what laws or theories they had to use to solve this particular problem and to make the necessary calculation. They had to draw upon their procedural knowledge to define the design problem and to determine what calculations could be applied to support a design solution. They selected the law of thermodynamics from among other available formulae after applying their procedural knowledge to the problem.

Procedural knowledge concerns the “how” in knowledge dimension while both factual knowledge and conceptual knowledge represent the “what” (Anderson & Krathwohl, 2001, p. 53). This distinction resides in the fact that procedural knowledge depends upon knowledge of different subject-specific processes and procedures.

Procedural knowledge is specific to particular subject matters and in engineering this knowledge represents the knowledge of skills, algorithms, techniques, and methods. An example of procedural knowledge common to all engineering disciplines is the skill of project management. Students in all programs will apply such knowledge during those compulsory courses that focus on professional skills. On the other hand, particular engineering disciplines tend to develop and enhance subject-specific procedural knowledge important to that field. For example, the procedural knowledge emphasized in mechanical engineering pertains to thermodynamics, heat transfer, fluid mechanics, solid mechanics, and dynamics. In this program, students develop procedural knowledge of algorithms and techniques used in the design of internal combustion engines, heat exchangers, automotive body structures or machine tools.

In this study I found that students from different engineering disciplines brought subject-specific procedural knowledge to their multidisciplinary project groups and specific disciplinary ways of thinking to solving the design problem as:

> The different skill sets of all of the team members offered many different ways of looking at a problem, and many different approaches to forming a solution for the problem. The amount of different ideas really allowed us to look for what would work best. In our project we were often combining positive aspects from many of the suggested solutions into one design (Survey respondent C2).

This quotation is from an open ended question in the survey in Study 1, in which students were asked about their experience during the project. The difference in group members' procedural knowledge was viewed as a positive aspect of their learning experience because it resulted in many different possible ideas applied to the solution of a given design problem. The variation in group members' procedural knowledge was seen to be complementary to any individual procedural knowledge:

> Different backgrounds in the group meant that we had different past experiences and knew what was important in different areas of the project. It allowed us to determine the nature of the most important information for our project more accurately than an individual could have. A member of my group is a student in civil engineering and he provided us with many helps in structural analysis that I do not know as I am a chemical engineering student.

This quotation from an interview with Mark, a chemical engineering student, revealed that the procedural knowledge of the civil engineering student had not been available to him before he began working on this project. Eric, an interviewed mechanical engineering student, recalled that one of the group members had had the chance to learn about searching patents, since the skill had been offered in one of the classes in a different program. Students with different procedural knowledge, gained in a particular subject area, taught each other skills they were missing:

> Some people happen to know things from previous experience that helped us with the research. For example I learned from another group member about different classes of patents and how to use them to look for information. I think he knew about these things in some courses in his program. I also remember one day that I found some data sheets for electronics I thought they might be useful for our project but I asked my roommate who is in electrical engineering to inspect them immediately. I found out they were not [as] useful as I expected; then I was able to disavow information quickly and keep searching.

One student knew to use classes of patents rather than keyword searching as a more efficient way of retrieving patent documents online, while another, who had domain-specific knowledge in interpreting a data sheet, was able to judge the relevance of found information in a better way than had the interviewee, who did not have this procedural knowledge.

Procedural knowledge, the "how to" dimension of knowledge, is an important aspect of those learning tasks associated with engineering design projects. In these learning tasks students had to know how to solve an engineering problem and how to apply their engineering conceptual knowledge to the design process in order to create a designed product or solution.

6.2 Metacognitive knowledge

In the revised model of Bloom's taxonomy of educational objectives, Anderson and Krathwohl (2001) have added *metacognitive knowledge* to the other three defined types of knowledge described in the original model. Metacognitive knowledge is "knowledge about cognition in general, as well as awareness of and knowledge about one's own knowledge" (Anderson & Krathwohl, 2001, p. 55).

Research in metacognitive knowledge in education makes a clear distinction between knowledge of cognition as a representation in the knowledge dimension and metacognitive activities that result from metacognitive knowledge (Pintrich, 2002, p. 220). In his classical article on metacognition, Flavell (1979) suggested that metacognition includes four classes: (1) metacognitive knowledge, (2) metacognitive experiences, (3) goals (or tasks, and (4) actions (or strategies). Metacognitive experiences were defined in the same article to be "any conscious cognitive or affective experiences that accompany and pertain to any intellectual enterprise" (p. 906).

Pintrich (2002) represented Flavell's (1979) previously-defined classes of metacognitive knowledge, in their relationship to learning objectives, as three related subcategories of knowledge: (1) strategic knowledge, (2) knowledge about cognitive tasks, and (3) self-knowledge.

The first subcategory of strategic knowledge is the knowledge of general strategies for learning, thinking, and problem solving. The second subcategory, knowledge about cognitive tasks, includes appropriate contextual and conditional knowledge and also knowledge of the cognitive demands of different tasks. The third subcategory is self-knowledge representing knowledge about the self in relationship to cognitive components in performing tasks.

In this dissertation, metacognitive knowledge was found to include the strategies students would use to seek, search, and use information in solving problems to accomplish the learning task requirements. Metacognitive knowledge is comprised of possible action plans to seek, search, and use information to meet specific goals of the learning task by having knowledge of the context in which the actions will be taken for desired objectives. Metacognitive knowledge describes how students can use self-awareness of the breadth and depth of their own knowledge, accumulated from prior knowledge in other courses, to meet the requirement and objectives of the task on hand.

In the following sections, metacognitive knowledge will be discussed as being part of the learner's knowledge dimension through its relationship to information behavior. Accordingly, metacognitive knowledge will refer mainly to knowledge of cognitive strategies, not the actual occurrence of those strategies.

Types of cognitive strategies will be discussed in Chapter 7 dealing with the learner's activity and interaction dimension and will describe the actual use of those metacognitive strategies as being a component of the student's information behavior.

6.2.1 Metacognition in self-regulated learning

The learning tasks in this research were designed to be performed by students in a self-regulated manner as detailed in the previous chapter on the learning task dimension. In self-regulated learning, students themselves plan, monitor, and evaluate learning in the performance of their assigned tasks (Pekrun, Goetz, Titz, & Perry, 2002).

In self-regulated learning, students use their own constructed problem-solving strategies from the beginning to the completion of leaning tasks. They define the problem and use available resources to find a solution. In relation to metacognition, strategies in self-directed learning include goal-setting, self-monitoring, and self-evaluation (Zimmerman, 1990).

Goal setting is an important component of self-regulated learning. It is the process of identifying future actions or outcomes (Zimmerman, 1995). The setting of goals serves as a standard by which students can monitor, judge, and adjust their activities in performing a task (Pintrich, 1995).

As presented in the previous chapter, any learning task will have objective goals to achieve. Students set what learning-task goals they need to meet and when during the project's different stages and phases. Following a self-regulated approach, students strive to achieve those goals based on the requirements of the learning task and, in a larger sense, the goals they have set for all the activities they perform. Metacognitive knowledge greatly affects the ways students, guided by particular goals and based on their knowledge of the cognitive demands of the task at hand, monitor and evaluate their self-regulated cognitive activities.

6.2.2 Collaborative metacognition

Research on metacognition in learning has focused mainly on the individual learning experience, but further research has found that metacognition is also affected by aspects external to the learner, such as the social context and social interaction (Brown, 1978; Brown, 1987; Flavell, 1976, 1979). These studies, which had investigated metacognition by way of the learner's individual experience, also found that such contextual variables as socialization and collaboration can facilitate or hinder the learning of individual students.

Individual metacognitive experience is formed by those subjective cognitive faculties that monitor, regulate, and inform a person about a feature of cognitive processing in relation to the task at hand (Efklides, 2006). In collaborative settings similar to the group learning tasks represented in this dissertation, researchers found that metacognitive experience is embedded in the social and collaborative context of the learning task and that metacognition as a process is both individual and collaborative in nature. This finding is similar to other research on group metacognition in learning that found a strong relationship between individual and group metacognition in collaborative contexts (e.g., Efklides, 2009; Goos, Galbraith, & Renshaw, 2002; Hogan, 2001).

Research in metacognition in collaborative contexts is still emerging and scattered, as is reflected in the different labels that have been used to describe metacognition in groups (Iiskala, Vauras, Lehtinen, & Salonen, 2011, p. 380). Many terms have been used to describe metacognition in a collaborative group setting to distinguish it to from individual metacognition. These include *socially mediated metacognition* (Goos et al., 2002), *collective metacognition* (Hogan, 2001), *shared regulation* and *socially shared metacognition* (Iiskala et al., 2011).

These studies looked at how metacognition would be extended in group-based learning, from a focus on the individual's self-regulation to that of the group's co-regulation of the multiple and varied cognitive processes governing overall learning in collaborative tasks.

As previously noted, metacognition refers to the person's own knowledge about cognition and the regulation of cognitive processes; the concept of socially shared metacognition refers to "the consensual monitoring and regulation of joint cognitive processes in demanding collaborative problem-solving situations" (Vauras, Salonen, & Kinnunen, 2008, p. 305). I have developed a working definition of collaborative metacognition as a dimension in collaborative information behavior, based on the original definition of metacognition (Flavell, 1976) and the developed concept of socially shared metacognition (Vauras et al., 2008), to be: the group's shared knowledge about cognition *and* collaborative awareness and the regulation of cognitive processes in collaborative situations to achieve a particular group goal. To illustrate collaborative metacognition in collaborative learning tasks, I quote from Bill, an interviewee in Study 2:

> In initial design selection in November, each of our group members was able to define two possible ideas of the design, but we needed to evaluate these ideas to properly weigh how well our options met the criteria; ideally we would have had numerical estimates for all of our metrics (6 main ideas, 8 to 10 metrics). However, we felt that we would not have time to benchmark all of our ideas across all our metrics, since this would require detailed design and calculations for each of our ideas and we had to make a decision soon. Since we had a basic understanding of how each design functioned, and perhaps some idea of how similar designs are presently used, we estimated from this knowledge how well each of our designs would perform in the different criteria. From this, we did a weighted evaluation matrix to select a design for detailed design. In hindsight, this probably wasn't the greatest plan, since effectively we were making up estimates based on arguably related information, so a vital decision was based on guesswork.

Bill’s account of his experience reveals elements of collaborative metacognition in a group situation during a particular learning task. As collaborative metacognition it includes the group’s knowledge of possible strategies, the group’s knowledge about their cognitive tasks, knowledge about the self (a group of individual students in this situation), and knowledge about the group members’ cognitive processes.

The group evaluated their suggested design ideas using their knowledge of the cognitive task at hand, their knowledge of possible strategies, and their knowledge of the self in relation to the cognitive components of performance. Awareness is identified here in students’ knowledge of the cognitive task at hand and the strategies to solve it. Regulation is evident in the way they selected a strategy by which the group would proceed, performing the task based on their knowledge of the anticipated cost, in time and effort, of possible strategies. Awareness of co-regulation is evident towards the end of the quotation, in which John reveals that the group selected not the best process for achieving their goals but the one most of them accepted.

In this situation, the group set many goals for itself as it strove to define possible design solutions and to evaluate them. Students' strategic knowledge of such evaluation techniques as the weighted evaluation matrix depended upon conceptual and procedural knowledge they already had. Their self-knowledge as learners and their awareness of the situation helped them to select the most adaptive strategy to solve the problem. Table 6.2 shows the components of collaborative metacognition identified in this situation, in which students engaged in a variety of cognitive processes to monitor and regulate their learning by taking into consideration the task's goals and constraints.

Table 6.2: Components of collaborative metacognition

Components of Collaborative Metacognition	Examples
Strategic knowledge	• Each student defined two design ideas. • Students as a group evaluated the six developed ideas. • Students were aware of different strategies for design evaluation.
Knowledge of cognitive tasks	• Development of evaluation criteria for the developed solutions. • Calculation of the weighed score for each design idea.
Self-knowledge	• Students had basic understandings of how each design functioned. • Students estimated the related workload to be performed in evaluating the possible design ideas.
Collaborative awareness and regulation	• Students had awareness of the needed time for evaluating ideas • Students regulated their plans and actions according to the task's constraints.

The previous example illustrates the role of collaborative metacognition in those learning tasks that demand high-level cognition. In this experience, students shared their individual metacognitive knowledge at the planning stage, identified the demands of the task, reviewed possible problem-solving strategies, shared their awareness of the activity and its requirements, evaluated and examined the task results, tested the authenticity of the performed task, and finally checked the task outcomes.

The relationship between collaborative metacognition and cognitive processes in information seeking and use can also be seen in the students' self-reported progress statements. Their analyses of their group's deliverables shows that collaborative metacognition, in its relationship to information seeking and use, developed dynamically, emerging at different stages and phases of the assigned projects.

In the following example, students in a project group (Ben, Bill, and Sam) were tasked to design a mounting system for a solar-panel rack. In the third week of the project, after meeting with the project client, they assessed the information they needed. They evaluated their own knowledge, planned various approaches and strategies to enact their plan, and created a timeline for the activities. They also identified how the results of their individual activities would be shared among the group in order to complete the task at hand, as shown in Table 6.3.

Table 6.3: An example of students' collaborative metacognitive experience

Item Description	Action
Gather Research on Potential Materials: The Solar Photovoltaic Rack must be constructed out of strong and durable material, while maintaining a low cost.	Sam will be gathering information and conducting research on materials (Anodized Steel and Aluminum) as they were brought up in the meeting with the client.
Research for Solar Panel Sizing and Solar Module Manufacturing: The multiple sizes and weights of solar panels will play a great role in the design and construction of the solar rack. The solar panels will influence the adjustability of the mounts, the height and length of the racks, and its physical construction.	Bill will research and gather information regarding solar photovoltaic panel specifications. This information will then be sent out to all group members.
Research of Solar Panel Mounting and Efficient Construction of Racks: Solar Panels are more efficient at an ideal angle, for each season, to get maximum exposure to the sun, hence more power generated. The assembly of the solar rack will have a great effect on the final cost.	Ben and Bill will research the most efficient/ideal angle in which the solar panel needs to be positioned. As well as the most efficient way to assemble the rack.
A preliminary design idea needs to be produced	Each member will create an idea to present it to the group.

Timeline:

Research should be emailed to the rest of the group before the next week team meeting.

Next meeting:

All research conducted will be presented to the other members of the group and discussed. Brainstorming will commence and ideas will be generated. Constant contact between our group and Mr. Jacques [the project client] will be maintained for regular feedback and additional information.

In this collaborative metacognitive experience, students at an early stage of their project were able to identify their information needs to achieve the task goals. They shared their speculations with regard to the possible application of different concepts to their projects. They clarified understandings and defined possible cognitive strategies to *gather* information on particular concepts in the project task. Except in the case of the third project task, which was assigned to a pair of students, each student was assigned a separate project task.

In both previous examples, collaborative metacognition is seen to be at work in students' estimates and judgment of their information seeking and use. They were aware of their task's cognitive processes and they shared their individual metacognition in group meetings. This further triggered such metacognitive regulation processes as the division of the task components and assignment of roles, as well as an evaluation of the timeliness of these activities.

These metacognitive experiences were found to be an essential component of individual students' self-regulation and of the co-regulation of activities in collaborative learning situations. When students met, they were able to communicate their cognitive processes as a function of individual progress towards shared goals. Collaborative metacognition tended to enhance a cognitive task because it led learners to establish new goals, add to their knowledge base, and activate strategies "aimed at two types of goals: cognitive or metacognitive" (Flavell, 1979, p. 908).

6.3 Collaborative metacognition and task complexity

With regard to task complexity, as described in the previous chapter, Flavell (1979) found that different cognitive tasks can be more or less complex, resulting in differential demands on the cognitive system and possibly requiring different cognitive strategies. Vauras et al. (2008) and Goos et al. (2002) found that in group settings as task complexity increased metacognition tended to emerge more frequently and be more collaborative. There is no obvious need to collaborate when the task is easy (Iiskala et al., 2011).

According to Prins, Veenman, and Elshout (2006), metacognition emerges in advanced learners during complex tasks when the learners are still operating within the boundaries of their knowledge. In a previous study, Efklides, Papadaki, Papantoniou, and Kiosseoglou (1998) also found that objective task complexity affected the intensity of students' metacognitive experiences in problem solving at different levels within the different stages of their learning tasks.

Task complexity is related to metacognition in that it determines the point at which it is necessary for the student to regulate cognitive and metacognitive activities (Efklides, 2008). In many metacognitive experiences, learners perceive task complexity when it imposes cognitive demands as task difficulty. For example, in the progress report in the third week of a project to develop a residential thermal energy storage unit, the group members (Daniel, Peter, Sophie, and Paul) reported their perceived difficulties with regard to the task and their actions at this stage, as shown in Table 6.4 in which emphasis on difficulty or its synonyms was added.

Table 6.4: An example of collaborative metacognition and task complexity

Issue	Description	Action plan
Difficulty obtaining exact specifications	Outside of some material supplied to the team by the client, most industry knowledge on this subject is not available to students	Daniel and Sophie will continue internet research, specifically in academic papers where calculations and data may be more readily available.
Scaling issues	Estimating efficiency of the project will be *difficult* because temperature change is related to the surface area to volume ratio, which is much higher for small projects (~6) than commercial systems (~0.25)	Peter and Paul will develop engineering assumptions for the time being. The group will complete dimensional analysis for more accurate answer, then create computer model for interim report.
Efficiency definition	Efficiency of this system is *hard* to define because of the boundary problems inherent to power systems design	Daniel will use thermal energy storage textbook to create a list of possible alternatives, then the group will choose the alternative best suited for a small prototype.
Market analysis	Because the market for this product is very small, it is *difficult* to conduct a numerical market survey. In addition, the field of thermal energy storage is relatively new and as such utility expectations may be undefined.	Sophie, Peter, and Paul will develop a qualitative survey of industry to determine requirements
New issue#1	The largest *problem* we are currently dealing with is the *difficulty* finding information about storage facilities as described above.	
New issue #2	A possible *barrier* in the future will be the relative novelty of constructing a functioning prototype. As such, the team will endeavor to order parts and supplies in December rather than during February so that there is time to deal with design flaws.	

The previous example illustrates how students' collaborative metacognition was affected by their perceived complexity of the task at hand. As well, we see the resultant collaborative information activities requiring one or more students to seek and search for needed information from different information sources (e.g., internet, and thermal energy storage textbook). The perceived task complexity was a product of different factors related to the objective task complexity and the students' knowledge as they worked to solve the design problem. The following sections describe metacognitive experiences in which students perceived the cognitive requirements of the task to be difficult and as a result changed their collaborative information behavior.

6.3.1 Ambiguity of information need

Many of the students' project documents, such as progress reports and group memos, described their perceived task difficulty at the beginning of the project when the project scope was not clear to them:

> At the beginning of the project we were given very little initial information about the project itself. This required each of the team members to learn most of the physics and concepts ourselves and to piece together what the requirements of the project would be (Progress report in project C).

Another project group, the task of which was to develop a modular tent, perceived ambiguity in the problem as it was laid out for them:

> At first, when we did not understand the scope of our project, we researched over the internet as much as we could but we were able to find some basic information about the used technology but not on how these products would function; as a result we went to different stores to talk to

> employees who sell these products as they are potential vendors for this product and they gave us more useful information than what each of us was able to find online. The sales representatives gave us catalogs and contacts for other companies that produce similar products. This helped us to understand how this technology works which enabled us to work further on developing design solutions (Final report of project E).

These students' perception of their task's complexity compelled them to search for information in different and increasingly imaginative ways. Another group, developing an energy solution for a general hospital, reported that their perception, that the project was not clearly defined, was rectified in group meetings:

> As it turned out there was some confusion in the project scope and requirements. Each of us understood the project requirement differently and we ended up being in three different directions to select one design solution. Each member was searching for a different technology as a solution without agreeing on what the design problem was and what our client wanted exactly. This has been cleared up in further team meetings. The entire team had a discussion regarding our specific aims for this project and we were able after a number of meetings to be able to agree on the project scope and what we can do in developing a solution…[B]eing in a multidisciplinary group made understanding [of] concept[s] easier since everyone had specialties in certain concepts (Interim report of project A).

Seeing ambiguity in the information needed to complete their project, students perceived difficulties in finding relevant information. When it became difficult to identify the information they needed, it became harder for students to explore possible strategies for identifying and searching for it through all possible channels. The solution was to hold further meetings to discuss and agree on a collective understanding of the project scope.

6.3.2 Lack of domain-specific knowledge

Students perceived task complexity when the task required them to have domain-specific expertise in the project's subject area before they could solve a particular problem. They were aware of their limited conceptual or procedural knowledge in particular engineering domains, seeing themselves as students lacking the expertise of professional engineers. For example, Sue, an interviewee in Study 2, describes a problematic situation in her project, which was to develop a treatment for residential hard water:

> I am still a student. I do not have enough knowledge on how different processes of water treatment would be applied in a solution beyond what I learned in one course. This is the same for the other students in my team. Even though we tried to find information to understand how a small scale solution will be applied for residential use with less costs than the current available products in the market. We felt that what we were doing was more theoretical than practical; we needed to have more applied knowledge to create a doable solution. Charles' [a member of the group] father is an engineer in Toronto who connected us with his friend Mr. Christopher who works as an engineer in a water treatment plant to help us. Mr. Christopher shared his experience with us by guiding us to really good links to really good websites that gave us more of the applied side of using different technologies in water treatment technologies. We contacted Mr. Christopher many times especially when we needed help with getting estimated costs of some materials as we did not know much about possible Canadian suppliers.

According to Sue, the group members were aware of their limited knowledge in the domain of the project. They collaboratively shared their metacognition among the group to select possible strategies to get the needed information from experts who might have more knowledge from professional practice. They were not able to contact an expert in this particular area without the help of a student's father as a personal contact who connected the group with his friend to guide students with resources and information based on his professional expertise.

Lack of domain-specific expertise was also found to be related to some particular tools with which the students were unfamiliar. For example, in the 14th week of a project to design an electric system for a hybrid tractor:

> The client informed us that the user interface they would like us to use is LabVIEW™. Only one team member has had some exposure to this program; however it is felt that a tutorial for the entire group would be extremely beneficial. Sophie will contact the teaching assistant who is familiar with LabVIEW™ as well as a LabVIEW™ expert that provided a workshop for our project client employees (Progress report in project D).

In this case, students were able to share their metacognition regarding their knowledge of that particular software and then were able to identify possible strategies to get support to gain more procedural knowledge so that they might use the software to meet the project requirement.

In other situations, students were not able to use conceptual knowledge in solving engineering problems in areas with which they were unfamiliar. For example, a group reported in the 16th week of the project that they needed to perform mathematical analysis using the computational fluid dynamics (CFD) laws:

> Although the design has been finalized, the team is having difficulty with the CFD analysis as it is unfamiliar to all group members. The team has tried to get the needed information ourselves but it was difficult to agree on what equations to use and how to use them. The team has resorted to searching for a graduate student in civil engineering willing to give a tutorial for us (Progress report in project F).

In all of these examples of metacognitive experiences, students first tried to acquire the needed knowledge themselves when they were faced with the complexity of the task. When they had no success getting the needed information themselves, they sought the information from other people at the same university, people they expected to have more expertise in such a particular domain.

6.3.3 Anticipated cost of information seeking and searching

In many situations, students preferred to seek and search for information collaboratively because they believed it would save them time and effort. This preference was not reported in students' deliverables but in the responses to the survey in Study 1and during the interviews in Study 2. In such situations, when a student was not able to find the information needed for her or his assigned task, the individual returned to the project group for support and new ideas. As Eric put it:

> I was responsible for the technical aspects of our project; I had to do all calculations needed for the design and look for information to support my arguments. The other two members were responsible for the budgetary and marketability sides of the project. Many times I felt that I cannot handle information search myself as it needed a lot of time to find the information I need especially that I have other courses to work on. I found it was easier for me to ask other team members to find the relevant

> information and references I need for the technical part of the project. I believe that my other members did a good job in finding the information I needed when I asked them for help.

In this situation, Eric felt that he would spend more time and effort than he could afford to get the information needed to perform his assigned subtask in the project. He also acknowledged the help other members gave him, thus saving him that very time and effort. In another response to the open ended question in Study 1, a student wrote that explicit collaborative information behavior saved the group time and led to better results than did what could be achieved by an individual:

> We preferred to search for information as a group most of time especially when we faced a roadblock in our project. We did not use one computer, but each of us was using his [own] computer. The main advantage was seen from the utilization of different group members' researching skills (some had skills in researching journal articles, whereas others had skills doing patent research, etc.). That saved us a lot of time [than] if we did that separately…Collaboration of different minds to brainstorm different keywords and additional topics to be researched, leaving no stone unturned (Survey respondent D3).

Some students found out that collaborative information searching as a group was more efficient than was individual information searching. However, as Bruce reported in Study 2, this was a developed experience in which over time the group came to realize the advantages of collaborative searching:

> Working together in the same room makes it more enjoyable, we can throw ideas back and forth. I guess it was easier to work as a group because you could always ask for a second opinion. Just using the overall group knowledge of the available databases and sources we could search for information made it easier for all of us particularly in difficult

situations when we needed to finalize a required report or before a meeting with our client, which is just something we've learned over time. We did not do that often at the beginning of the project as we divided the work but we realized later that each of us did not have the needed time and sometimes the searching skills to save time and improve the overall team efficiency.

6.3.4 Unavailability of information

Perceived task difficulty also impinged on collaborative information behavior when students discovered that the information they needed was either insufficient or unavailable. In the 20th week of a project to develop energy efficiency in a general hospital, a group reported:

> The team is still facing difficulties in determining the design required specifications as we are still missing two vital pieces of information for the steam pipes operations and maintenance calculations. This information was expected to be obtained through [Mr. John] at the hospital but he is on leave till next month. We also have a big difficulty because of the missing information on the expected increases in steam price and finding a formula to calculate it and this information is necessary for the sensitivity analysis. Our project client has redirected the team to contact [Mr. Gordon] at the central heating plant. Given the remaining time of the project, the group met four times during this week to find alternative information that can support our design solution till we are able to meet with Mr. Gordon (Progress report in project B).

In the previous situation, the students needed information specific to the hospital where the project was to be performed. This information was unavailable because the employee who could give them this information was absent. In addition, when they were unable to find conceptual information needed to calculate the sensitivity analysis of their design, they were guided to contact another person, someone who had access to the necessary information. Given that the time remaining for completion of the project was running out, they collaboratively decided to look for alternative sources of information.

Another group needed information that did not exist in any physical form. Their 8^{th}-week progress report of a project to develop an energy retrofit for a retirement manor revealed that:

> The team is still having difficulty calculating the available rooftop area of the building because the rooftop drawings are difficult to locate in the manor. Our project client told us that he is not sure if these drawings are available because the building was built more than 80 years ago. The team is also having difficulty determining the flow rates of the steam entering in each of the three pipes to the building due to the lack of flow meters. The group met yesterday to search for any possible information online but without success (Group memo in project G).

Without crucial information, in this case roof drawings and steam flow rates, the group could not complete their project to improve energy use in the building. As a collaborative metacognitive strategy, the group decided to look for information on the Internet but with no success. In the 11th week they reported that they had to develop the roof drawings themselves and estimate flow rates based on monthly consumption of steam, calculated using the building's monthly energy bills.

Availability of information, it was found, could affect the nature of the project itself. In some projects, company-developed information was proprietary and considered too confidential to share in digital format. In these situations students had to visit the project's physical site in order to view the information they needed and record it there.

6.4 Collaborative awareness

As previously defined in section 6.3, collaborative metacognition is the shared group's knowledge about cognition *and collaborative awareness* and regulation *of cognitive processes* in collaborative situations to achieve a particular group's goal. Awareness was found in this study to be an important component of collaborative metacognitive experiences in learning tasks. The previous examples, in which students reflected upon perceived difficult situations during their learning tasks, show how important is awareness of the task's requirements to any decision made about information seeking and search, within possible strategies, to solve a recognized problem.

But awareness of what? Awareness is only meaningful when it refers to a person's awareness of something (Schmidt, 2002, p. 288). Awareness in a group setting is "an understanding of the activities of others, which provides a context for [a person's] own activity" (Dourish & Bellotti, 1992, p. 107). Individualized contexts, however, could lead to a situation being perceived differently by each group member. To avoid such fragmentation, each group member needs to be aware of every other group member's understanding, plans, activities, roles, and achievements, in order to perform the task at hand when a new situation evolves. Awareness that "integrates individual and social levels of cognitive orientation" (Cool, 2001, p. 25) is termed *situation awareness*.

6.4.1 Situation awareness

Situation awareness is the "continuous extraction of environmental information, integration of this information with previous knowledge to form a coherent mental picture in directing further perception and anticipating future events" (Vidulich, Dominguez, Vogel, & McMillan, 1994, p. 11). A mental model or a mental picture is a set of well-defined, highly-organized yet dynamic knowledge structures developed over time from experience (Glaser, 1989, p. 270).

Situation awareness is an achieved state of knowledge when individuals "must do more than simply perceive the state of their environment. They must understand the integrated meaning of what they are perceiving in light of their goals before they can choose a suitable action" (Endsley, 1995, pp. 33-34). Accordingly, the individual's situation awareness in performing tasks is not limited to what is happening in the vicinity but includes the individual's creation of a meaning of the situation in order to select an appropriate action to perform the task.

Endsley (1995) developed a model (Figure 6.2) to include three components that together constitute situation awareness: "[1] the perception of the elements in the environment within a volume of time and space, [2] the comprehension of their meaning, and [3] the projection of their status in the near future" (p. 36). In this model, the primary components of situation awareness are the levels in hierarchical phases. In the same paper, Endsley emphasized that his model's defined levels of situation awareness did not encompass all of a person's knowledge but referred only to that portion of knowledge pertaining to the state of a dynamic environment.

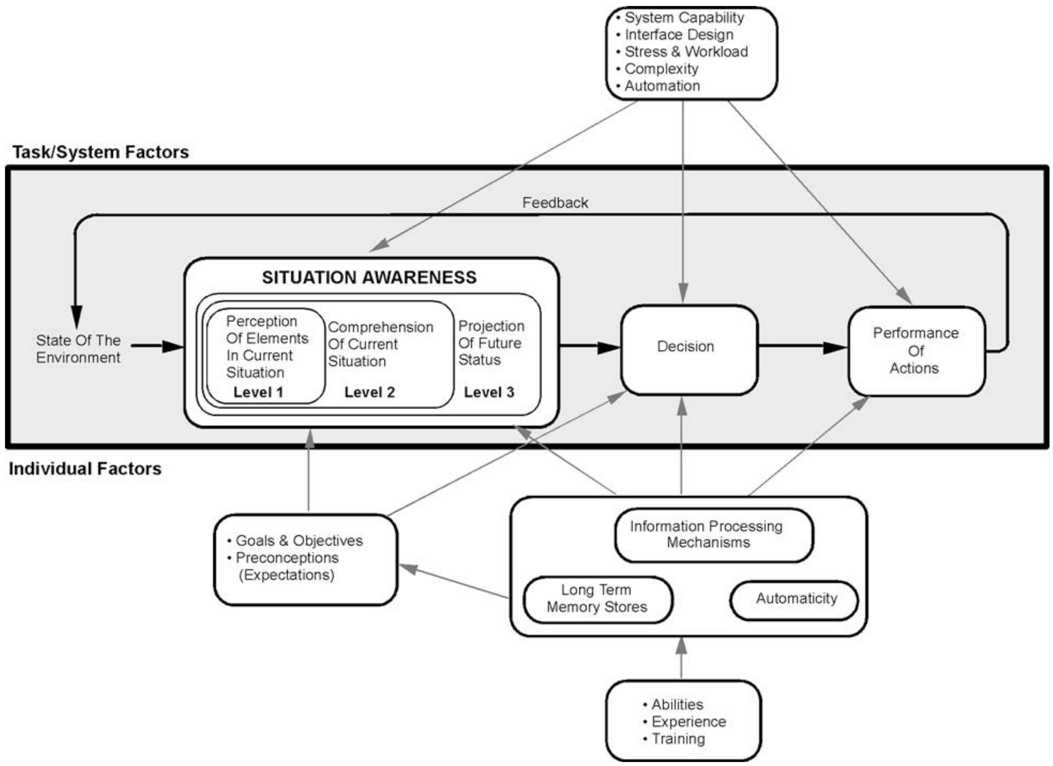


Figure 6.2: Endsley's model of situation awareness.

Situation awareness was found to be an essential component of metacognitive experience in relationship to collaborative information behavior. For example, Bruce, an interviewee in Study 2, described his experience in the first weeks after he was assigned his project:

> When I was first assigned to my project, I was not sure about the project scope and if I have enough prior knowledge to develop an engineering solution in an area that I am not that familiar with for such a big company. However, I understood that it could be a challenge for me but I was ready for it. After our first meeting with the project client, I realized that I have some good knowledge learned from previous courses that I can apply in this project. I just need to review what I learned before so I could

remember the formulae to use. However, in the same time, there were some new areas for me to explore that required me to do a lot of information research to learn more about this technology. The most difficult part was that I had to learn a lot of new things in a very short time because we had a brief project report due in two weeks after the visit to our project site.

According to Bruce's metacognitive experience, the three levels of situation awareness can be seen as:

1. Perception of the elements in the environment: The first step for an individual to achieve situation awareness is to perceive the status, attributes, and dynamics of relevant elements in the environment where he or she is situated (Endsley, 1995, p. 36). Thus, at this first level of situation awareness, Bruce perceived the assigned project topic from its given description based on self-evaluation of his prior knowledge as an engineering student. This first level of situation awareness enabled him to be aware of multiple but disjointed situational elements: requirements of the given project, his prior knowledge related to the project topic, a possible challenge to him, and a possible opportunity to perform such a project in a big company.
2. Comprehension of the current situation: the next step in situation awareness formation involves an amalgamation of disjointed situational elements resulting from the previous step (Endsley, 1995, p. 37). When Bruce visited the project site, the project client gave him additional information that affected his understanding of the specific requirements of the given project. He integrated this new information with the disjointed

situational elements he had identified in the first stage of awareness. As a result, he was able to create a mental picture of the overall situation. He already had some of the knowledge he needed for this project, but there were some new aspects he was not familiar with.

3. Projection for future status (situation): The third step of situation awareness involves the ability to plan any future actions based on the created mental picture from the preceding two steps. Bruce planned to review the courses he had taken in previous years in order to remember the formulae needed for his project. He also decided to search for information to learn more about new subject areas. He based his projected actions on his achieved state of knowledge, his knowledge of the dynamics of the elements, his comprehension of the situation, and the time needed to achieve these actions.

Situation awareness was found to change dynamically during the different stages and phases of the learning task and to result in a variety of decisions regarding information seeking and searching. Group members had to maintain a high level of shared situation awareness with regard to each other's information searching so that what they found could be successfully integrated and implemented in the project's solution.

6.4.2 Collaborative situation awareness

The level of shared situation awareness in groups is dependent on the nature of the group's task and the responsibility of each group member; each group member would have a specific set of situation awareness elements about which he or she is concerned, as determined by each member's responsibilities within the group (Endsley, 1995). Sonnenwald and Pierce (2000) found that a sufficient overlap among individual group members' awareness is always needed so that all members are connected in some way; this overlapped situation awareness is termed *interwoven situation awareness*. An example of situation awareness in a group setting is reflected in this quotation from Emily, an interviewee in Study 2:

> Face to face meetings were typical for my group to discuss and share the information we need for our project. At first we were dividing up information searching. We realized after a month or so that we hadn't done much sharing of the findings of our searches, instead meetings were focused on the next steps without evaluating where we were and the implications of what we had found. After this, we did more working and searching for information together face to face, and sharing our findings as we found them. Occasionally we would send emails, but this wasn't very effective, they weren't being read or replied to. In the second half of the project, when we stopped working on information searching together face to face, we did more detailed reports to each other in our face-to-face meetings on the progress of each subproject we were working on, and what we were looking for.

According to Emily, the project group experienced different situations during the lifespan of the project, some of which group members were aware before they planned their information behaviors. The group members shared their situation awareness during in-person meetings to look at what the group had performed in the past. This helped them understand what they needed to do in a current situation in order to plan future action. At the beginning, the group members decided that each student would search for information without an agreement in place as to how the found information would be shared. After a month, the group became aware that, in their situation, sharing information by email was not very effective, and so they decided to search for information together during their meetings in order to improve group performance. In the second half of the project, the group gained a different awareness of the situation, allowing them to evaluate the found information more during their meetings and to create a collaborative awareness of what each of them was performing, in order to plan their future actions.

6.5 Conceptualization of the learner's knowledge dimension

The learner knowledge dimension explores the extent to which students' knowledge types affect their collaborative information behavior. Students' collaborative information behavior is triggered by different metacognitive experiences during the lifespan of a project. Students' activities in information seeking and searching were dependent on how they perceived task complexities based on their existing knowledge (factual, conceptual, and procedural) and on their collaborative awareness. Figure 6.3 represents a constructed conceptual framework of the learner knowledge dimension based on the found results in this research.

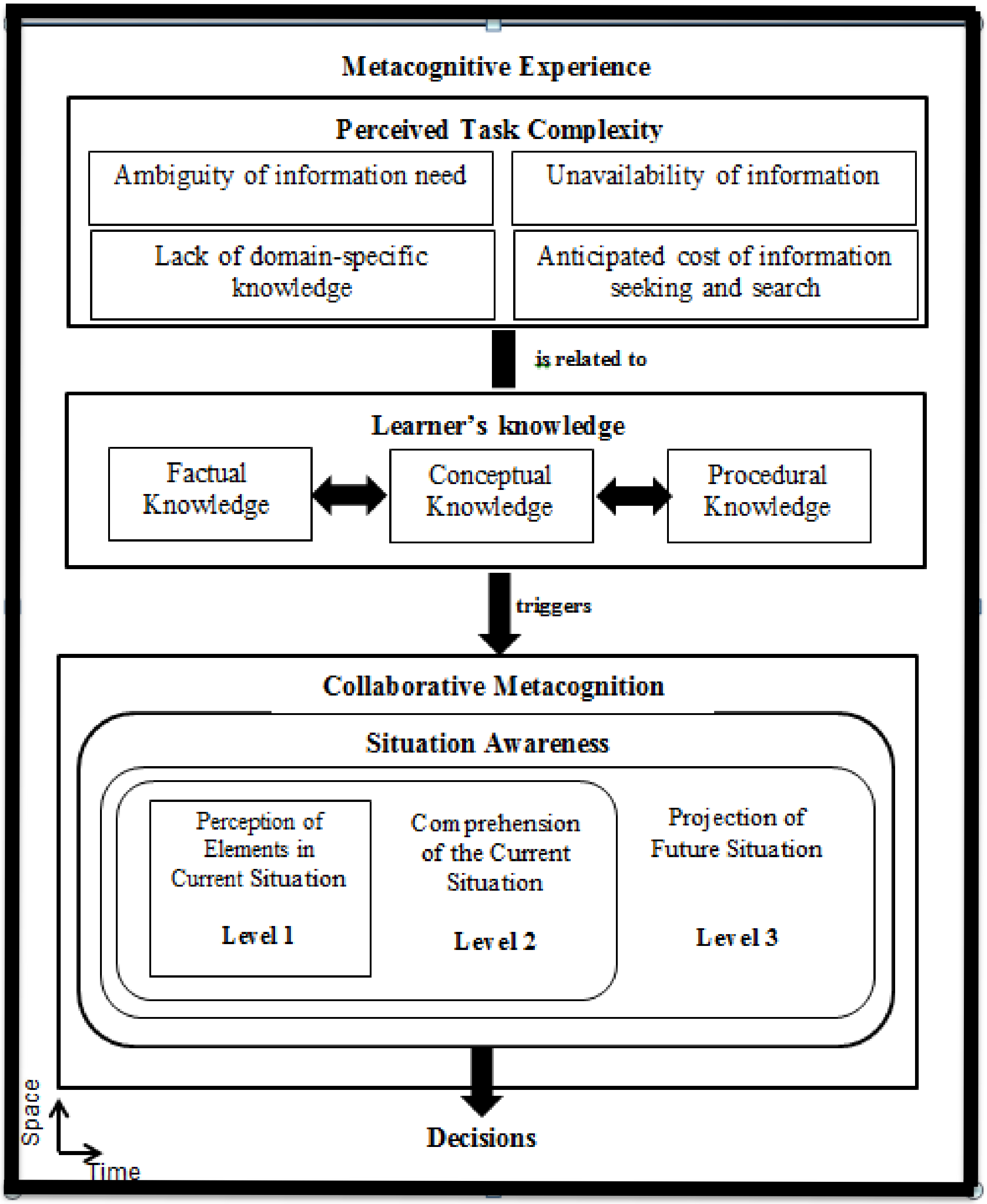


Figure 6.3: A conceptualization of the learner's knowledge dimension

The conceptual description of the learner's knowledge dimension represents a temporal-spatial representation of different metacognitive experiences in which students perceive an aspect of task complexity that would trigger their actions for information seeking and searching. It is important to state here that perceived task complexity does not only include situations of task difficulty as perceived by learners, but it also includes all tasks' information requirements based on learner's existing knowledge during each metacognitive experience.

According to this constructed dimension, students were found to experience different metacognitive experiences that trigger collaborative metacognition among group members. Each metacognitive experience was found to be dependent on the extent to which each member shares his or her situation awareness of the information needed to meet the task objectives according to their subjective task requirements at that particular point in the project. Collaborative and shared metacognition among group members enables them to decide collectively what information is needed and how to seek or search for information sources individually or collaboratively. These decisions create multiple pathways that group members agree upon by: (1) assigning roles, (2) defining possible information channels, whether they are experts outside the group or such documentary information channels as the internet or subject-specific databases, or (3) reusing already found and shared information objects.

7. THE ACTIVITY AND INTERACTION DIMENSION

This chapter details my findings with respect to students' activities and interactions in relation to their collaborative information behavior while they undertook their assigned learning tasks. Students' activities and interactions were introduced in previous chapters discussing learning tasks and learners' knowledge dimensions.

7.1 Information seeking

Information seeking is a subset of information behavior, which is understood to be the intentional seeking of information for a specific purpose or to fulfill a particular need (Wilson, 2000). It is a behavior in which "humans purposefully engage in order to change their state of knowledge" (Marchionini, 1995, p. 5). Various models of information seeking have been proposed and developed in understanding individuals' behavior while they look for information, as discussed in Section 2.2. Individuals are seen to be engaged in information seeking once they have recognized and accepted an information requirement, defined an information problem and selected an appropriate source that might address the information problem. Thus, the information seeking of students under investigation in this research was found to be a purposeful activity involving two main sources of information: (1) people and (2) documents.

7.1.1 Information seeking: People

Students purposefully sought information from people who were seen to be experts, to help them access and understand information needed to proceed with the project. Students approached different people during the lifespan of their projects, as the following survey respondent said:

> The vast majority of the information for this project was obtained by speaking to a range of people including: clients, users, current owners of the facility, other engineering firms which we were working with collaboratively, government and agency officials, etc. (Survey respondent N1).

Given that the nature of the different projects varied greatly, students approached different people for the information they sought. These included the project's client, the course instruction team, experts, and suppliers.

7.1.1.1 Information seeking: The project's client

The most important information channel of information for students was the project's client representative or other contact person within these companies or organizations. The project's client was considered an important channel for information, particularly for the project's specific information, such as the project requirements and objectives, in addition to information related to the client's market. As a survey respondent put it:

> Our client was the main source of the information we needed for the project. We asked for more information almost every time we talked to him on the phone. He gave us a bunch of information: building layout, asset report, utility cost log, building drawings and some technical information that was generally numerical figures specific to our project, which we could not obtain from other places (Survey respondent L2).

The project's client provided students not only with information relevant to their projects but also with references to other people who could provide additional information. As Sue indicated:

> The client provided us with contacts for other employees who gave us more information. They helped us a lot especially with contacting existing suppliers, who gave us price quotes for the materials we needed. One of the important people we were referred to was a member of the Ontario Health Association, who helped us with data on pump systems and got us a report on government incentives.

Accordingly, the project's client representative referred students to other valuable contact people, who provided additional information useful to their projects. The additional contact persons were not attainable to students without the help of the project's client representative.

7.1.1.2 Information seeking: Course instruction team

The course instruction team consisted of the course instructor, teaching assistants, and a project advisor for some projects. Students had a weekly meeting with the course instruction team in addition to continuous communication through email between these meetings:

> We got a lot of information from our teaching assistant about the logistics and resources we needed for the project. She has been so helpful to us, forwarding us many useful articles and reports whenever she got into them (Survey respondent E3).

In that situation, the teaching assistant supported the students' experience in information seeking by giving them the information needed and also any relevant information viewed to be useful to the students. Students also reported that they approached the course instructor when they needed some procedural information:

> At the beginning of our project, we faced many difficulties as the project subject was totally new to all of us and we had no prior knowledge about it. We asked for help from the course instructor, who gave us an excellent textbook to read that provided us with many design ideas and also referred us to another professor who met with us for two hours and gave us a lot of information on how and where to start (Survey respondent B1).

The course instructor, who has adequate understanding of students' situation in their project, supported them by giving them a textbook that was not a part of their previous courses and also referred them to another professor who has more knowledge in that particular design area.

7.1.1.3 Information seeking: Experts

Students reported that they sought of information from people considered to be experts in particular engineering areas. In the previous example, students were referred to an expert by the course instructor, but in many situation students looked for experts themselves:

> We needed help in how to perform a linear regression analysis of an electric system, since none of us were from electrical engineering. We went to some professors for information that we couldn't find. We attained help for more of the math related to our project. We also checked the website of the department of electrical engineering to find professors or graduate students who have an expertise in that area. We sent an email to two professors and some graduate students. A professor replied to us with some online resources while a graduate student met with us and showed us a web-based tool that saved us a lot of time (Survey respondent D2).

Students often started looking for experts who are available at the university as their first preference. However, when they were not able to locate an expert internally they expanded their circle to look for experts in other organizations:

> We could not find someone who could help us with the measurement option for an aircraft sensor, as we do not have anyone with such a specialization here. We sought help from a professor at another university who had prior experience in a small area we were working on (Survey respondent A3).

Experts were not limited to university professors or academics, but included people with professional expertise in particular industries:

> We asked for information from people at two companies when deciding on a data acquisition device to use for the project. A lot of information and advice was also given by other engineers whose contacts were given to us from previous-year students who had worked on the first phase of our project (Survey respondent P1).

7.1.1.4 Information seeking: Suppliers

Students contacted suppliers to get price quotes and specifications for the required materials and components for their projects. Suppliers were found to be key sources of information for students' projects. As Bruce put it:

> We needed estimated costs for possible design ideas so we could evaluate possible solutions based on the available budget for our project. We started contacting suppliers preferred by our client, but we looked for other suppliers so we could compare prices. There were two main challenges: many of the suppliers were based in the US and there were not that many Canadian ones, many of the suppliers we contacted did not reply to our emails. We followed up with phone calls and that was a more efficient way to get replies to our requests.

Suppliers were sources not only of prices, specifications and other cost-related information but additional technical information that helped students in their design projects. As one survey respondent put it:

> There was a lot of information obtained from calling geothermal companies to get an idea of installation procedures and costs, and a complete picture of the components of a geothermal heating and cooling system (Survey respondent F2).

This quotation illustrates the additional value of approaching suppliers as information channels for needed information, given that many of the sales and technical representatives had adequate experience in and knowledge of the field pertaining to the students' projects.

7.1.2 Information seeking: Documents

As seen in the previous section, students sought information from different people who provided them with needed information in a number of ways: by giving the needed information verbally, by referring students to people who had more knowledge in that subject area, and by giving students documents that ranged materially from physical objects such as books to web-based sources such as websites and online sources.

During their projects students sought different types of documents, either from other people or by engaging in an active and purposeful search for information. Depending on the type of needed information, students would seek these documents from people rather than searching for them online. As Mark revealed:

> We needed data specifications for the unit we are developing; this information is only available at the company and it is not something that we could find online. We actually tried to find them online before we contacted our project's client, but we realized then it might be easier for us to ask for help. The project's client got back to us, asking us to be more specific about what kind of data we were looking for, since there was some proprietary information that the company did not want to release.

As this example shows, when students sought particular information they started by searching online before realizing that it was more feasible to contact the project's client, given that the information they needed was so specific and was probably not available online as publicly accessible information.

7.2 Information searching

Information searching is the "behavioral manifestation of humans engaged in information seeking and also… the actions taken by computers to match and display information objects" (Marchionini, 1995, p. 5). As part of their learning experience while undertaking these assigned learning tasks, students searched for information using computer-based information channels such as the Internet and databases to search for information that would support their learning and help them solve the design problem at hand.

7.2.1 Lookup search

The lookup search is a basic kind of search used when students were looking for a known item or retrieving facts needed for their research. This type of search often starts with a specified query and returns discrete, precise, and well-structured information objects such as a particular journal article, a technical report, material or component specifications, or any other specific files of text or other media. As Emily put it:

> I liked to use Google Scholar to find the articles I was looking for. It is easy for me to type the article title and I press enter to locate the full text of that article from our library collections. I do not need to check each database to find that article as I am not always certain where that article would be found.

In this situation, Emily was using a web-based search engine designed to discover scholarly documents from different indexes and full-text databases. She was able to find the link to that requested article from Google Scholar and then retrieve the actual document from a database that the library subscribes to. This was one of the more common sources students used when searching for particular documents that they had already identified as necessary for their projects.

Other students reported that they used particular databases to find specific documents after they tried to locate them using a web-based search engine. Bruce describes a situation in which he sought a Canadian technical standard:

> I was looking for a Canadian standard that our client mentioned to us at one of the meetings. It was issued in 2009 and was on energy efficiency test methods for small motors. I search for it on Google and found the link to it, but I could not access the standard because I needed a username and password. I searched the library website and could not find it there. To save time, I emailed the library reference desk and they sent me a direct link to the standards database, which I have not used before, and I was able to get the document.

Bruce looked for a particular document using a web-search engine that he often used for finding information. His commonly used method did not return the requested document and he used the same strategy using the library website that has a different structure compared to search engines. He did not spend time looking for where he could find the needed standards and if the library has such a document and he contacted a person, the library reference staff, to refer him to the needed document. The situation shows that Bruce did not want to put more effort in looking for such information on the library website but he preferred to use the help of a person who was perceived to have more knowledge about the content of the library collections.

Lookup searching occurs when an information user wants to find a particular document using a well-formed query. The results of lookup searches have been found to be dependent on: the underlying information need of the searcher, the query statement, and the collection being searched. Lookup searches are "suited to analytical search strategies that begin with carefully specified queries and yield precise results with minimal need for result set examination and item comparison" (White & Roth, 2009, p. 4).

Lookup searching was found to be an individual activity most of the time, although some students reported some situations where collaborative lookup searching took place, as in Bill's case:

> During one of our group meetings, I looked at a journal article that another team member shared with us and I saw a reference to a patent document that I thought was relevant to us. I tried to search for it online using Google search, but I could not find the full text…Another team member used his computer to search a patents database and he successfully found it and shared it with us immediately.

Bill described a situation when he needed to search for a particular patent that he found as a reference in a journal article and searched for it using a web-based search engine with no access. Another member, who was aware of using a patent database as an information channel that can be used more efficiently in retrieving such a specific document, looked for that patent document and was able to locate it and then to share it with the group.

7.2.2 Exploratory search

As previously described, students performed lookup searches when they were looking for a known specific item, but this was not always the case when students searched for information. Students reported that they searched for information in iterative ways when they had an open-ended project with a broad topic that required them to acquire information from different sources. As Eric put it:

> The process I usually take is the following. Almost always I look for information on the web. I always start with a general Google search with different terms until I get results that look like what I'm looking for. I maybe skim the Wikipedia article and skim some of the top hits, opening different Google search tabs when I see terms that might be useful to search for. I keep track of related sources and a short description of what is contained in each source, so I can quickly return to it later if it becomes more relevant. I repeat until either I have found the information I need, or I know what the relevant search terms are if it's highly academic. Then I go to the library catalogue and look for reliable information using Academic Search Complete, if I'm looking for journal results; or look on IEEE Xplore for more technical journals; or look on Knovel if I am looking for general guidelines in handbooks or textbooks. If I've found what I need, great; if not, I accept that the specific information I need

> probably doesn't exist or maybe ask someone if I think they might have expertise in the area.

Eric described his information searching experience in this project that he started with a broad search to get more understanding of the topic that he needed and sought more information to acquire. He started with background information from Wikipedia and repeated the search with other more related queries using different search keywords. Once he recognized the need to get more academic, described by him to be more reliable information, he used databases where he could find scholarly and technical information. However in any case that he was not able to find the sought information, he articulated that the information did not exist and he did see that he was not able to locate or retrieve his sought information. In such a situation, he looked for an expert in that subject to provide him with the needed information.

Such a scenario for information searching was reported by other interviewees in this research and also from a survey respondent in Study 1:

> As an engineering student I want the most cutting edge information. I rarely look for information in print because I usually believe that there will be something more up to date on the internet. For my project, I looked at print for fundamental engineering information, but when it comes to specifics it has to be the most recent. I guess my style would be use the internet, mostly the databases. First I will go to Wikipedia to get a broad understanding of the topic that will help me use the search engines more effectively. Then I use the databases provided by the engineering Library. I then look through patents using freepatentsonline.com. I try to look for standards, but usually only after they are mentioned in a paper (Survey respondent F2).

This experience, as reported in the previous quote, is similar to Bruce's, in that he explored different information sources to get an adequate understanding of the project requirements before performing lookup searching for particular and specific information found during his exploratory search.

Information exploratory searching within the scope of learning tasks was found to be associated with students' learning experience. Marchionini (2006) argued that the key components of the exploratory search process are learning and investigation. In exploratory searches, users search for information to close a gap in their knowledge by acquiring, evaluating, and using information in a particular subject. In learning tasks, exploratory searches were performed by way of multiple queries and by using different sources to discover new information and acquire new knowledge to support learning.

The original explanation of exploratory search, introduced by Marchionini (2006), was derived from many of Bloom's taxonomy of educational objectives to describe information searching as a higher level of cognitive activity for problem solving and learning. White and Roth (2009) expanded on Marchionini's explanation to define exploratory search in terms of context and process:

> Exploratory search can be used to describe an information-seeking problem context that is open-ended, persistent, and multi-faceted; and to describe information-seeking processes that are opportunistic, iterative, and multi-tactical. In the first sense, exploratory search is commonly used in scientific discovery, learning, and decision-making contexts. In the second sense, exploratory tactics are used in all manner of information seeking and reflect seeker preferences and experience as much as the goal (p. 6).

Students were seen to be engaged in exploratory searches at various times during their projects, when they needed to define their project's problem statement, conduct background research, define possible design solutions, select one particular solution and, finally, design a solution for the assigned design problem. Because students did not have prior experience from their previous courses to help them with their currently assigned project, they needed to learn about the assigned topic through different information sources to achieve the project objectives.

Observations of students' exploratory-search behavior revealed that they might become engaged in lookup searching as a result of the investigation and learning processes associated with exploratory searching. These findings support the exploratory search model (Figure 7.1) suggested by Marchionini (2006) and developed in this figure by White and Roth (2009).

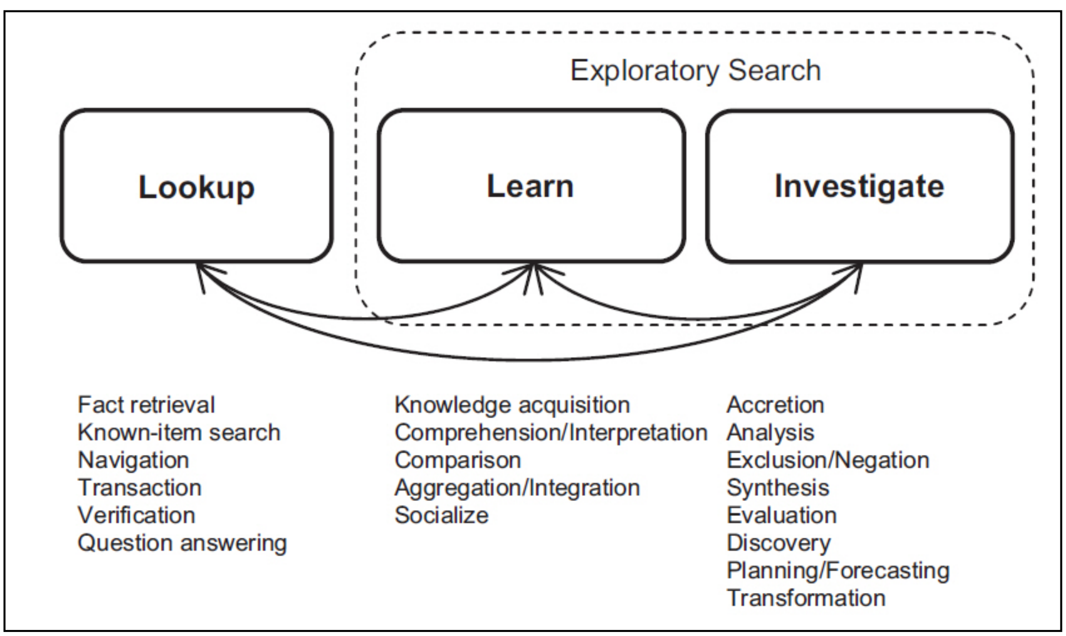


Figure 7.1: Components of exploratory search

Exploratory searching was found to be primarily an individual activity, given that student groups generally assigned a different subject area to each member to work on during the project, as has been discussed in previous chapters. However, there were some situations in which students reported collaborative exploratory searching, as Sara describes here:

> I do remember after a conference call with our project's client we needed to find relevant provincial and federal reports on drinking water quality. We were at a group study room at the school of business where they had a flat screen monitor mounted at the wall. One group member had his laptop connected to that wall display and he started to search for these reports using Google. We, the other three members, were looking at the display, looking at the results, and giving directions with some suggested search keywords to get better results. It was the first time we did that as a group and I think it was a nice experience as we saved a lot of time in finding useful reports.

In this situation, the fact that students engaged in collaborative exploratory searching was a direct result of the study-room setting, which had one computer and a shared display. Even though this group had not planned to search for information collaboratively, they used iterative searches and exploratory browsing of possible documents to pursue their search objectives.

7.3 Collaborative grounding

As previously found, collaboration among group members requires a shared understanding of the task objectives and activities to be performed during the project lifespan. Because activities and interaction in information seeking can be performed either individually or collaboratively, each group member needs to maintain what is often termed as a common ground (Clark & Brennan, 1991). The findings in this research confirm Hertzum's (2008) argument that collaborators in any task have to maintain a commonly understood set of terms, parameters and goals informing cooperative and individual activities in both information seeking and group-based tasks. Without an established and maintained common ground among students as task performers, collaborative information behavior during their tasks was unlikely to occur or, if it did, to succeed.

It was found that students actively constructed and maintained a shared understanding of the project requirements and an awareness of what each individual had already performed, in order to proceed with their project. This common ground, their shared understanding and awareness, was found to affect students' collaborative information behavior, specifically in the way they assimilated and evaluated available information sources. Collaborative grounding was developed and maintained among group members by way of group meetings, the shared use of software tools, information sharing and the development of shared representations of their work.

7.3.1 Group meetings

Students held in-person group meetings with varying frequency while they worked on their projects. At the beginning they met once a week to plan project activities and develop such course-required deliverables as the team weekly memo and the weekly progress report. The frequency of group meetings changed over the course of the work according to the task requirements and their deadlines. As Sue described it,

> I really enjoyed that most of our work during this project was performed at our meetings. At the beginning we met once a week one day before the weekly reports were due. During these meetings we needed to report what each of us was doing and what information we had found based on the topic we were each assigned. We started to meet more frequently when there were important project milestones coming up, such as the interim reports, and when we'd get new information from our project's client in a site visit or through a conference call. I remember in the last three weeks of the project we met daily and the meetings lasted longer than they had before because we had to collect the information we had gathered during the project into one single report. Even though we were able to share what each of us was doing by email, it was much easier and efficient to meet face-to-face and discuss our findings.

This preference for in-person meetings was reported in other interviews and in students' reports in Study 1. In this case study, in-person meetings occurred easily and regularly because the university where the research took place is a small residential campus where students study and live a short distance from each other.

Groups meetings were found to be an important facilitator of collaborative grounding with respect to information behavior, as Bruce put it during the last interview in Study 2:

> I remember in the early interviews we had in the last months, I was arguing that I preferred to search for information individually because it was easier and more efficient than if we all had to look at the same computer screen. It happened that when we were getting closer to developing the selected design we started to have more meetings during which we discussed and evaluated the information each of us had found. During one group meeting, while we were discussing the design, I noticed that another student seemed skeptical about some of the information we

> had used in our calculations. He pulled out a report on his computer and showed us some information that was quite different than the one I had used in my calculations for the design. We looked at the two sources we had and the other two members joined the discussion. Then we looked as a group for other sources in handbooks, to compare our findings and to determine which information was more reliable to use. The process took two hours, but we were able to find other reliable and accurate information and learned new things about the problem that helped our design be a better one.

This situation as reported by Bruce described the role that a group meeting played in creating a common ground for the group members, one that affected their collaborative information behavior. In this group meeting, while the students articulated the information they needed to develop a solution to their project's problem, it unfolded that another student disagreed with the information used for the design. After he shared the different information source with them, his group started to compare it to the one Bruce had already found. Because the initial discussion had not created a common ground of understanding, the group engaged in explicit collaborative information searching that resulted in the discovery and use of a new information source. In addition, a shared understanding among the four members of the project group was reached when their individual perspectives came together.

7.3.2 Information sharing

Information sharing tended to take place during group meetings when students reported their performed activities and especially when the task was purposefully distributed among several students. Information sharing integrates "both active and explicit and less goal oriented and implicit information exchanges…[It] is about sharing already acquired information" (Talja & Hansen, 2006, p. 114). Sharing already acquired information objects was found to be one of the main activities in student groups' interaction. Bill described it this way:

> I preferred to share all the information I was able to find, and which was relevant to our project, with the rest of the group. Even though I was responsible for a particular area of the design project, I came across many documents that were useful to others. I liked to share and refer to these documents in our meetings.

Sharing already acquired information was not limited to the task at hand. As Sara puts it, below, her group also shared information in a repository that could be used for future activities in the project:

> We always tried to share all the information that each of us had found during the time between group meetings and to discuss how this information could be useful for our project. I remember that in November another student found a lot of articles that we knew were going to be useful for us when it came time to implement the design solution. We didn't use these articles until February, but it was helpful that we did not have to search for other relevant articles. We already had them.

Information sharing was found to be essential for creating a common ground in collaborative information behavior, not only in sharing acquired information objects but also in communicating ongoing information needs. As a survey respondent in Study 1 put it:

> During our meetings we looked at the information we had found so far to decide if it was good enough for us to use. Sometimes we decided that we

> still needed further specific information and assigned who would search for and retrieve it in time for our next meeting (Survey respondent D3).

Information sharing was also found in this research to involve the sharing of search strategies:

> At one group meeting, I shared with the group that I still needed to locate a patent that was referenced in one article I found in a library database. I tried to find it before the meeting but was not able find the actual patent document. Another student said that he could help me to find it, as he knew how to use a patent database that I was not familiar with. He used my computer and showed me where to find the database and the possible ways that I could search using specific keywords. I used it immediately during the meeting and was able to find the document I was looking for and also newer patents based on that design (Survey respondent A4).

Students shared information at different levels and for different purposes during their projects. Information sharing was found to evolve gradually and dynamically, however, depending on the achieved level of the developed collaborative common ground among group members. Students reported that information sharing depended on how well the group members interacted with each other socially during the project lifespan. For example as Emily put it:

> At the beginning of the project we did not share a lot of information, because we did not know each other very well. The more time we spent together the more we became friends and started to share stories about everything we do, not just what we should do for our project. In our meetings we talked about other things such as music and food [chuckles]. We became more comfortable sharing all the information we'd found and talking about the difficulties we'd faced in finding information. We got to

> the point where we genuinely enjoyed working together as a group in everything we did for our project.

7.3.3 Using software tools

Students used software tools to support their collaborative activities and interactions in information seeking and use during their projects. Students reported the use of file sharing tools such as DropBox™, a software application enabling them to create a repository of the project's information objects including project documents, found information sources and all developed drawings and tables. As Bill described it:

> The use of file sharing was a good thing that we did during our project because it enabled us to store everything we found to be useful for our projects, whether we needed it for what we were working on or for future use.

The course instructor suggested his students use file sharing tools as a way to manage project documents. Some students reported that they had used DropBox™ in previous courses. A few, like Laura, below, were new to the program:

> I used DropBox™ for the first time during the project and found it to be a useful tool. Whenever I work on my project I can get back to the stored files and use them for reference or look for information within the documents that others have collected.

Students recognized the advantage to using a file sharing tool that gave them an archive of all of the project's documents and created a shared awareness of the information objects that each student had found or developed to meet the task requirements. In one case, they discussed how file sharing should be managed to organize documents and facilitate their retrieval and reuse when needed as Sara described it:

> My group preferred to put our found documents in a shared file folder. The number of documents was increasing every week. While we were meeting to write the second interim report, we noticed that many of the documents uploaded by another student had file names written only as numbers. Because the name did not tell us what these files contained, we needed to open each one to see its contents, and so I suggested we rename those using descriptive words. We decided we had to organize the documents in a meaningful way. I volunteered to be responsible for organizing the documents in the shared folder and to get back to the group in our next meeting with a filing system that we could follow.

Identifying a problem with their existing practice in file sharing, this group endeavored to find a solution that would help them during the rest of their project. Sara described her strategy:

> I renamed most of the files to include more information such as subject, author and year in their titles. Then I created subfolders for the subjects of these documents, so that we had folders for technical and business information and one for the documents we received from the client. I also created a Word document that had a list of the documents with their full references so we could use them in creating bibliographies of our reports. I actually did that in an internship I had last summer at Environment Canada and I think it was a useful way for our project to save time and to be more organized.

Sara was able to organize already stored documents and create a system to organize the storage and retrieval of future documents to be stored and used during the project. The collaborative software tool helped group members decide what information needed to be shared within the group. Mark describes a situation in which group members discussed the way information object would be shared. For Bill, one concern was the distracting frequency of group file sharing:

> In the first month of the project I noticed that another student was sharing a lot of documents that were not related to the task I am working on. I did not like that because it was like a lot of noise since I always receive a notification email when new items are added to the folder. So we met to discuss how to share documents efficiently and decided that each of us would have a personal folder and another shared folder for the documents that were found to be relevant to other students' tasks.

In this case, for any piece of information, a distinction would have to be made between what was useful for an individual and what would be relevant to other group members for reuse or future reference.

Collaborative software tools let project groups gather information objects in repositories accessible only by their members. In one case, however, students provided broader access to some shared folders:

> We were working on different aspects of the project and we put our documents in a shared folder all the time. During one conference call with our project's client we wanted him to give us feedback on what we had done so far. So we gave him access to our shared folder so he could read the documents and put his notes inside them. This was an easier way to manage our files than using email messages with attachments. We continued to give him access during our project and he uploaded a number of documents that he felt would be useful for the project. We liked the feeling that he was involved in the process at each stage; it felt like he was a member of our project group! We continued to do the same with a

> supplier who gave us quotes with specifications and drawings. He was also able to upload all the files he shared with us (Survey respondent E3).

The use of a collaborative tool extended the collaborative common ground to external users who were involved in the project, maintaining a shared understanding of the project's development and an awareness of its progress.

The use of collaborative software tools was not limited to file sharing systems. One group took advantage of the collaborative document editing function of Google Docs™ as well as the instant messaging of such applications as Blackberry Messenger™. As Eric described it:

> The three of us had blackberry phones and we used blackberry messenger to communicate between our meetings, especially when someone had something that other members should know immediately. We had a conversation thread open all the time between the three of us during the project.

While Eric was describing his group's use of instant messaging, he looked at his phone and said "You know that we exchanged 640 messages in eight months". The frequency with which they use this tool shows that students have harnessed the technology to create a communication medium allowing them to share information and generate that collaborative awareness essential to the establishment of common ground.

7.3.4 Developing shared representations

In the previous examples, students used conversations and shared information sources as co-present cues (Clark & Brennan, 1991) for the grounding of their communications and interactions during their projects. Students also collaboratively developed shared representations, such as tables and drawings, interactive communication media enabling the construction of a common ground in their information seeking and use.

Students developed external representations, as required by the task, in which information was accumulated, transformed and interpreted as new information objects. To give an example of a developed shared representation, I will discuss the weighted evaluation matrix that students had to develop, detailed in section 5.2.5 and described by Eric:

> When we developed the weighted evaluation matrix for our project, each of us had a design idea. We talked about them in one group meeting. We needed to put all the information about each one into a single table and evaluate them based on criteria we needed to identify as well. It was an extensive process. Each of us had a different idea and tried to explain it to the other members of the group based on the information we had found.

In this situation, Eric described that each student had a design idea that was based on available information to that individual student. As a result, students engaged in a conversation to understand individual ideas in order to create a shared understanding within the group about each particular design idea before evaluating it. Eric continued to describe the process by stating that:

> One student presented the design idea he got, but it was not that clear for the rest of the group. We asked him to explain it and he opened an article that he found and we all looked at that document from the shared folder to understand how his design idea was based on that article. We also felt the same about another student's design ideas and we tried to understand the information she has used. We could not evaluate the design ideas during the meeting because we did not understand the rationale behind all of

> them, so we decided to go away and read everybody's documents, then meet again in two days to continue the evaluation .

The reported situation showed that a shared understanding within the group was not easily constructed. Some students were unable to comprehend all information objects found by every student in the group, and so, collectively, they were unable to evaluate all of the proposed design ideas. The externalization of ideas during the meeting led to identification of differences of interpretation taken by the group members. Students engaged in verbal communication before using documents (nonverbal information artifacts) to create a common ground that would lead to a shared understanding. Because the process took longer than originally anticipated, the group decided to use the found information in order to continue the task of design options evaluation. Eric continued, describing how the group collaboratively finalized the process:

> At the following meeting we had a better understanding of each of the proposed design ideas. One student started to build a table using his computer. In it we listed all the design criteria and gave a score to each criterion based on its importance. We discussed what were the important ones based on the information we had from the client and from the information we found online in many websites and articles. When it came time to score each individual design idea, based on these criteria, everyone gave a high score for his selected idea. We started to argue, discussing the specifications of each idea, and we ended up looking again at the same documents we had before, but also we searched for new information in some handbooks that one of the group members suggested. The meeting lasted for more than three hours. We ended up selecting the design idea that I'd suggested based on the calculation in the matrix. That made me happy because I already knew a lot about it.

The development and construction of a shared representation such as the weighted evaluation matrix followed a sequence of activities and interactions involving all group members. Any student's design idea could be challenged by another student or other students if they did not fully understand its meaning. Discussion, argument, reexamination and explanation ensued until an accepted shared understanding by all group members could be developed.

Designers always to try to externalize their thoughts and ideas by getting their thoughts and thinking processes out of their head into charts, diagrams, and tables that commonly feature in design methods. This externalization process is "a significant aid when dealing with complex problems…it is a necessary part of the team work… providing means by which all the members of the team can see what is going on and can contribute to the design process" (Cross, 2008, p. 47).

The development and use of a shared information object can lead to an external representation of students' ideas that would differ from one person to another. When ideas in Eric's group were challenged, further explanation and justification of these ideas among all group members was required. The externalization of ideas was based on the information that each student had found as reference and support for every suggested design idea. Overt verbal argumentation during group discussion, in addition to a table created as a nonverbal communication medium to aggregate their findings, facilitated the construction of a common ground for the group. Their eventual shared understanding was based on information available to them before the meeting, in addition to new information the group was able to acquire through explicit collaborative information seeking during the meeting.

Students' activities and interactions during the process of developing a shared representation resulted in a new information object. This newly constructed group knowledge was a product of their articulation of available information and of information needed to support the development of an agreed shared understanding. Suthers (2005, p. 2) argues that the process of knowledge construction is evidenced by the accretion of interpretations on an information-base that is simultaneously expanded by information seeking and transformations.

The development of a shared representation required the transformation of a large amount of information into a new representation through a process that has been described by Russell, Stefik, Pirolli, and Card (1993) as the learning loop complex (Figure 7.2). In a learning loop complex, information users first search for a good representation through the available information (the generation loop). Then they attempt to encode this information in a representation (the data coverage loop). During the process of creating a new representation, information users identify the information that does not fit in the constructed representation (residue) and identify any other information needed for the creation of a new information object.

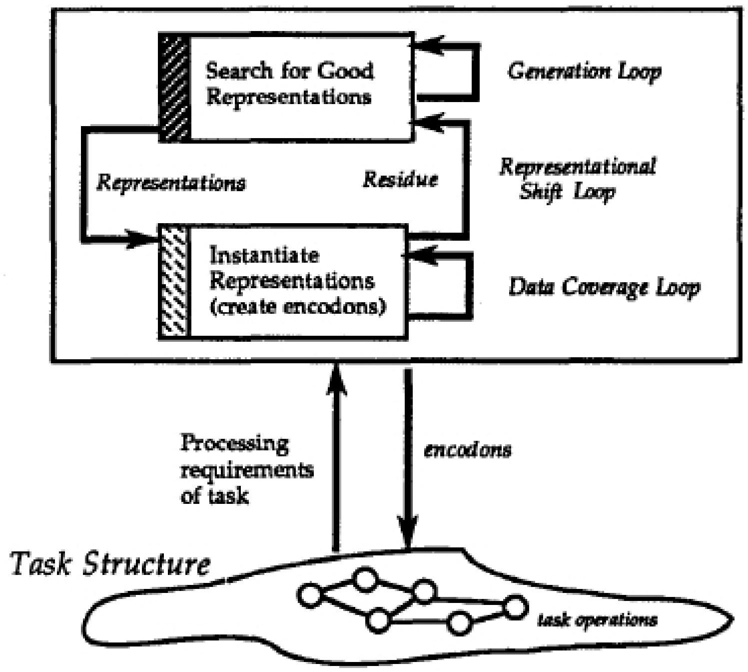


Figure 7.2: The learning loop complex.

The process of developing a new, shared representation was found to play a central role in enabling the construction of a collaborative common ground for every project group in this study, through the interpretation of available information along with constructive argumentation and collaborative articulation of the task requirements.

Information was found to play an essential role in creating a common ground for collaborative information behavior. This is in line with Clark's theory of common ground, which states in part that "everything we do is rooted in information we have about our surroundings, activities, perceptions, emotions, plans, interests. Everything we do jointly with others is also rooted in this information, but only in that part we think they share with us" (Clark & Brennan, 1991, p. 129). Collaboration in information seeking and use is a cooperative activity that requires the coordination of activity of all students. As such, "grounding is crucial for keeping that coordination on track" (Clark & Brennan, 1991, p. 148).

7.4 Collaborative information synthesis

Synthesis is defined as "the putting together of parts or elements so as to make up a complex whole" (Oxford English Dictionary, 1989). As an activity related to knowledge construction, it is also understood to be "the dialectic combination of thesis and antithesis into a higher stage of truth" (Merriam-Webster's Collegiate Dictionary, 2004). In education, Bloom's taxonomy of educational objectives defines synthesis as a high cognitive activity in which learners compile information in a different way by combining elements in a new pattern (Bloom et al., 1956). Simply put, synthesis is the process of turning available information into new knowledge.

Research in engineering design also recognizes the role of synthesis in the design process. Archer (1984) developed a model in which the design process (Figure 7.3) consists of three phases: the analytical, creative and executive phases; synthesis was viewed to be the core of the design process's creative phase.

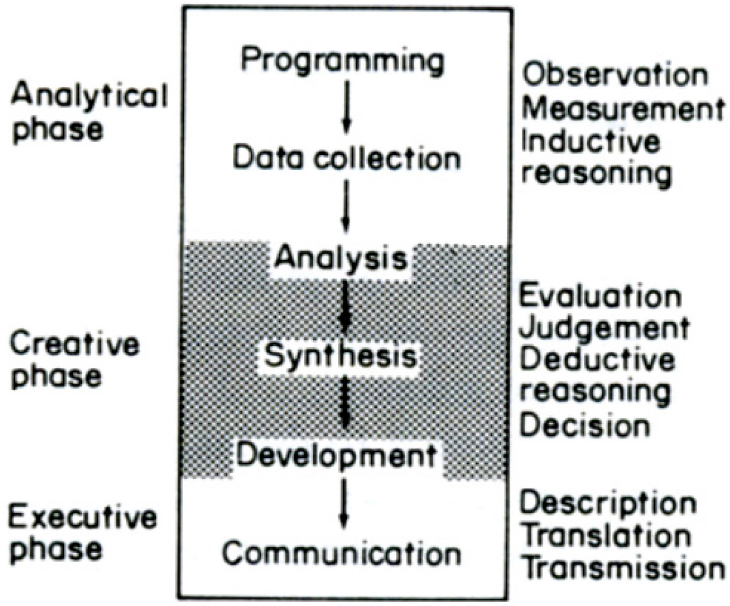


Figure 7.3: Archer's model of the design process.

Clive Dym, a well-known researcher in design methodologies, defines synthesis in his work *Engineering design: A synthesis of Views* to be a process of "assembling a set of primitive design elements or partial designs into one or more configurations that clearly and obviously satisfy a few key objectives and constraints. Synthesis is often considered to be the task most emblematic of the design process" (Dym, 1994, p. 28).

The design process includes the collection of different types of information from documents or from people whom designers consult in their quest for a design-problem solution. During the design process designers have to actively integrate, organize, filter, and evaluate information in order to understand the design problem and ultimately solve it.

Information synthesis is an integral part of the design process, enabling designers "to organize, manipulate, prune, and filter gathered data into a cohesive structure for information building" (Kolko, 2007, p. 2). Kolko further defines information synthesis during the design process as "an abductive sensemaking process. Through efforts of data manipulation, organization, pruning, and filtering, designers produce information and knowledge" (Kolko, 2011, p. 21). Sensemaking is "[the] motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively" (Klein & Moon, 2006, p. 71). This definition of sensemaking was built on Brenda Dervin's findings, described in Section 2.2.1.1. It implies that people learn when they make meaning themselves.

Thus, information synthesis in a group-based design project was found to be a process in which students collaboratively process large amounts of information along with individual students' interpretations into a coherent whole that produces new information and knowledge. Kolko (2010) argues that sensemaking is always an internal cognitive process, while "synthesis can be a collaborative, external process" (p. 18).

7.4.1 Prioritizing of information

As previously discussed, students in this study were engaged in many information seeking and search activities resulting in a large amount of information being shared among group members. During the process of information synthesis, students attempted to decide what pieces of information were more important than others. As Sue put it:

> After the client approved our suggested solution, we started collecting as much information as possible so we could find the best way to develop the

> prototype and make the necessary tests and calculations. Each of us had a folder in our shared file where we put the documents we'd found online. During a group meeting, we talked about what we absolutely needed to know before we could start working on the design and what information was less important and wouldn't be needed until later. We started by reading a case study that one member of our group had found and that we agreed was going to be the most informative and helpful to us during this next stage.

In this situation, because they had gathered so much information for analysis, students had no choice but to prioritize these collected information objects, ranking them on a scale of relevance and importance with respect to their potential objective use in meeting task requirements. It was found that students did not use all of the information objects collected during their projects, utilizing only the information that they judged to be relevant to their projects. As Emily put it:

> During the background research, each of us found a lot of articles and websites that we thought would be useful to give us the background information that we needed to start the project. We shared the links to websites between us by email and uploaded the files we found in our shared folder. We met to prepare our brief report and we looked at the documents and discussed if they are useful or not. Some of the articles were too academic and covered theoretical topics that were so complex for us to understand…. We kept them for possible later use, preferring to concentrate on the ones we could understand, to help us write the first report.

Emily's group selected useful information based on their understanding of the content of these information objects. The selected information types were considered useful when there was a collective understanding of their content; discarded ones were seen to be not useful when their content was too difficult for students to interpret based on their limited knowledge.

7.4.2 Judging relevance of information

With so many definitions of relevance (Lavrenko, 2009), it is important to mention that judging relevance, described here as being an important part of the synthesis process, is concerned mainly with relevance to the task requirements and objectives. This type of relevance had been described by Mizzaro (1998) as task relevance, which specifies that the information object is useful to the task being performed.

Judging the relevance of information is a subjective activity; different students will make different relevance judgments about the same information objects. In such a situation, students engage in a discussion about the task relevancy of information until a joint collective judgment of relevancy is shared by all. As Laura described her group's experience:

> One member of our group used information from a patent he found online and he incorporated some of this information into his proposed design idea. During the meeting we were reviewing the references included in our report and I found out that the patent is not approved. It was filed but still in the application process. We discussed whether or not we should use such a patent in our report and the other two students said that they didn't see a problem, while I insisted that it might be a problem. After a long conversation we searched Google for information about how patent documents can be used in design. We agreed that we should indicate clearly in the report that the patent is still pending.

In some situations, as Mark describes, below, students discussed the relevance of the information object itself and its characteristics to be included as a source for information for their projects:

> When we were preparing our interim report we assigned a section to each of us, so we collected these four pieces together in one document and met to discuss and finalize it. One of the sections had a table that contained data in numbers about the use of solar energy in Canada but without a clear reference to its source. The student who had included that table said that he got this information from an engineering forum he subscribes to online and he showed us the link to the page where he had copied the table from. We looked at that page and another student said that it looked like a Wikipedia page. The website turned out to be a personal website. Because we couldn't use it for our report, we searched online and found the same table in an article that references the original source of the information.

Relevance of information was judged on the credibility of the information sources; in this case, students were able to question the credibility of an information object suggested by one student and then engage in a collaborative activity to search for a more credible source that would be found and judged by them to be relevant to the task. As one survey respondent reported, relevance was also found to be related to the currency of information objects:

> I preferred to look for everything online, as I can find more current information that is more relevant to our project than information in print, especially since we were developing a new solution for an existing product that has been around in the market for three years. I believe that we did not use any information that was older than five years, so it was not only me who though that way (Survey respondent K1).

Here, the student judged the relevancy of information sources based on their currency and used his identified evaluation criterion for relevance to select information objects useful for the project. He also felt justified in his selected criterion, given that he and his fellow group members had acted similarly in choosing the most up-to-date sources.

As a first step, individuals were able to judge whether or not what they had found was relevant, as they sought and used information within the scope of their particular assignments. Given the nature of group-based inquiry, the relevancy and usefulness of the found information could then be re-judged by more than one student in their group. One survey respondent describes the advantage of collaborative information-judging:

> Each person would present and explain the information he had found… explaining why it was relevant and how we could use it, [he] would then answer any questions from other members of the group, until everyone felt comfortable with the information found. [Each] would also provide the references and a summary of the material…so that any of the group members could look at the information themselves and use it if needed (Survey respondent B2).

7.4.3 Building connections of information

Synthesis is about creating new knowledge from different items that are put together. During synthesis, students looked for relationships between discrete and separate bits of information they judged to be relevant for their tasks. The result was new knowledge represented in a newly constructed information object. For example, in the previous sections on prioritizing and judging the relevance of information, there were situations that required students to synthesize information that had been gathered individually or collaboratively because of a particular project activity or a milestone such as a project interim report, project brief report or created shared representations. These situations required students to build connections between information, as Bruce describes:

> After we got the client's approval on our selected design idea, we needed to develop an estimation of the cost of the prototype before we could get an approval to purchase the needed materials. We looked for prices online and we asked for quotes from different suppliers. We started to make calculations using an Excel spreadsheet where we had the required quantities based on our calculations and the different prices we were able to get, but we found that the total cost was going to be higher than our available budget. We contacted the same suppliers again to see if we could get better prices. Some of them provided us with lower prices but for lower quality materials that would not meet the project's client expectations. One supplier gave us a good price, but the delivery date would be too late for our project. We created three different scenarios with possible budgets that included the pros and cons of each scenario as we envisaged them. We shared this information with the client, discussing it with him during a conference call, and he selected the project scenario that fit his needs.

The passage above describes a situation when students had to build connections between different pieces of information available to them within a constructed frame. They based their decisions on the information that represented the project's constraints, including the project objectives, available budget, available time and selected materials specifications. As a result they were able to create three possible cost estimates, as shown in Figure 7.4.

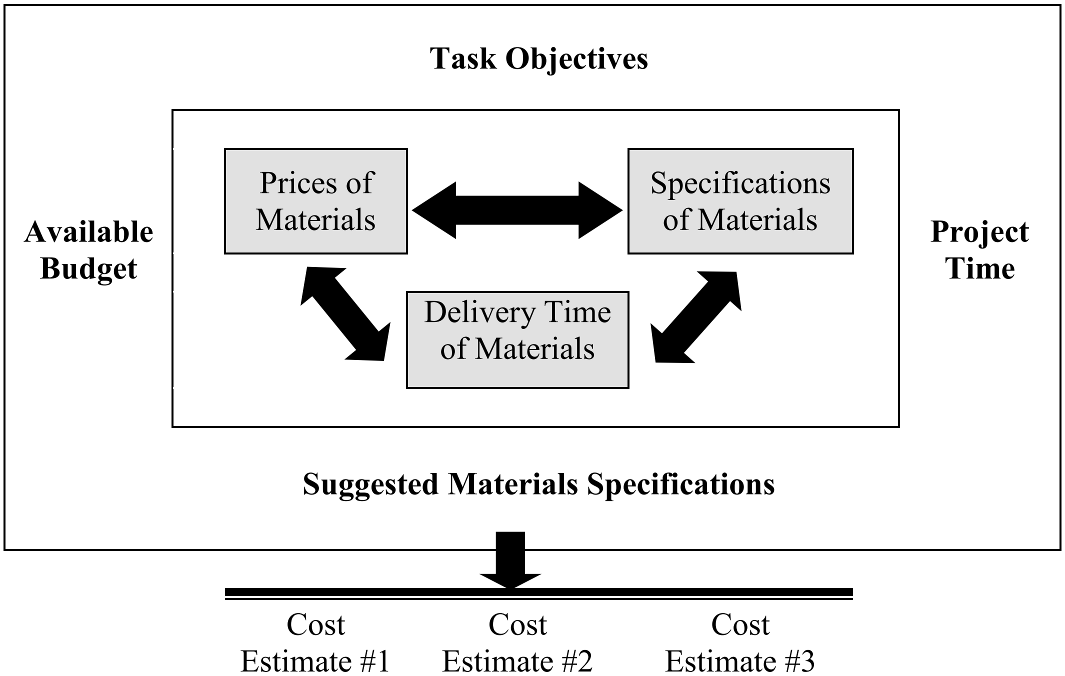


Figure 7.4: An example of building connections of information as a part of the collaborative information synthesis

Students synthesized different types of information within a constructed frame that allowed them to comprehend the meaning of each in order to create new information objects needed for the task to be performed. The constructed frame affected the students' process of collaborative information synthesis as they made selections from and decisions about the possible cost estimates. Schön (1984) argues that a normative framing of each situation during the design process is essential to the creation of hypotheses upon which design problems can be solved, based on salient features that constitute the complex reality of the design task.

Developing shared representations enabled students to collaboratively synthesize information by building connections between information that was mainly empirical, such as market reports, lab reports, measurements, specifications, etc., in order to transform them into a form that could be used to define the required characteristics of the proposed design solution. As an example, a weighted evaluation matrix of possible design ideas became the frame within which students transformed the information they had into a new information object used to calculate the score of each design against determined evaluation criteria.

Another example of the role of framing in building information connections is from a project in which students had to develop a user interface for an electric tractor. Based on the information they had from the project's client and from the identified literature, the students decided what information should be displayed on the user interface. In group meetings during which members examined and discussed all of this information, they were able to define a number of different variables that could be displayed on the use interface as quoted by a survey respondent:

> We were meeting in a group study room and we looked at all the information we got so far from the company and what we had found online from other companies that sell similar tractors. We discussed what information a tractor's operator would need to see on the display unit. We brainstormed and created a list of possible variables, which we wrote on the white board. We identified the most important ones and discussed how we would measure these variables. Each of us voted for five variables out of the many that we identified and we were able to select eight variables that got the highest votes (Survey respondent E3).

The reported situation describes the process of collaborative information synthesis. This includes the prioritizing of discrete pieces of information by ranking them within a frame based on the project's requirement and students' knowledge of these variables and of how they could be measured. The students' report showed that they had developed a map (Figure 7.5) of the identified possible information to be displayed, with variables, represented in green, which students had further investigated in detail during the project. The map also showed all the connected information that needed to be considered as part of the final display design.

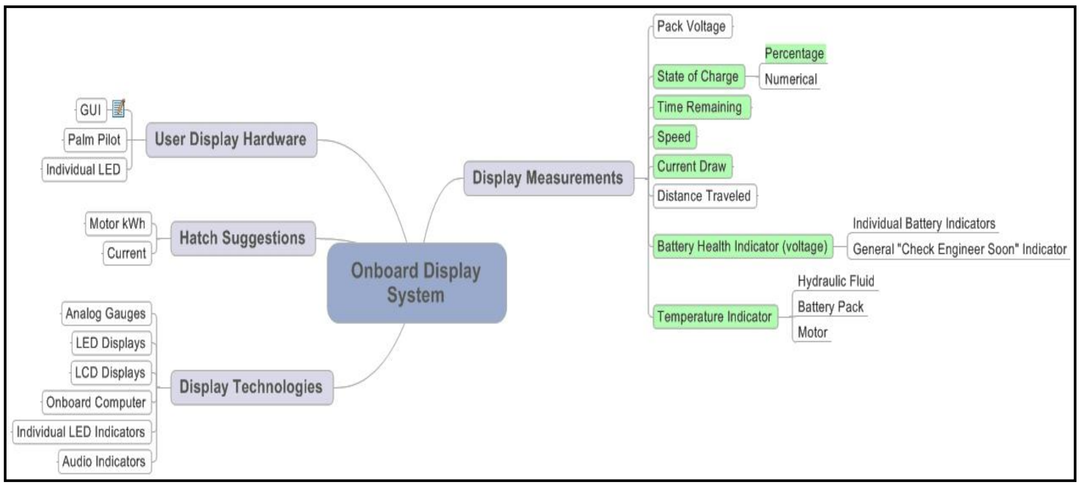


Figure 7.5: A constructed map for information display of user interface.

Once the variables that had to be displayed were identified, the actual interface was designed. In designing the front panel, students reported that they considered numerous methods for displaying information. By making measurements of the tractor's electrical system, they were able to identify a range of variables and decide how these could be displayed on the panel and easily interpreted by the tractor's operator. During the implementation of the design solution, the students developed a representation (Figure 7.6) using LabVIEW™, an engineering simulation software, to represent how these interconnected information variables could be integrated onto the front panel to appropriately display information to the tractor' operator.

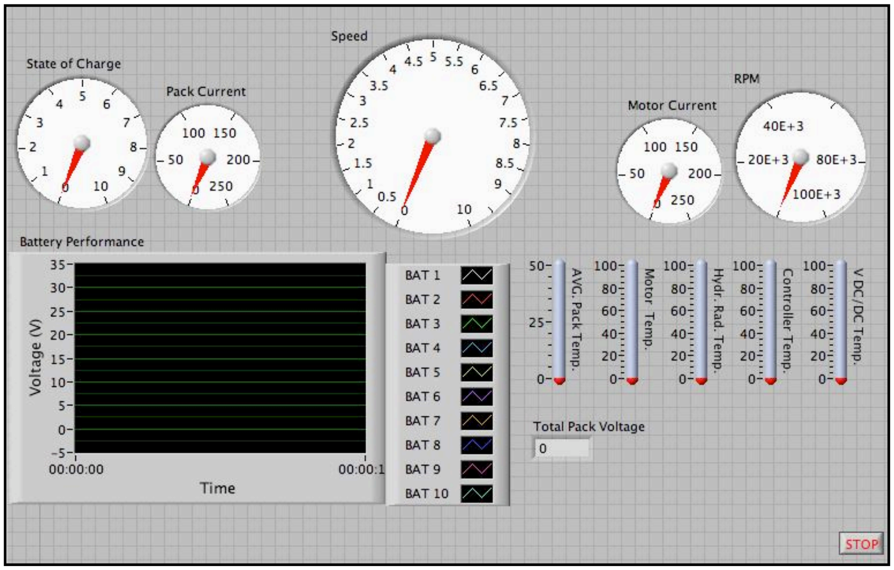


Figure 7.6: A developed representation of the electric tractor's front panel to show user-pertinent variables during tractor operation

The constructed outline of the proposed display shows how students synthesized the information, produced by the machine, in such a way that it could be displayed by way of different scales and meters. After interviewing a number of tractor operators, students used logic and intuition to integrate feedback from the operators into the proposed design, in order to make the user interface easier to use.

During the testing phase of the proposed design, the students were able to identify potential trouble that could occur during operation. Correlating the findings of lab experimentation with information they had from the components' specifications, they investigated possible problems and their causes. As a result, the students were able to develop a new information object (Figure 7.7) as a representation of the troubleshooting process that would deal with the system's operational malfunctions.

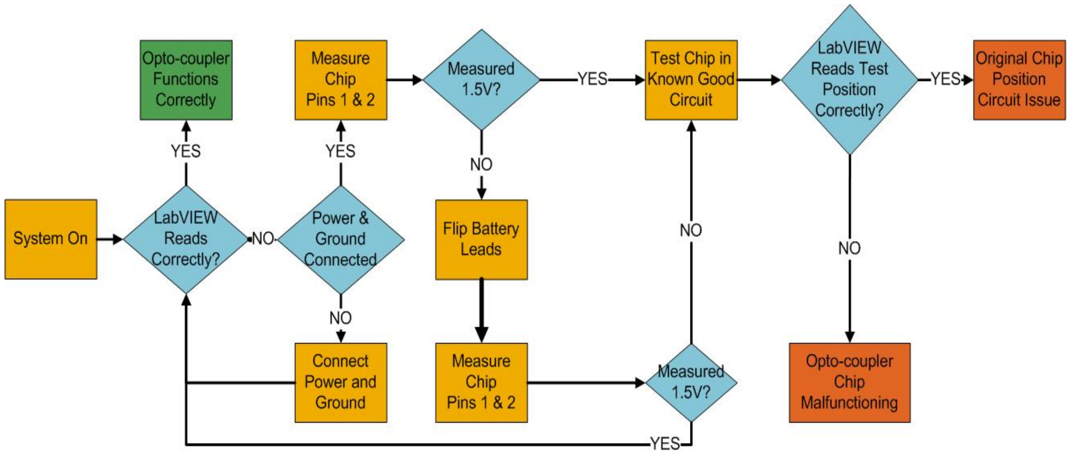


Figure 7.7: A constructed representation developed for troubleshooting of no-voltage readings

These aforementioned examples are but a few of many, reported in students' deliverables during the course and during the interviews, that show the different ways students represented their constructed information-artifacts, These tables, diagrams, maps, charts, etc. represent new information supporting the proposed design solution.

7.5 Collaborative activities and interactions

During the last interview in Study 2, at the end of students' projects, the interviewees (Bill, Bruce, Emily, Eric, Laura, Mark, Sara, and Sue) were asked to reflect on their project experience as it related to collaborative information behavior. As described in Chapter 3, the interview protocol was changed from semi-structured interviewing to a think-aloud protocol, to allow students to describe their project-related experience in a more open-ended manner.

Students were given a number of papers with blank forms designed to think aloud and recall their activities and interactions, they could estimate and tabulate what percentage of their activities were collaborative and what percentage performed by one person alone. Table 7.1 shows the data collection method that was used to get an estimation of collaborative activities in defining information needs.

Table 7.1: An example of tables used during Interview 4

During our project, we identified the information needed:		
Individually Collaboratively		% %

It should be noted that the reported numbers here are only estimates of the ratio of collaborative activities and interactions in the overall group's activities and do not reflect an exact measure of how many collaborative activities have actually occurred. They are approximate overviews of students' reflections that were also supported by their feedback and discussion during the interviews.

7.5.1 Collaborative identification of information needed

The eight interviewees indicated that they engaged in both collaborative and individual information gathering, depending on the nature of their projects and their assigned roles during project performance. Students reported that they collaboratively identified the needed information at the beginning of the project, since they needed different types of information in order to define the design problem and then to identify possible design solutions. As Emily put it:

> My group worked collaboratively most of time. Because we did not know much about the subject of our project, we had to explore as much information as possible. We needed technical information about how different technologies work and also about existing and future markets. During our meetings, we continuously looked at what we'd been able to find, sharing the information and deciding what we still needed to find out.

As a collaborative learning task, each group had to make sure that all members had all the information they needed, and so assigned individual students to find different parts of that needed whole. The experience of defining the required project-information tended to be similar from group to group, as students maintained a high level of awareness of what they needed to know to successfully execute the assignment. In general the level of collaboration in identifying information needs varied according to different project stages and their corresponding phases, as Bruce indicates here:

> We didn't work together all the time to figure out what data we needed. At first we each picked a different subject to research and we were individually responsible for making sure the information we found had an application to the project. However, when we got closer to choosing our design solution, we worked more as a group to define what more we needed in the way of information, since it wasn't long before we were all working on the same problem.

The collaborative identification of needed information varied among groups, the interviewees reporting different percentages to represent these collaborative activities, as shown in Figure 7.8. It was found that collaborative identification of information needs [median=0.80; mean=0.72; standard deviation=0.20; variance=0.04] happened in general more often than did individual identification, according to approximate percentages and reflected also in students' feedback during the interviews.

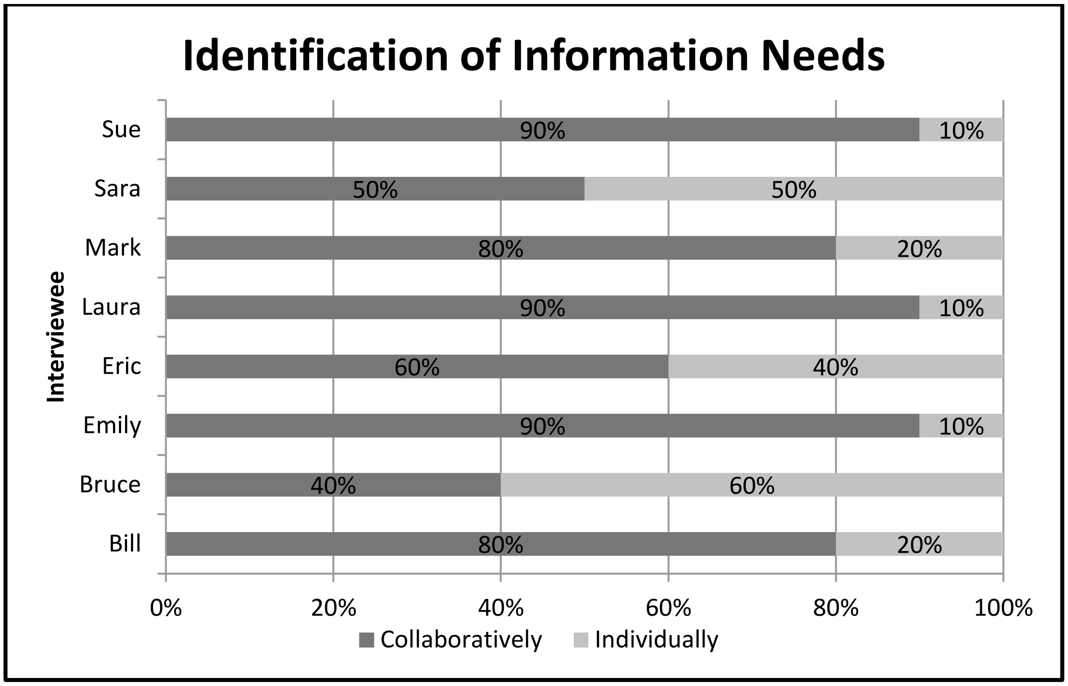


Figure 7.8: Collaborative identification of information needs

7.5.2 Collaborative search for information

Most students reported that searching for information was done individually more often than collaboratively, especially given that many groups assigned roles and responsibilities to each student to search for information and report their findings to the rest of the group. As Mark recalled:

> I searched for information individually most of time because it was easier for me to use my own computer to decide what information was going to

> be useful for the topic I was working on… In some meetings in the second half of the project, while we were searching for materials and component specifications, everybody was using a laptop and when someone found something they thought was useful to the group, they saved it in the group folder or sent it out to the others by email.

This situation was similarly reported in other interviewees' feedback, as most of them saw that searching for information has always been an individual activity to use one computer and to find relevant information that can be shared with other group members. However, in some groups the interviewees reported that searching for information was a collaborative activity. As Sue described it:

> In my group we enjoy doing everything together. We realized at the beginning of the project that the three of us did not have enough knowledge about the project subject and we needed to learn more about what we were supposed to do. We actually preferred, whenever possible, to work together on the project, so we've been meeting about two or three times a week. In our meetings, we have our own laptops and everybody searches for the same thing. Then we go around the room looking at each other's monitor to see what we've found and immediately talk about it to decide if it is useful for us or not.

Although interviewees reported different perspectives as to their perceived level of collaboration during information seeking [median=0.45; mean=0.48; standard deviation= 0.20; variance= 0.04], overall it constituted about half of their activities in information *searching*. The levels and differences in students' experiences in collaborative information searching are shown in Figure 7.9.

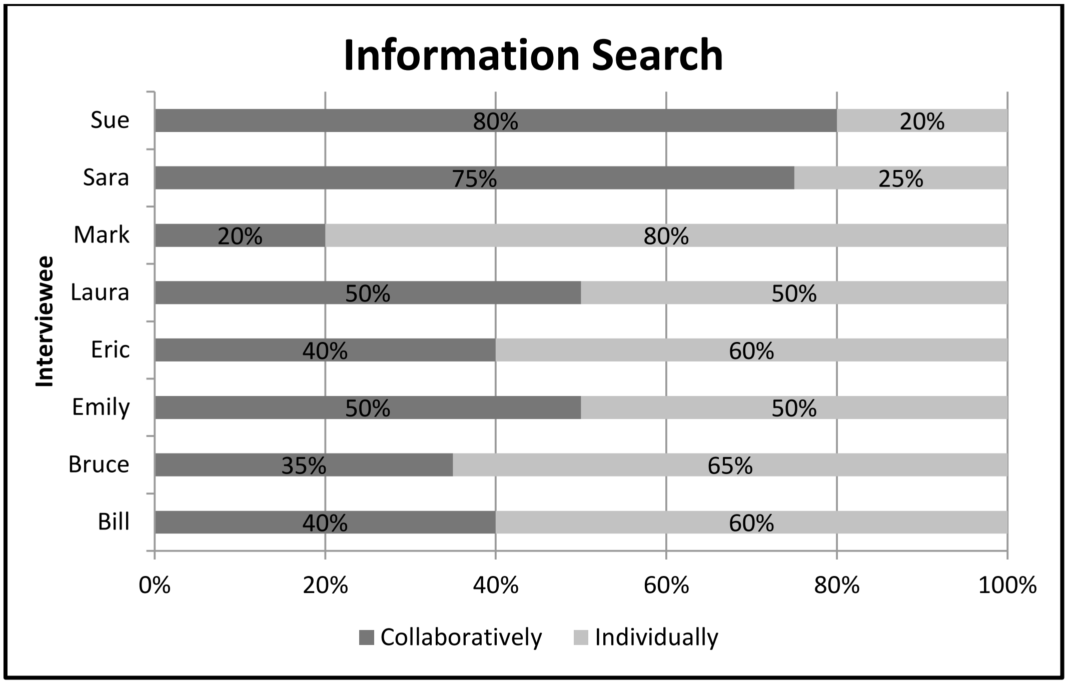


Figure 7.9: Collaborative information search

7.5.3 Collaborative evaluation of information

The interviewees reported that evaluation of information was performed collaboratively particularly during the phase of developing the design solution. Evaluation of information is related to information synthesis that was discussed in Section 7.4. Sara indicated that, in her group, evaluation of information was performed collaboratively all the time:

> I always have difficulty deciding if the information I find myself is good enough to be used for our project. I prefer to evaluate the items I've found first to select the best of them before sharing them with my group and discussing everybody's findings. I like the idea of having a second and third thought from my team members about whether something is useful or not.

This was the case among other interviewees who reported that evaluation of information was a collaborative activity. The exception was Eric, who emphasized that the process of information evaluation has been an individual process for him most of the time during his project. He based this on his assigned role as someone with an area of expertise not shared by his fellow group members:

> I evaluated our found information individually all the time. I was in charge of the mechanical part of our design, since I am in mechanical engineering and the other two students in my group are in different departments and don't have enough experience in mechanical design. I used my knowledge to decide what information would be relevant to my task. In few cases, during our project meetings, my group mates would share some information they'd found and we would discuss the information to decide if it was useful for our project design as a whole.

The differences in the levels of collaborative activities in evaluating information were found to be related to the nature of each project and also to be dependent on the subject areas in which students had prior expertise and knowledge. The overall results from the eight interviewees showed that evaluation of information was mainly collaborative [median=0.75; mean=0.68; standard deviation= 0.27; variance= 0.07], as shown in Figure 7.10.

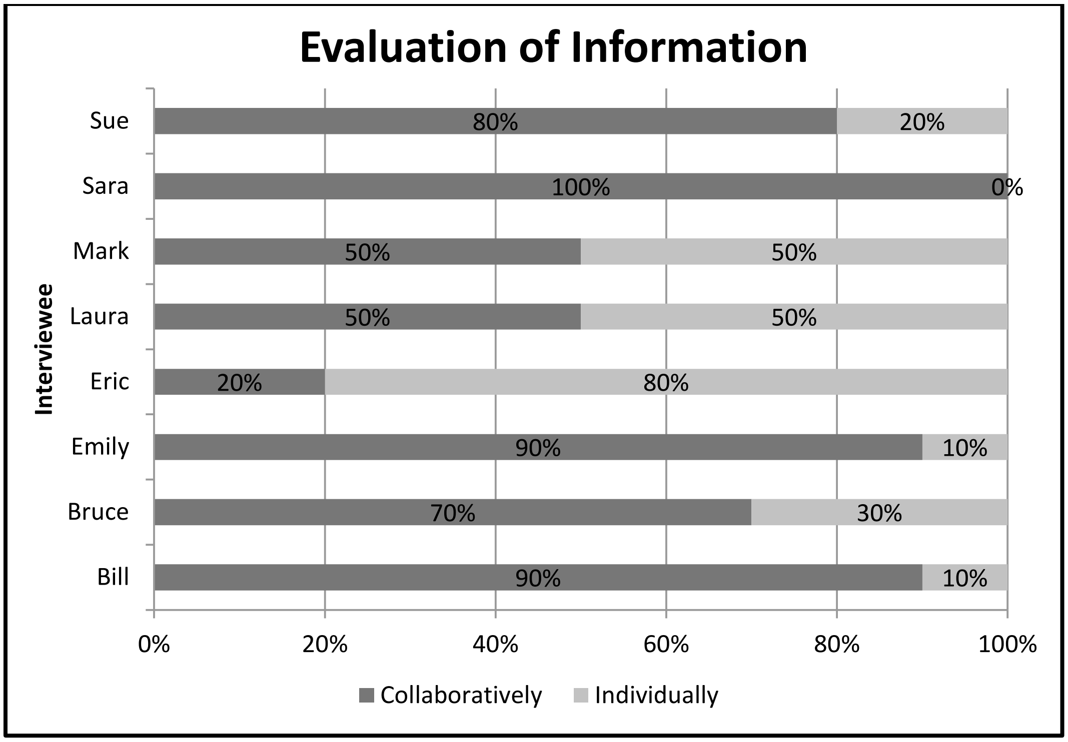


Figure 7.10: Collaborative evaluation of information.

7.5.4 Collaborative use of information

As discussed in Section 7.3.2, students shared most of the information they had found individually. The interviewees reported that they used many information objects that other team members found and then shared with the rest of group. As Bill described it:

> I mainly used the information I myself had found, because it was relevant to our project and credible, but I believe that other members of my group used the same information source for their part of the research. I've used some of the information my team members found and made available in our shared file folder. On a number of occasions during our group meetings, we turned to the collected documents in our shared folder or to previous emails we had exchanged, to look for whatever specific information we needed for the task we were working on.

In the interviews, students reported that their use of information tended to be more collaborative than individual. An exception was found in the group that included Sue, who reported:

> I was responsible for the business and marketing side of our project, so my focus was on the marketability of the developed product. I used the information that I had located in industry and market reports and I think that maybe others in my group used information from these reports, which dealt with technical aspects of our topic, as well. I do remember that I used a few articles from other group members, as I found some links to some websites that I hadn't used before for market research.

Over all, collaborative use of information was found to be significant in many groups [median=0.70; mean=0.60; standard deviation= 0.21; variance= 0.05], constituting more than half of their activities in information use. The levels of collaborative activities in information use are shown in Figure 7.11.

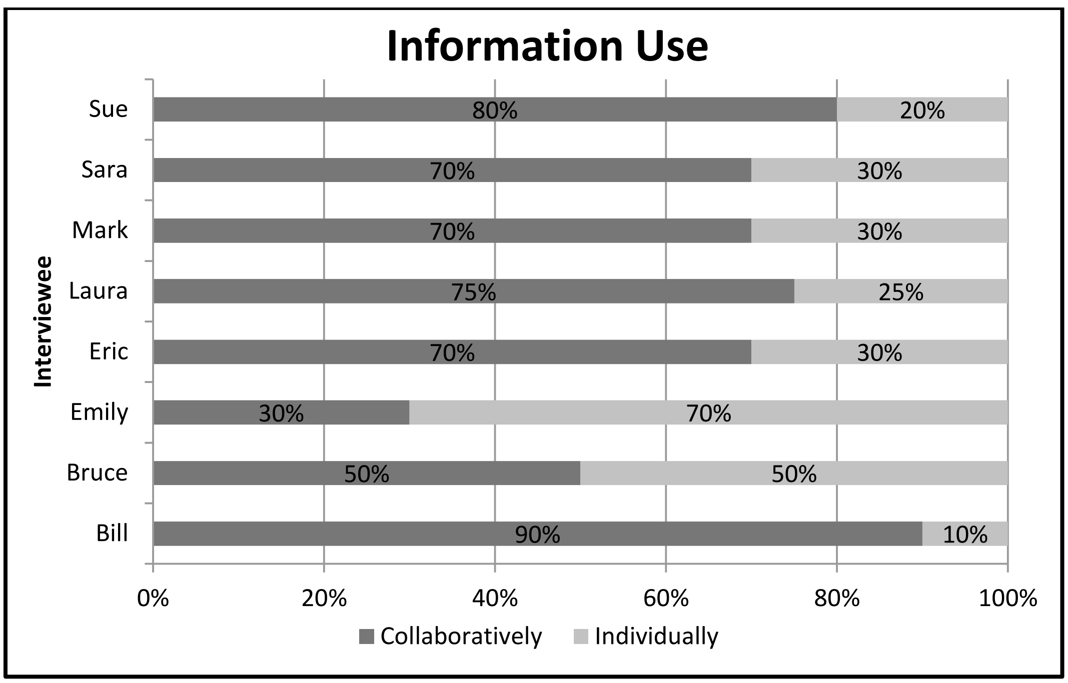


Figure 7.11: Collaborative use of information

7.5.5 Overall collaborative information-related activities

Collaborative activities in information seeking, searching and use took place to different degrees in students' experiences of their project's learning tasks. As it was noticed that the levels and the type of collaborative activities were dependent on different stages of the learning task, the interviewees were asked to report on their collaborative activities within their groups per month, by estimating what percentage of their information-related activities were collaborative and then describing why the ratio had changed from one month to another. Table 7.2 represents the findings along with a basic descriptive statistical analysis.

Table 7.2: Overall collaborative information related activities

	Ratio of Overall Collaborative Information Related Activities							
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Bill	0.80	0.85	0.60	0.50	0.70	0.20	0.85	0.95
Bruce	0.75	0.70	0.60	0.70	0.60	0.60	0.70	0.70
Emily	0.90	0.90	0.50	0.90	0.80	0.70	0.50	0.70
Eric	0.30	0.80	0.75	0.20	0.40	0.60	0.70	0.80
Laura	0.70	0.50	0.40	0.70	0.60	0.60	0.50	0.50
Mark	0.60	0.50	0.50	0.90	0.20	0.60	0.80	0.50
Sara	0.20	0.70	0.85	0.80	0.80	0.80	0.80	0.80
Sue	1.00	0.70	1.00	1.00	1.00	0.60	0.90	0.90
Descriptive Statistics								
Minimum	0.20	0.50	0.40	0.20	0.20	0.20	0.50	0.50
Maximum	1.00	0.90	1.00	1.00	0.80	0.80	0.90	0.95
Mean	0.65	0.70	0.65	0.71	0.59	0.59	0.72	0.73
Standard Deviation	0.28	0.15	0.20	0.26	0.20	0.17	0.15	0.16
Variance	0.08	0.02	0.04	0.07	0.04	0.03	0.02	0.03

Collaborative activities were found to be of higher percentage than individual activities in all months with a noticeable increase in the last two months of the projects when students had to develop one single design solution for their design problem. Most groups reported that collaborative activities started in the first month, when they needed to define the design problem; exceptions were Sara and Eric, who reported a relatively low ratio in September because they were not able to have a meeting with the project's client as early as expected to get the preliminary information about the project's design problem and its activities.

Figure 7.12 shows the trends and also the level changes of collaborative information-related activities among the interviews per month, where month 1 represents September and month 8 represents April. The figure indicates that collaborative activities were at higher occurrences during the defining of possible design solutions (October and November) and also in the implementing and developing of the selected solution (March and April).

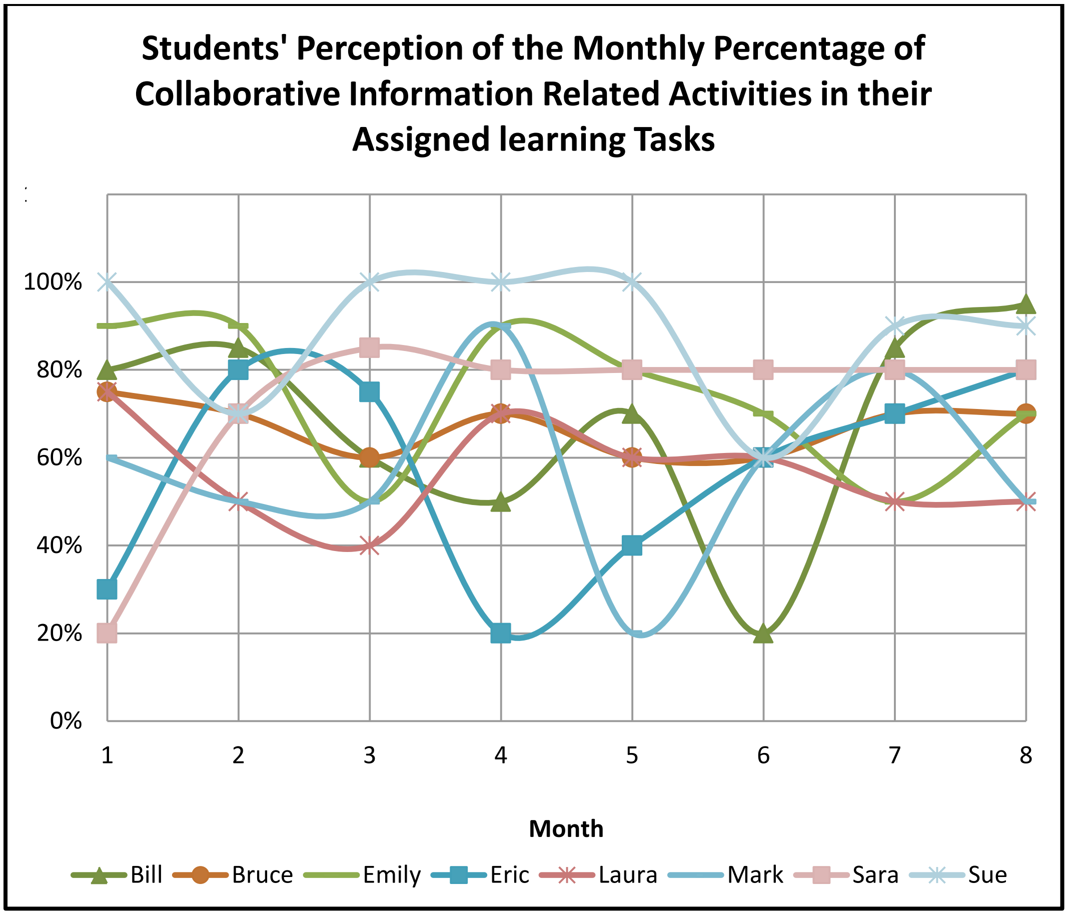


Figure 7.12: Students' perceptions of monthly percentage of collaborative information related activities

These findings showed that the levels of collaborative activities were not consistent during the learning task but varied in converging or diverging mode depending on the characteristics of the project and also on the project's stages and phases. Collaborative activities were found to converge more when a group deliverable was due or when a collective decision was needed to evaluate and select a single design idea and also during the implementation and the development of the design solution. The highest occurrences of collaborative activities related to information behavior were found to occur in the last two months of the project and before handing over the final design to the client.

7.5.6 Collaborative interaction in information behavior

Near the end of the last interview, the interviewees were asked to provide a graphical and verbal articulation of their information behavior in the context of their learning tasks. The interviewees were asked to draw a map to show all the information channels and the types of information sources they sought or searched for during the project. The interview protocol used to develop the maps was based on the information horizons technique that was developed by Sonnenwald (1999) in order to collect data that are hard to acquire in traditional interviewing techniques, such as "when and why people access individuals and other information resources; relationships among information resources; the proactive nature of information resources; and the impact of contexts and situations on the information seeking process" (Sonnenwald, 2005, p. 191).

The information horizons map helped the interviewees to focus and to verbalize their thoughts about, reflections on, and evaluation of their project information seeking and searching processes. The map also helped them to synthesize their collaborative situations in information seeking and use over the course of their projects.

The constructed information horizons maps represented a holistic graphical representation of students' collaborative information behavior in their learning tasks, and illustrate their verbal reflections while they constructed these maps.

Sara constructed her information horizons' map (Figure 7.13) by drawing a circle representing her group and the particular areas group members were responsible for. Sara indicated that they started searching for technical information and data using Google and found some relevant journal articles. If these found journal articles did not provide the needed information, she searched for government reports, technical manuals and company information. When there was no success, she contacted people who could provide her with the information or refer her to other people who had more expertise in that particular area.

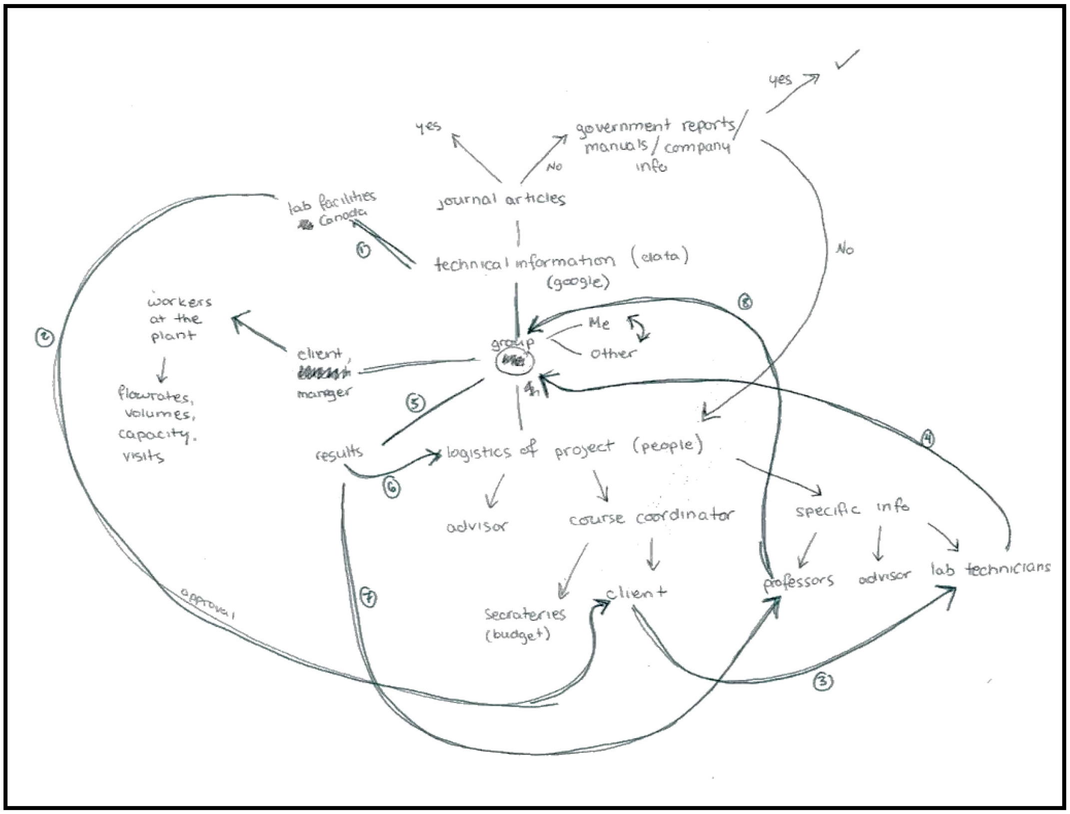


Figure 7.13: Sara's information horizons map

Sara identified many people as information channels. She also mentioned that the group got useful and relevant information from the workers at the project's site, and that they had not predicted needing this additional information during their preliminary or subsequent site visits.

Emily's information horizons map (Figure 7.14) describes the group members as having decided their information needs during their meetings and preferring to always start their research by approaching people as potential information channels who can provide them with the procedural information they need about how to collect samples and about different and possible testing methods.

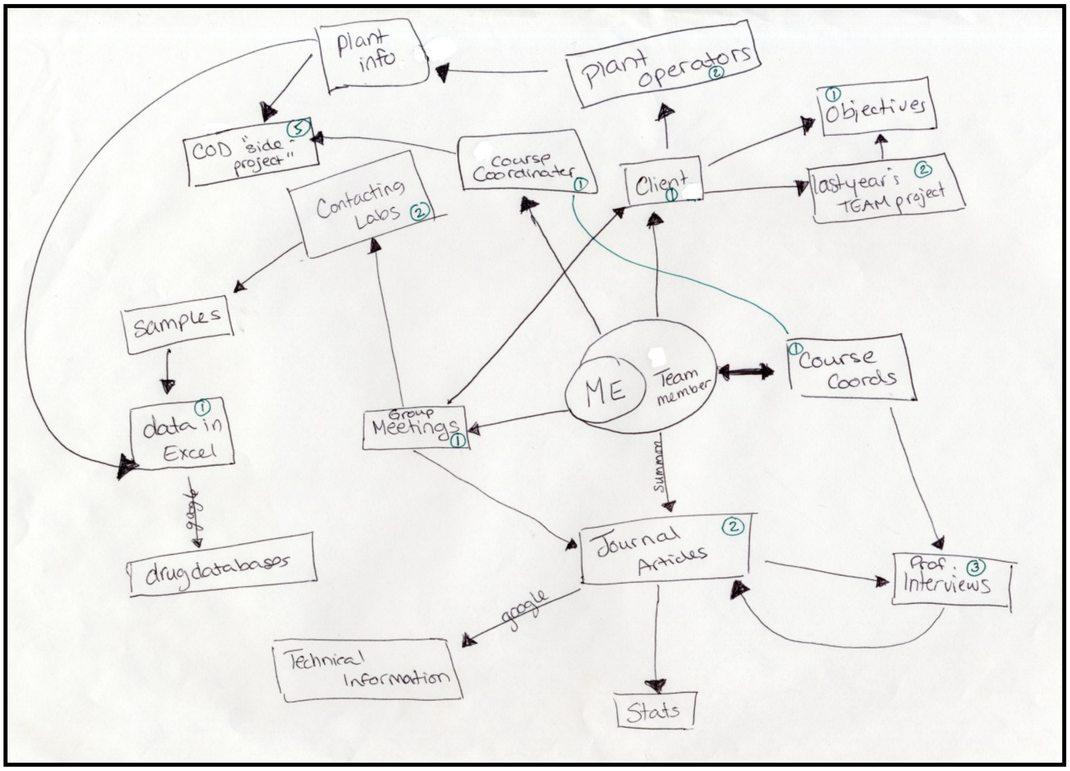


Figure 7.14: Emily's information horizons map.

In Emily's case, a previous-year report developed by another group working on the first phase of her project provided her with useful background information that saved her group time, since the information was found to be still relevant to her group's phase.

She also reported that she used library collections to get journal articles and engineering handbooks and then shared the found information with the group in their meetings. In many situations, the project group collaboratively used the found articles to locate references to other technical papers or to search for particular technical information using Google's web-based search engine.

A major part of Emily's group's project was to synthesize the results of analyzed water samples by working collaboratively on the stored date in an Excel file, for comparison and to make any necessary decisions about future recommendations:

> In January, we received three data files with the analysis of the three samples we sent to the lab in November and December. Each file had 120 records for different substances present at the samples. These results required us to find more information in handbooks about each substance and about water quality standards. My group thought that it would be easier to split the work among the three of us, so each one worked on a different data file. We started to work that way for two weeks and we decided at one meeting that was better and more efficient that we work together in analyzing the lab results. We met three times a week to search for the related information and make any necessary calculations. We were able to finalize this within four weeks and I believe that it was more efficient and timely for us to do the work collaboratively.

Laura started to construct her information horizons map (Figure 7.15) by drawing a block to represent the group members. As she drew, she said, "We worked all the time as a team," and indicated that her fellow group members were always the first she consulted when she needed any information for the project. When the information was not available within the group, they preferred to seek it from other people. Her map represents the types of information sources that were found or given to the project group.

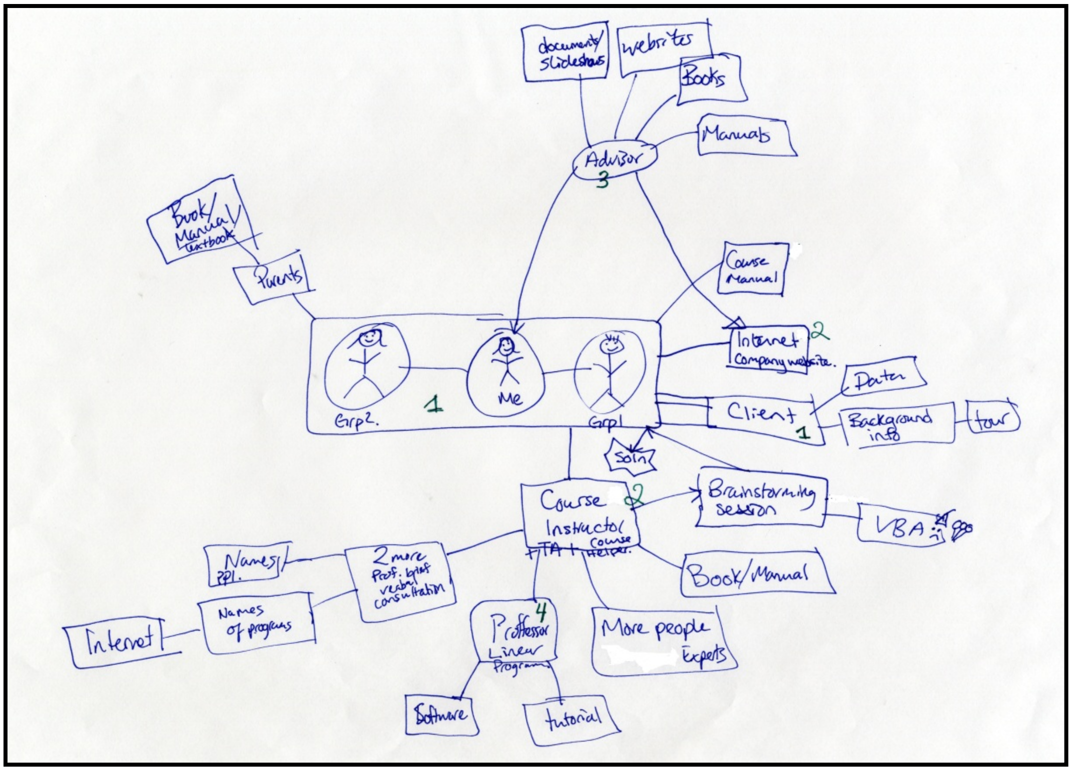


Figure 7.15: Laura's information horizons map.

Laura reported that the parent of one group member was an engineer who provided them with a useful book and manual at the beginning of their project. The course instruction team was another useful information channel, brainstorming with the group members to generate possible options for software packages that could be used to simulate the design of the project. The course instructor also gave the group a book and the contact information for a professor who had more expertise in linear programming. The referred professor met with the group for a tutorial on a particular software package they continued to use for the duration of their project. In a later stage of the project, the course instructor referred the project group to other two professors whom the group contacted by email to get more information about data analysis techniques. One of these two professors sent them contact information for three experts from outside the university and from whom the group got links to some useful websites and case studies that they ended up using for their project.

Laura reported that the group did not perform an extensive information search, because the information they got from these experts was good enough to use for the analysis of the data and the background information the group acquired from the project's client. She reported that in some of the group meetings they needed to search for information referenced in the documents they already had, in order to verify this information and to check if more current and reliable information, regarding the price of some materials and components, was available over the Internet.

Sue started developing her information horizons map (Figure 7.16) in a way similar to Laura's, by emphasizing the collaborative nature of her project experience; the project group preferred to do all the required activities in information seeking and search as a group whenever possible. She also reported that it was the preference of her project-group members to approach people to get the needed information, but mainly after they tried first to locate such information over the Internet.

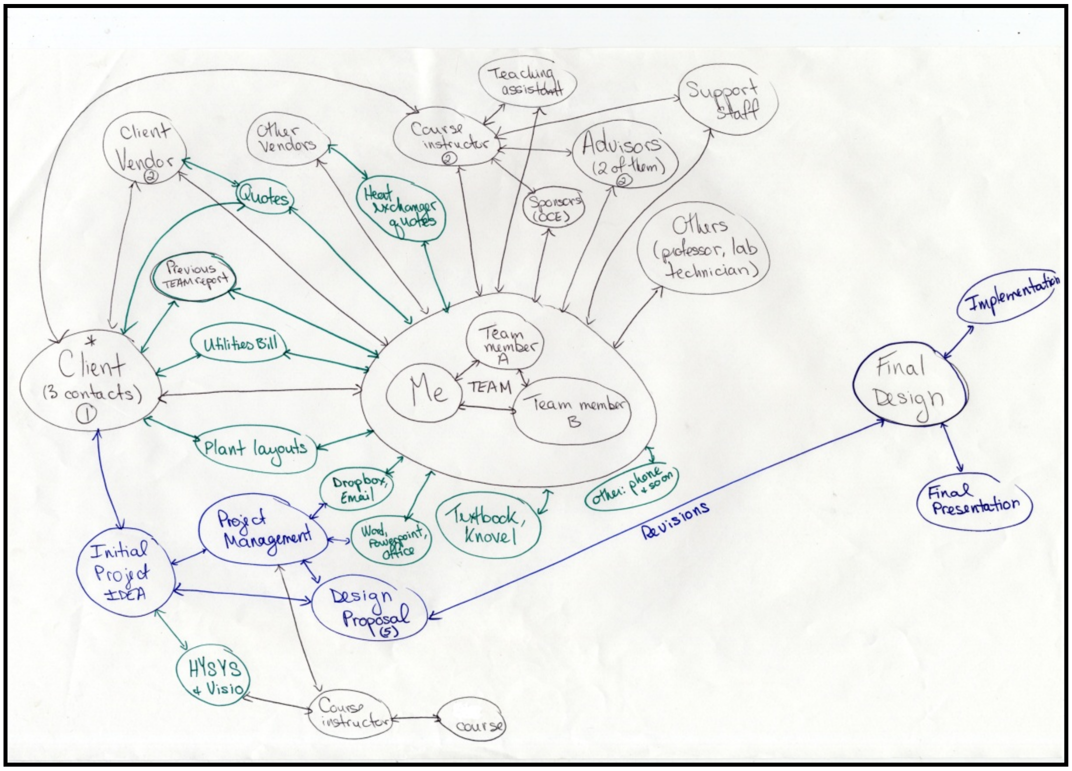


Figure 7.16: Sue's information horizons map

Sue's group used information they had from a previous course the subject of which was related to the project topic. They contacted that course instructor for assistance using a particular software package and to get technical standards related to the project. She also reported that the group contacted potential vendors for requested materials and to get price quotes. The group found the information they got from these vendors to be useful, as it covered technical information in addition to the cost information of the requested materials.

Mark made it explicit on his information horizons map (Figure 7.17) that each group member was assigned to a particular area in the project and that Mark was responsible for the economic aspect of the developed design solution. He argued that information searching was mainly an individual activity that he performed during the project.

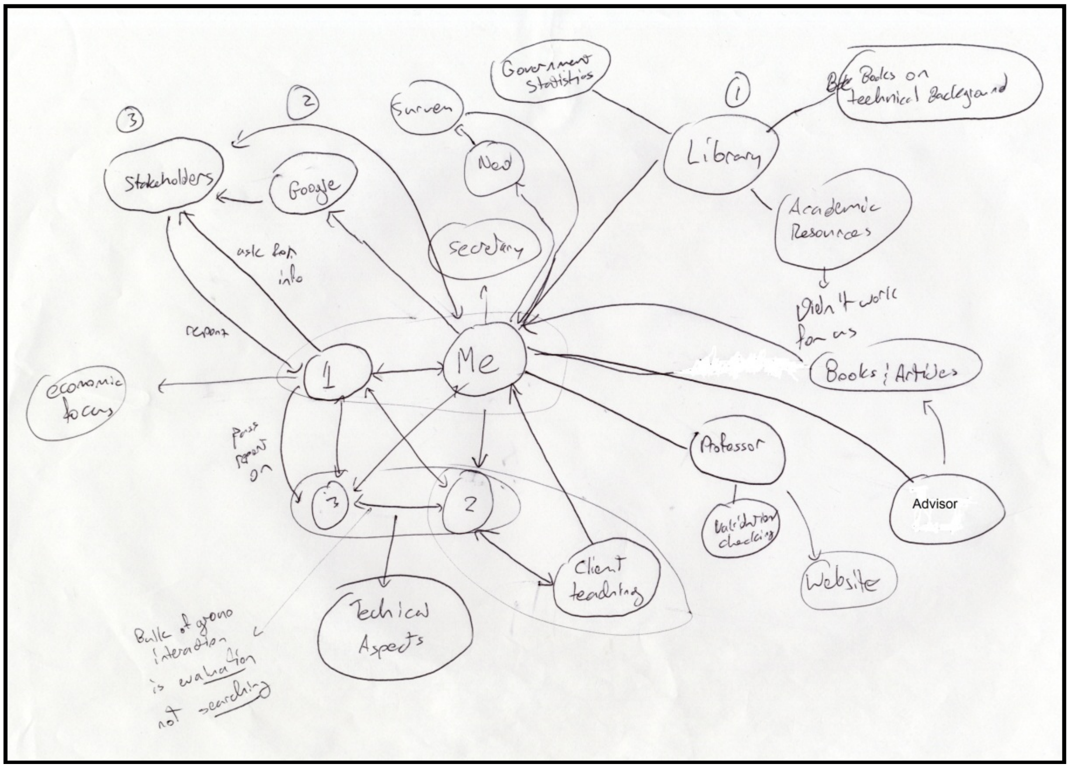


Figure 7.17: Mark's information horizons map.

Mark reported that he used the library website to locate relevant information sources, but found them to be so theoretical and academic in nature that they were not useful for his project. He did use the library collections for government reports and for statistical information, however. He also reported that he used Google as a search engine to locate possible suppliers and to request price quotes from them. The course instruction team was also an information channel that provided him with a link to a website and a book; however, he did not use these referred sources, as he was able to find more relevant and current information himself on the Internet.

Mark also reported that during the design solution implementation phase there was a higher level of coordination among the group members, establishing and maintaining a heightened group awareness of what each group member was doing. He reported, and put it on the map, that the group members during their meetings had noticeable interactions when evaluating information but did not perform any collaborative information searches.

Similarly, Eric indicated on his information horizons' map (Figure 7.18) that he had an assigned technical topic to work on, one that required him to seek and search for information individually, and that he maintained that responsibility over the entire span of the project. He reported that he contacted the client only at the project's beginning for project-specific information but the group conducted interviews with various current and potential stakeholders during the project.

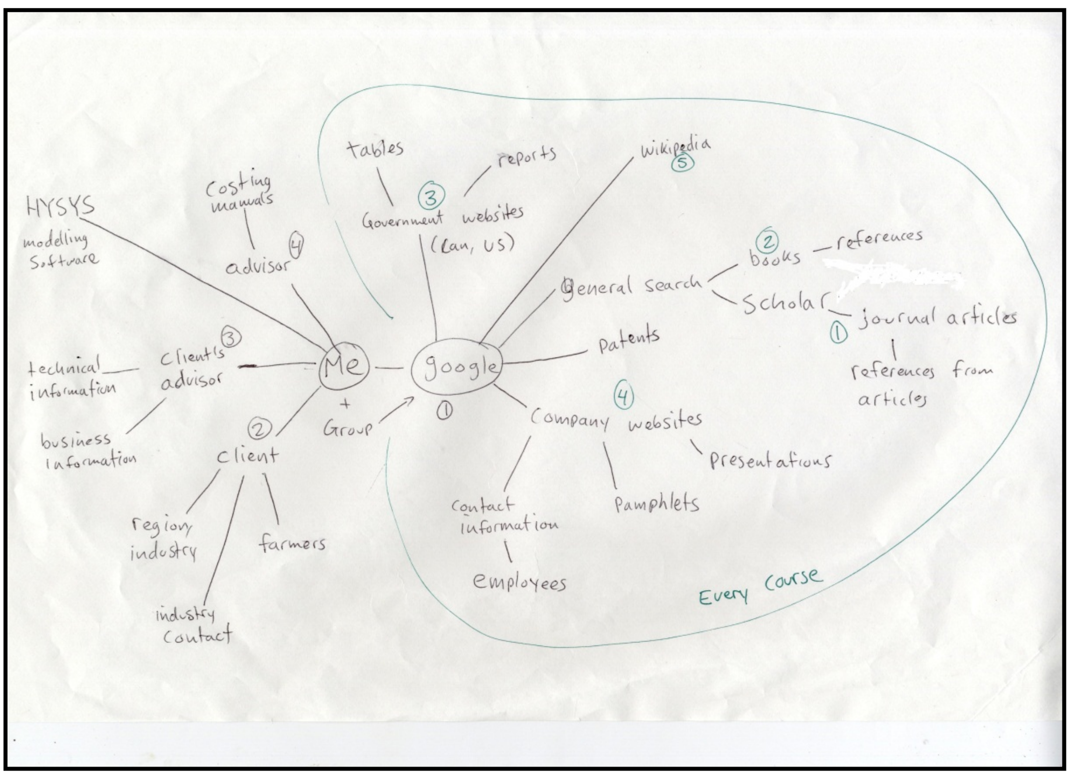


Figure 7.18: Eric's information horizons map.

Eric started constructing his map by drawing two circles representing him and Google. He described using the search engine to locate different information sources: government reports, Wikipedia, reference books, scholarly journal articles from the library collections, patents, and company websites. He described using company websites to get more information about their products and also to contact sales employees by email or phone to get price quotes.

Interestingly, when his map was almost completed, Eric looked at the map and circled those information searches that he had performed and which were similar to ones he had been doing in other courses. This, he indicated, was the first course that required him to approach other people for information.

Bruce's information horizons map (Figure 7.19) indicates that because his project was a feasibility study of a new product, it focused on the production costs and possible markets of the product to be developed. The project explored existing products in the marketplace and possible new markets. Each group member was responsible for a particular market area and searched individually for the needed information. However, Bruce mentioned, the group maintained a high level of awareness during continuous meetings in which members shared and evaluated the found information. In some situations the group engaged in collaborative information searching, especially after conference calls with the project's client.

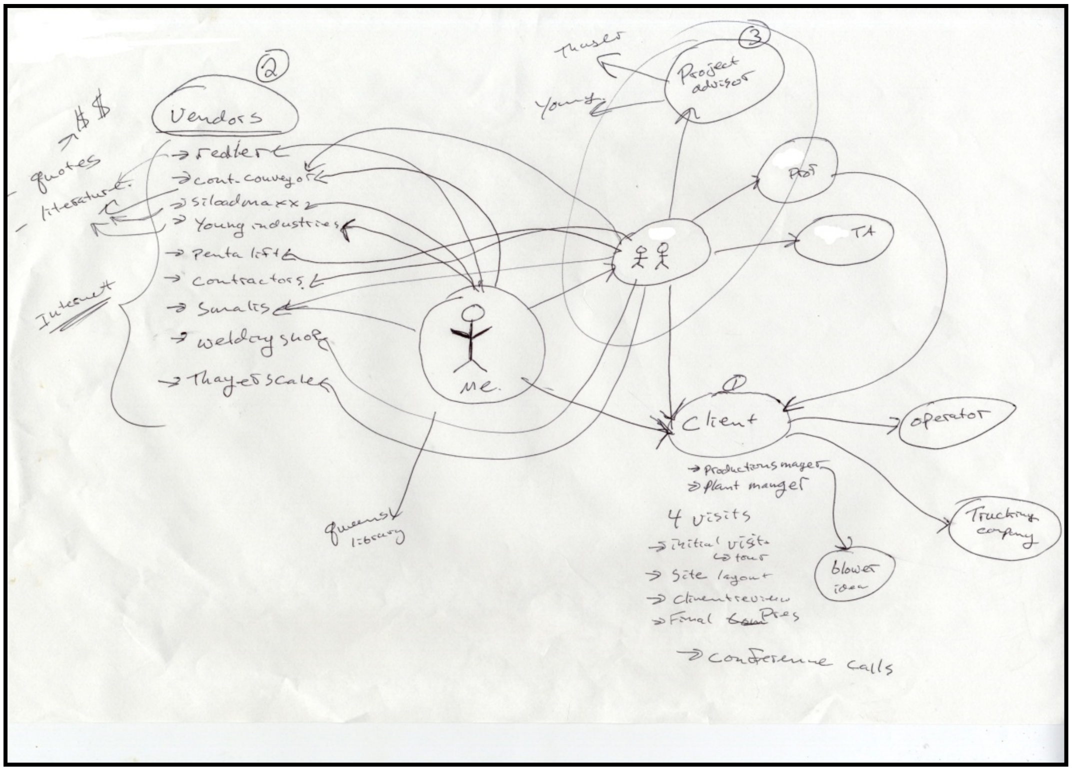


Figure 7.19: Bruce's information horizons map

The group got information from the project's client when they visited the project site on four occasions and during many conference calls. The group also gained information from the plant operator by email and telephone. The course instruction team was also an information channel but mainly for information related to the project's logistics and budget.

While Bruce was evaluating and reflecting on his constructed map, he mentioned that this experience was different from his experience in another project-based design course that he had undertaken during the same year. He reported that the level of collaboration in this course was higher than the other course because the project topic and requirements were different. He described that in the other course there were assigned roles for each group member that required more individual activities in information searching and use compared to collaborative ones.

Bruce constructed another map (Figure 7.20) for his experience in the other course, one in which he was responsible for information searching on technical aspects of the project and on the data analysis of the results that the group received from a lab that had performed an analysis of different soil samples.

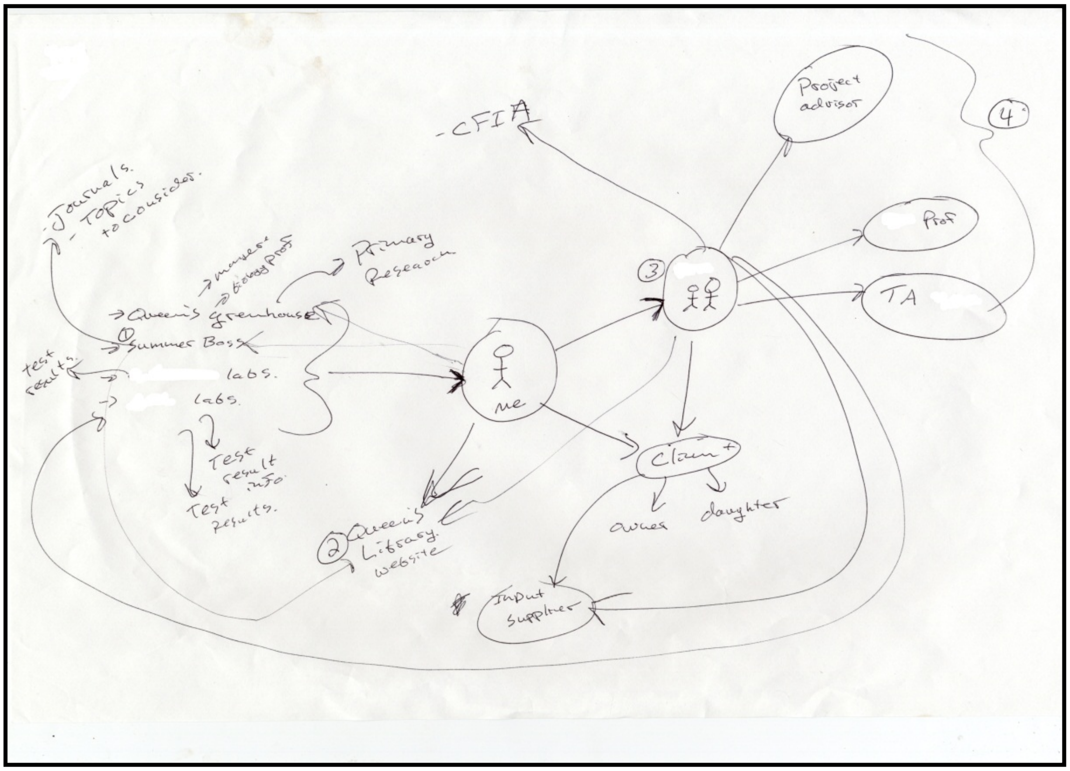


Figure 7.20: Bruce's information horizons map in another course

The information horizons maps produced by these students support the findings of previous chapters, specifically that collaborative activities in information behavior are dependent on the nature of the project, its requirements and different stages, and students' prior knowledge in the project topic.

7.6 Conceptualization of the activity and interaction dimension

The activity and interaction dimension was found to be a central aspect of collaborative information behavior in learning tasks. The findings in this dimension included the channels of information seeking, whether information was sought from people or from documents. Searching for information was found to be either exploratory, when students delved into new topics to discover possible useful information, or lookup searching, when they hunted for known items or to locate particular or specific information.

Collaborative grounding, essential to collaborative information seeking and search, creates a common ground upon which students can plan and perform their collaborative activities, whether by way of group meetings or software tools. The collaborative grounding, in its relationship to collaborative information behavior, results in information sharing and also in developing shared representations as part of the learning task.

Collaborative information synthesis was found to be an important aspect of collaborative information behavior in the design process. Information synthesis is the practice of integrating, organizing, filtering and evaluating information to solve the design problem and to implement a solution that meets the design objectives. Information synthesis as a collaborative activity and interaction among group members was found to be dependent on the level of collaborative grounding that the group was able to achieve, and on the group's ability to create that common ground necessary for all collaborative information behaviors to occur. The complexity of collaborative activities and interaction was reflected in students' constructed information horizons maps, developed in the last interview in Study 2 and presented in this chapter. A conceptualization of the activity and interaction dimension of collaborative information behavior is represented in Figure 7.21.

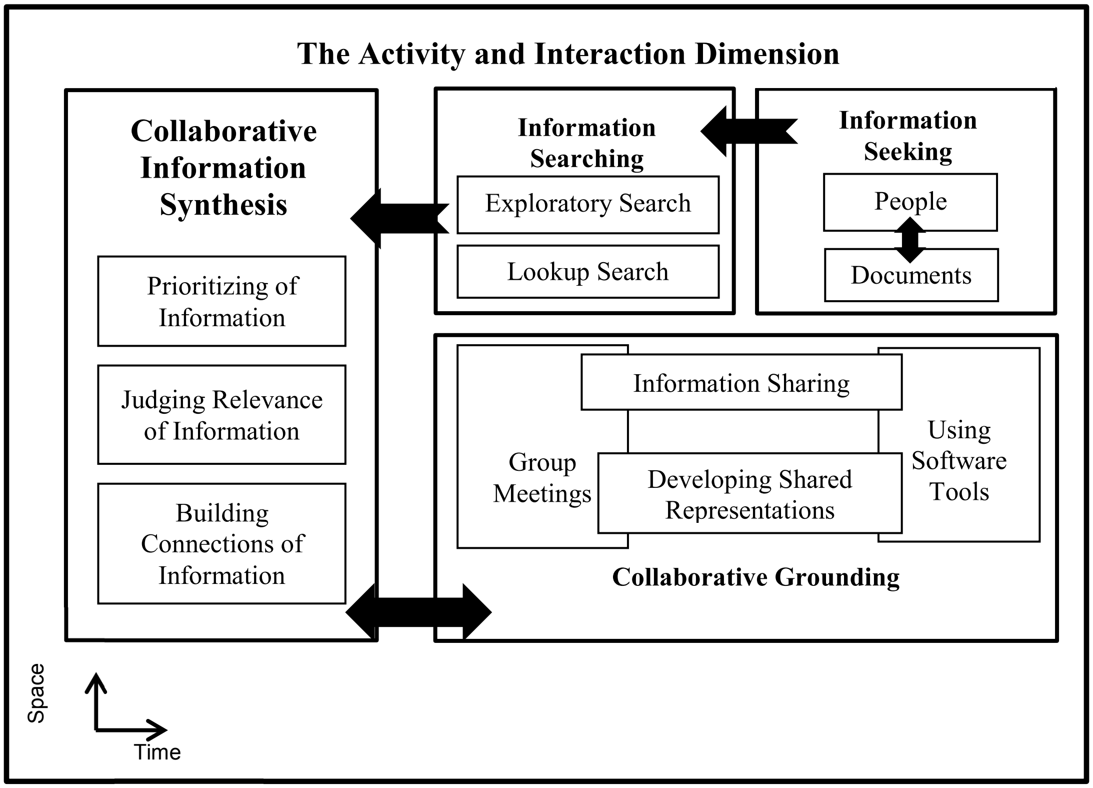


Figure 7.21: A conceptualization of the activity and interaction dimension

The following chapter will represent the findings with regard to the information objects dimension and will describe both collected information objects and developed representations resulting from students' collaborative activities and interactions.

8. THE INFORMATION OBJECTS DIMENSION

This chapter details the study's findings with respect to the information objects (sources) dimension as it relates to learners' collaborative information behavior. These findings concern all types of information objects, whether they were acquired sources from any information channels that students have used or constructed information objects developed during the lifespan of the assigned projects.

8.1 Types of information

It was found that the types of information used by different project groups were dependent on the context of each project. A variety of information types were reported in students' deliverables, whether through direct referencing in different project reports, through their projects' weekly reports or via the interviews in Study 2. It was found that students, in their assigned projects, inevitably used and generated enormous and complex sets of information objects over the eight months of the project.

Information types are categorized based on both the explicit information need and the actual use of information to fulfill task requirements. Information types were classified under the following categories: (1) project specific information, (2) product marketing information, (3) product end user information, (4) product design information, and (5) production information.

8.1.1 Project specific information

This information type includes the specific information related to assigned projects that was given to students at the beginning of their learning tasks by way of a brief overview of the project description. Students used this information to plan their project's activities and to identify any other important information they might need from the project client in order to perform the task at hand. This category represents an environmental scan of the background information for the project to include: (1) information about the project client, (2) the project client's services and products, (3) the project client's needs and future trends in developing an existing product or in creating a novel product, and (4) contact information of key personnel to communicate with the students' project group.

8.1.2 Marketing information

This category represents any information, related to the requested design solution and based on its existing and future markets that a developer would use to determine the value of the new product. If the requested design is for an already existing product, this type of information includes the item's sales history and the profitability margin from those sales. On the other hand, if the requested design is for a novel product, this information would pertain to the new product's potential marketability. In both cases, information on prices and performance of competing products in the market are needed to determine if there is a demand for the product, which other companies are producing similar products, the price range of these products, and the cost of producing the new product. Marketing information is needed at different stages of the project: at the beginning it helps to determine the feasibility of investing resources in such a new product, and during the design process to estimate the product cost and the profit margin based on an analysis of the size and value of potential markets.

8.1.3 End user information

This category includes information about the potential users of the designed product or service. If the design project required the development of an existing product or service, this information would include information about current users and their opinions of a particular product or service. Meanwhile, this information type also includes what users thought of and how they rated competing products and services. For new products, it includes information on potential and targeted end users, gathered by way of their opinions of a new product and their perceptions of existing competing products or services.

8.1.4 Design information

This category represents the information needed to solve the given design problem. Given the complexity of an engineering design project, this category includes a number of subcategories that emerged from data analysis of students' deliverables and interviews. My development of these subcategories of design information drew upon the work of previous researchers in the area of engineering design methodologies, notably Vincenti (1990), who developed a knowledge based categorization scheme for information in design projects, and Broens and de Vries (2003), who provided an overview of different taxonomies of design information and conducted a survey among practicing engineers, finding that Vincenti's model was the most acceptable one among survey respondents.

8.1.4.1 Fundamental design concepts

According to Vincenti (1990), this subcategory includes the necessary concepts for designing an engineering solution with all operational principles (how a device works), and normal configurations (the general shape and arrangement that are commonly agreed to best embody the operational principle). This subcategory includes information pertaining to the relationship between components that together constitute a new functional design. An example might be information about a certain material property, one that makes a device useful for a particular function. In general, this subcategory represents the information needed for a conceptual understanding of scientific principles and technical information. With this in hand, the engineer can plan and take steps toward the design of a product, thus achieving a prescribed goal within specified constraints. Examples of such constraints include the technical characteristics and specifications of possible designs; product operation; potential and known design problems; methods and techniques for product testing and evaluation; and possible equipment for testing design solutions.

8.1.4.2 Theoretical tools

This information subcategory includes those mathematical formulae or calculative schemes that might be needed in the design process and all the theoretical information necessary for solving the design problem based on the commonly used theories and models in the project's subject area.

8.1.4.3 Criteria and specifications

In this subcategory are component-specific specifications such as quantitative objectives for a device derived from general, qualitative goals. An example would be the information needed to construct a weighted evaluation matrix using qualitative measures (evaluation criteria) and represent the findings in a quantitative format (giving the score of each design solution against established criteria). It also includes any needed quantitative data, such as: universal constants, properties of substances, physical processes, operational conditions, tolerances, factors of safety, and hazards. This category also includes industry standards and regulatory codes for hybrid design components.

8.1.4.4 Non-technical information

Engineers use non-technical information to help them understand the interrelationship between technical objects, the natural environment and social practice. For example, environmental data for average snow and rainfall rates are essential to the design of new materials for rooftops, and medical information is needed when one is designing a biomedical solution to measure blood pressure or pulse rate.

8.1.4.5 Production information

This category represents the technical information or know-how required to produce or develop an engineering design solution. It includes the procedures and processes needed to make an artifact or develop a solution that meets the project objectives. This category of information reflects the practical nature and the direct information relevant to the engineering design activity. Examples of production information include the characteristics of production tools; the cost of different production tools, materials and production processes; and information regarding the possible work places in which design-prototype production will take place, including all safety requirements.

8.2 Types of information objects

Types of information objects represent the physical artifacts that students have used as tangible sources for information during their assigned learning tasks. These information objects are manifestations of previously defined types of information as objects that students sought, searched for or used during their projects. The types of information objects were found to be in two categories: (1) collected documentary objects, and (2) developed information objects.

8.2.1 Collected documentary objects

Engineering design projects were found to require a variety of information objects including engineering handbooks, manuals, textbooks, journal articles, standards, patents, laws, public surveys results, materials specifications, and data sheets.

8.2.1.1 Previous or similar designs

Types of information objects include detailed information on designs that have previously been created within the project client's organization or by their competitors. This includes requirement specifications, functional specifications, overall technical drawings, and descriptions of methods used in these designs. Designers often use cross-references between specific aspects from one type of information object and another to collect more design information as Emily reported:

> We found a patent document online for a recent design idea that detailed a comparable design solution to our project design problem. This document helped us to find related books, journal articles, and other patents as they were referenced within that document.

This type also includes information on similar products that were designed by other companies or solutions implemented in other locations. Students used information about previous designs similar to the one they had to design as a survey respondent said:

> Our group did not understand how the designed product would look and how it would function. We looked for similar products in the market and downloaded many specifications and user manuals that helped us to see how the product would function when we design it.

Students collected information objects that provided them with the characteristics of the component to be designed, whether it was a product, instrument, solution or module. Information on previous or similar designs was collected mainly at the beginning of the projects to outline possible design ideas and also to select and evaluate alternative design ideas collected from these information objects.

Previous designs also include explicit descriptions of known problems or weaknesses pertinent to the one currently being created as Mark described:

> Our client had a preferred technology to use for the requested design. While we were looking for similar solutions that use the same technology we got into some technical reviews in trade and professional journals that reported some overheating issues that were found in other products using the same technology. We discussed these issues with our project client

> who asked us to provide him with further research regarding these performance issues.

Known problems in existing products were found to be essential information that students needed to have before they could start brainstorming about possible design ideas to meet the design objectives.

8.2.1.2 Design rationales

As with information about previous and similar designs, a design rationale presents the reasons for decisions taken in the design. This includes the justification and the arguments for choosing a design solution and the rationale behind using a particular technique in implementation. Design-rationale information tracks the design processes and the rationale behind the decisions made in previous and similar designs as described by Bruce:

> At the beginning of our project, we looked at different design options but we were not aware why these different technologies have been used in these different designs. A design solution only describes how the product would work but there is no information on why this technology has been used. We needed to understand the advantages of each technology and we looked for this information in some engineering handbooks that we found online at the library website.

8.2.1.3 Production characteristics and specifications

This type of information object includes information on the production of existing designs and their components, including the cost of materials, descriptions of production tools, rationales for work place designs, and material and component specifications.

Working procedures, standard methods and techniques that define and frame how the work could be performed are all covered by this type of information object. This includes both organization-specific procedures and general procedures regulated by law. The project client provided information about the organization's working procedures, and students had to plan their design solution within that existing framework.

Students needed up-to-date information on the specifications and cost of materials, relevant technologies and necessary components, etc., to develop the design solution. This information varied in its scope and included such details as functional performance, price, possible suppliers, cost of shipping, and the timeline of materials or components delivery.

8.2.1.4 Technical standards

Technical standards represent established or accepted practices, technical requirements for products, services and systems. Designers need to follow these standards to ensure better, safer and more efficient methods for their designed products. Technical standards can be based on regulation, design or performance. They are developed by different standardization agencies, which, like the International Organization of Standardization (ISO), may have a global scope, or a national scope, as with the Canadian Standards Association (CSA). A design solution might be developed to meet a particular standard for a specific market, but it may need to be re-designed to meet a different standard applicable in another country as Bill described:

> We were able to find a detailed description of a useful design solution that was similar to the design that we have to develop. We were so excited that we could learn from that document to outline all the constraints that we need to consider in the designed product. However, one of the group members noticed that the design was following a European standard and not the Canadian one. We needed to locate the equivalent Canadian one to find out if there are major differences.

8.2.1.5 Relevant persons

Consistent with the findings represented in previous chapters, one of the most important sources of information is that of colleagues and other actors having knowledge of or experience working with specific topics. During their projects, students acquired this firsthand, person-to-person information mainly by way of reference from the course instructional team or the project's contact person, or by searching web-based directories. This type of information object also covers information on potential suppliers of needed materials and components for the design. Information on relevant persons included their names, contact information, and area of expertise as Sara described:

> We needed help to know which laboratory could do the required analysis of a sample of drinking water, and so our client sent us the email address of a contact person who is an expert in that area. We did not get any reply from that expert and we had to find a laboratory ourselves online. We *Googled* for that and we found many in the United States. We preferred to find one in Canada and preferably in Ontario but there was no success. After many days, we found a laboratory in Victoria, BC that can do that for us. We sent an email to them but we did not get a reply in the first week, so we followed that with a phone call with the lab manager who provided us with a lot of useful information on how to collect the samples

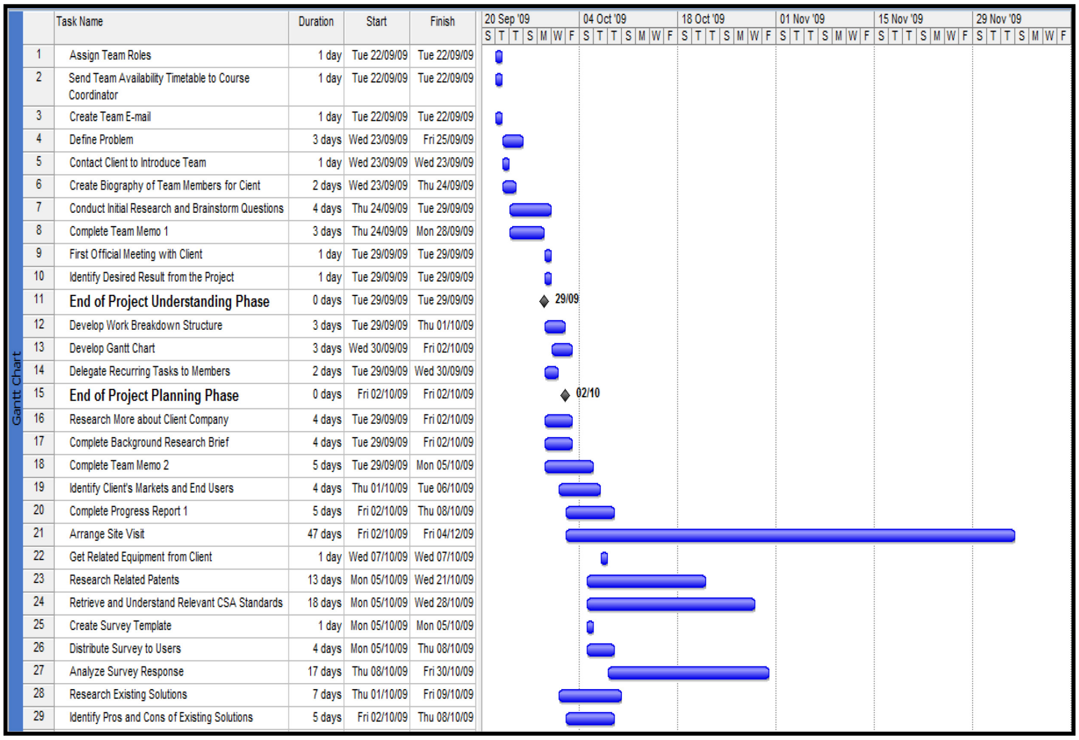
of drinking water, and they actually sent us the containers we should use. This has been so useful for us and saved us a lot of time.

8.2.2 Developed information objects

Students developed many information objects as course deliverables during the lifespan of their project, to document their design's process and solution. Project documentation consisted mainly of textual information objects produced during the project. These included project progress reports, weekly team memos, brief reports, an interim report and the final report. Developed collaboratively and based on collected information to meet the requirements of both the learning task at hand and the learning objectives of the engineering course, these documents also included a variety of graphical information objects such as tables and drawings. All were constructed as an integrated part of students' deliverables.

8.2.2.1 Project schedule

This constructed information object represents planned project activities along with their duration and inter-relationships. A basic project schedule (Figure 8.1) is constructed at the early stage of the project to include a list of activities, duration, and their starting and ending dates.



	Task Name	Duration	Start	Finish
1	Assign Team Roles	1 day	Tue 22/09/09	Tue 22/09/09
2	Send Team Availability Timetable to Course Coordinator	1 day	Tue 22/09/09	Tue 22/09/09
3	Create Team E-mail	1 day	Tue 22/09/09	Tue 22/09/09
4	Define Problem	3 days	Wed 23/09/09	Fri 25/09/09
5	Contact Client to Introduce Team	1 day	Wed 23/09/09	Wed 23/09/09
6	Create Biography of Team Members for Cient	2 days	Wed 23/09/09	Thu 24/09/09
7	Conduct Initial Research and Brainstorm Questions	4 days	Thu 24/09/09	Tue 29/09/09
8	Complete Team Memo 1	3 days	Thu 24/09/09	Mon 28/09/09
9	First Official Meeting with Client	1 day	Tue 29/09/09	Tue 29/09/09
10	Identify Desired Result from the Project	1 day	Tue 29/09/09	Tue 29/09/09
11	**End of Project Understanding Phase**	0 days	Tue 29/09/09	Tue 29/09/09
12	Develop Work Breakdown Structure	3 days	Tue 29/09/09	Thu 01/10/09
13	Develop Gantt Chart	3 days	Wed 30/09/09	Fri 02/10/09
14	Delegate Recurring Tasks to Members	2 days	Tue 29/09/09	Wed 30/09/09
15	**End of Project Planning Phase**	0 days	Fri 02/10/09	Fri 02/10/09
16	Research More about Client Company	4 days	Tue 29/09/09	Fri 02/10/09
17	Complete Background Research Brief	4 days	Tue 29/09/09	Fri 02/10/09
18	Complete Team Memo 2	5 days	Tue 29/09/09	Mon 05/10/09
19	Identify Client's Markets and End Users	4 days	Thu 01/10/09	Tue 06/10/09
20	Complete Progress Report 1	5 days	Fri 02/10/09	Thu 08/10/09
21	Arrange Site Visit	47 days	Fri 02/10/09	Fri 04/12/09
22	Get Related Equipment from Client	1 day	Wed 07/10/09	Wed 07/10/09
23	Research Related Patents	13 days	Mon 05/10/09	Wed 21/10/09
24	Retrieve and Understand Relevant CSA Standards	18 days	Mon 05/10/09	Wed 28/10/09
25	Create Survey Template	1 day	Mon 05/10/09	Mon 05/10/09
26	Distribute Survey to Users	4 days	Mon 05/10/09	Thu 08/10/09
27	Analyze Survey Response	17 days	Thu 08/10/09	Fri 30/10/09
28	Research Existing Solutions	7 days	Thu 01/10/09	Fri 09/10/09
29	Identify Pros and Cons of Existing Solutions	5 days	Fri 02/10/09	Thu 08/10/09

Figure 8.1: An example of a preliminary project schedule

Some students constructed project schedules that included explicit roles of project team members and their assigned activities. Figure 8.2 gives an example of group members' assigned roles with respect to information seeking and searching. Some activities were assigned to individual students while others were assigned to more than one student. The tendency of different pathways in the project schedule to move from individual to collaborative information behavior confirms the previous chapter's findings regarding students' activities and interaction as they seek and search for information.

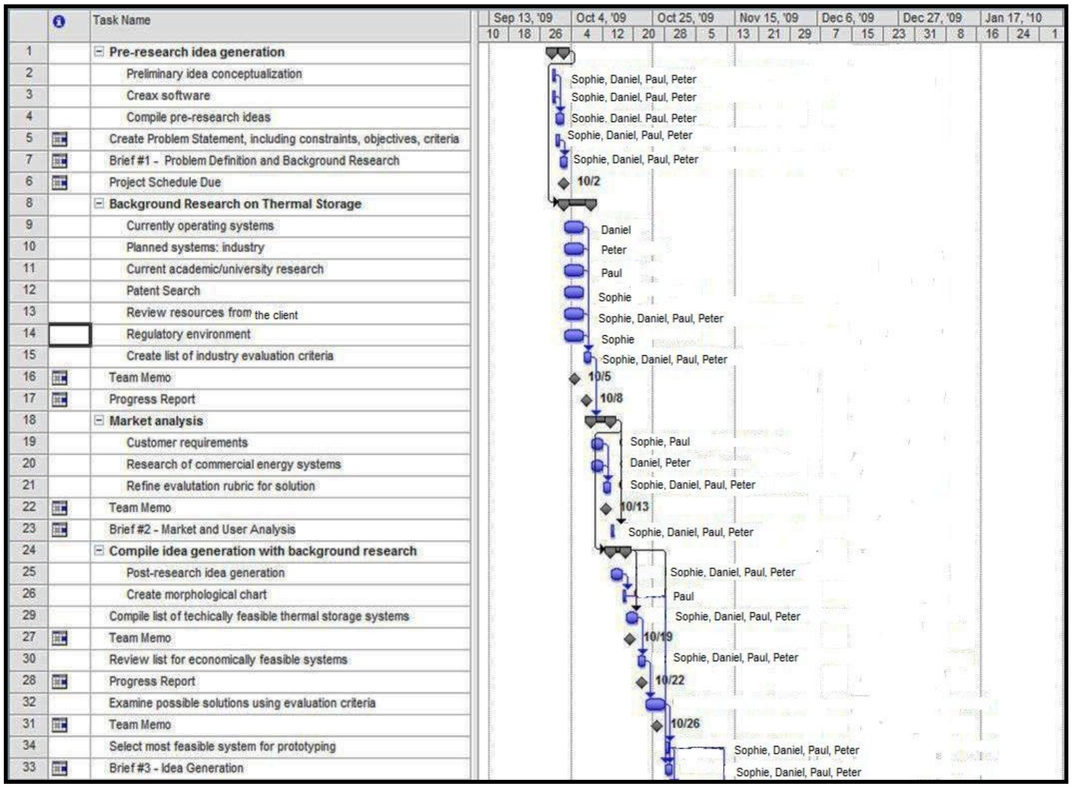


Figure 8.2: A preliminary project schedule with assigned roles

During their projects, students needed to review their preliminary project schedule and update it with the actual activities they had performed, adding any other activities that were not foreseen at the beginning of the project. The reviewed project schedule provided a baseline for students to evaluate their performance and define successive activities and their corresponding actors. An updated project schedule (Figure 8.3) shows the completed, in progress, and pending activities for the project.

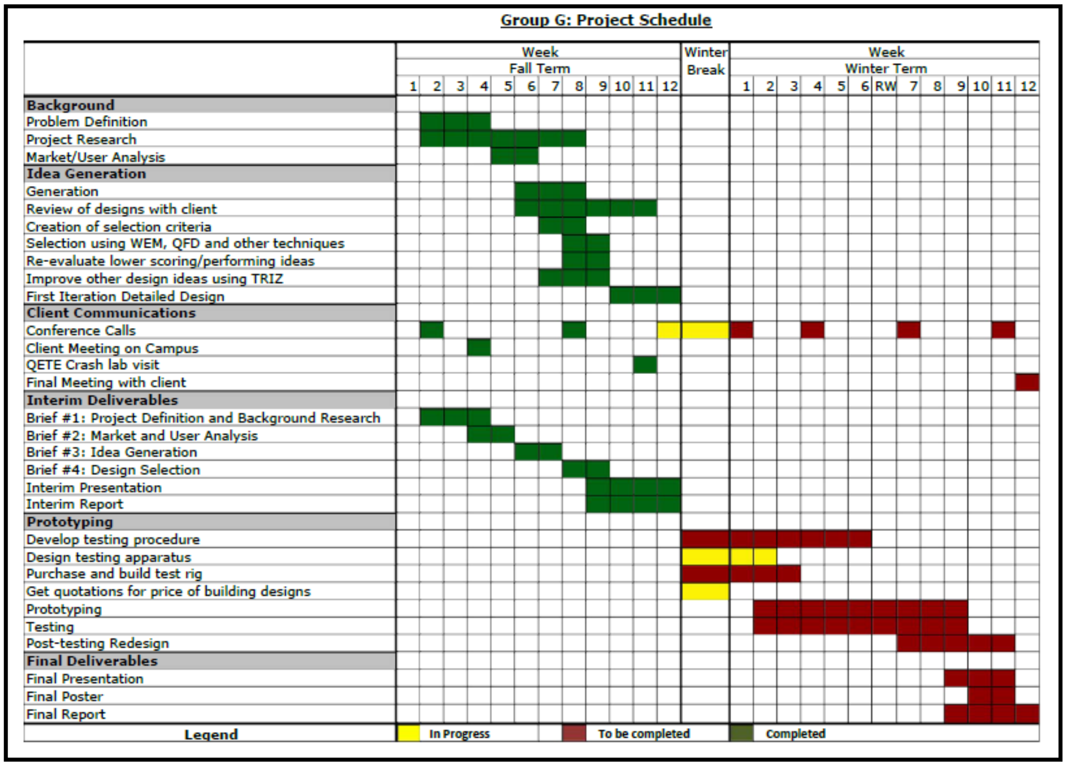


Figure 8.3: An updated project schedule

Nearing the end of the projects, students updated their project schedule to reflect their actual performed activities as compared to original planned activities. Figure 8.4 shows an example of the updated project schedule to reflect that students were able to meet the planned project activities at the first two stages of background research and idea generation. The difference between planned and actual activities in prototyping reflects the fact that selection and ordering of components, followed by design testing, took longer than anticipated at the beginning of the project. Within each project report, students had to state the reasons behind these differences and describe what corrective activities they followed in order to finish the assigned project within the available time frame.

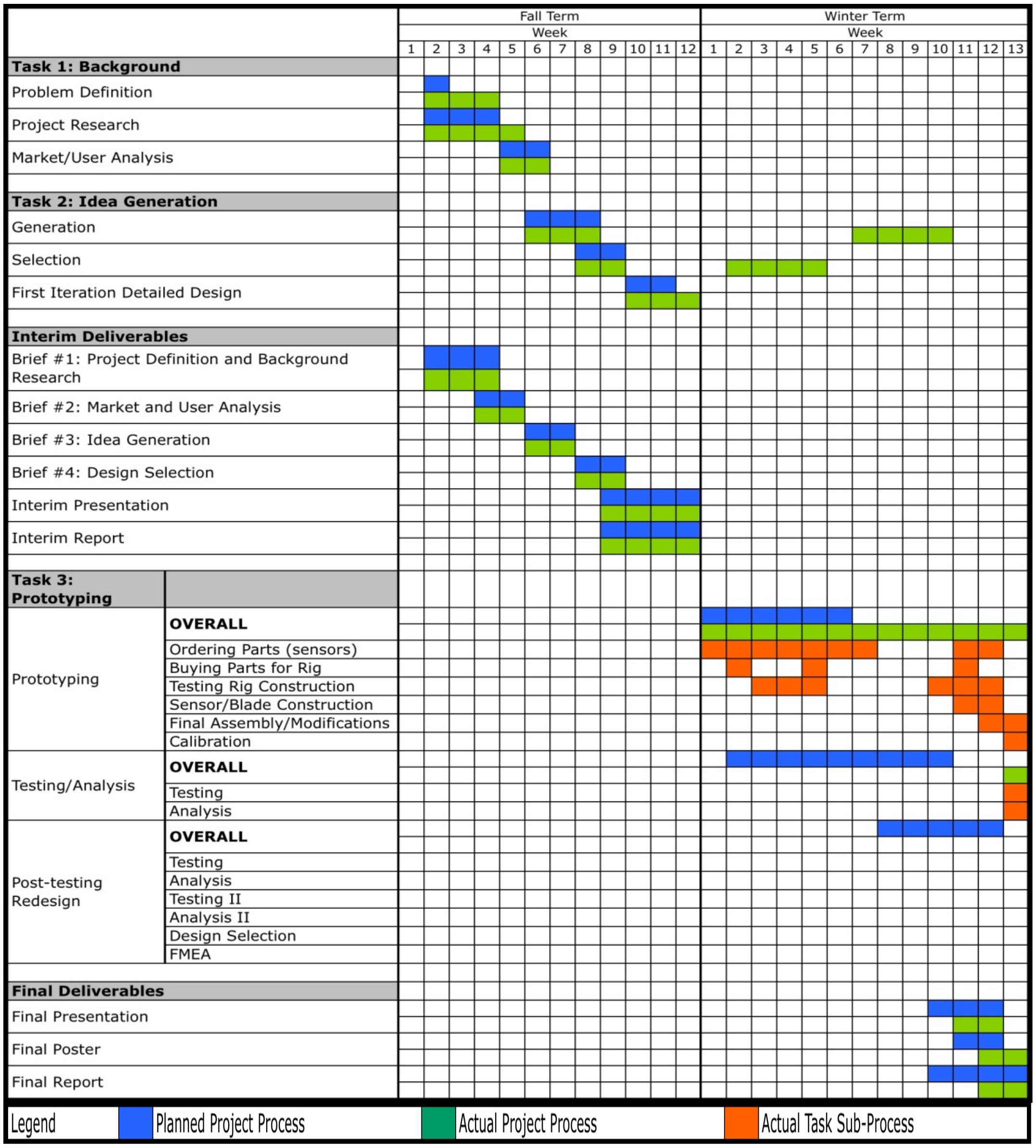


Figure 8.4: An updated schedule at the end of the project.

The constructed project schedule was found to provide a framework for students to plan their activities in information searching and use as Sara put it:

> It has been helpful for the group to sit together and update the project schedule during our weekly meetings. At the beginning we thought of it as extra work, since the teaching assistant reviews it with us when we have meetings. However, while we were working on the project we saw the

value in reviewing this chart as a group, as we all have different schedules and other courses to do. We were able to decide who should do what depending on the availability of any of the four team members.

In its relationship with students' collaborative information behavior, the project schedule was found to be an important constructed information object that students developed and updated over the course of their project. These constructed and revisable schedules provided a frame to support student's plans and to guide their individual performance, dependent on other academic commitments, at each stage of their projects.

8.2.2.2 Morphological chart

Morphological charts are graphical representations of different ideas that can be incorporated in the requested design. Using relevant knowledge and information acquired before they begin brainstorming possible design ideas, designers use these sketches to identify critical parts of a more general product. Construction of morphological charts is a domain-specific skill commonly used in engineering design, as discussed in Section 5.2.5.

Students developed a morphological chart for the assigned design problem to assist them in structuring possible solution attempts. Each group constructed a chart to reflect their commonly agreed insights into the nature of the requested design and possible resolutions of the design problem. Some project groups included their preliminary sketch as a basic representation using free handwriting (Figure 8.5) as an example of their brainstormed design ideas for a solar energy project.

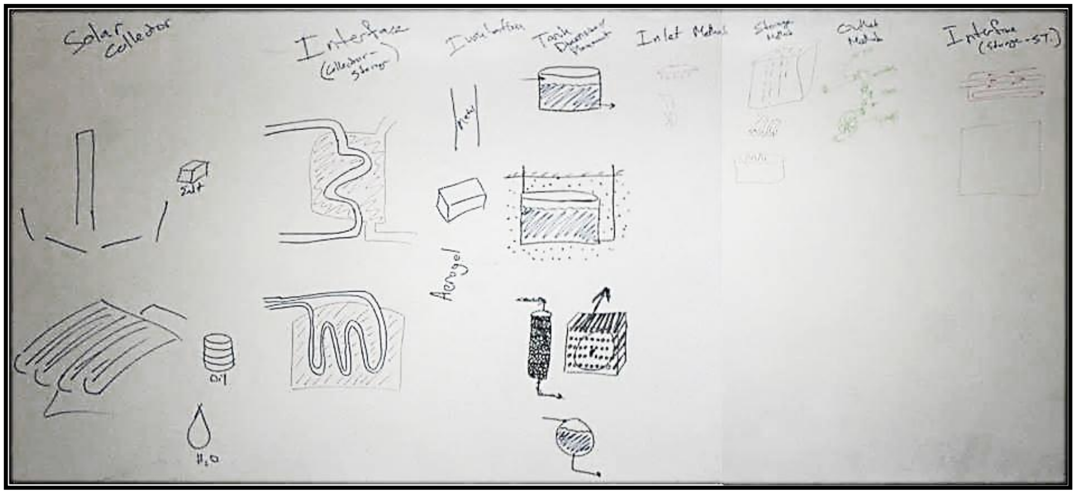


Figure 8.5: A preliminary morphological chart with free handwriting.

Morphological charts were produced in different formats depending on the purpose of the expected representation. A morphological chart can be constructed to include a conceptual representation of the constituent components of the proposed design, as shown in Figure 8.6, representing the components of a safety lanyard designed to prevent construction workers falling.

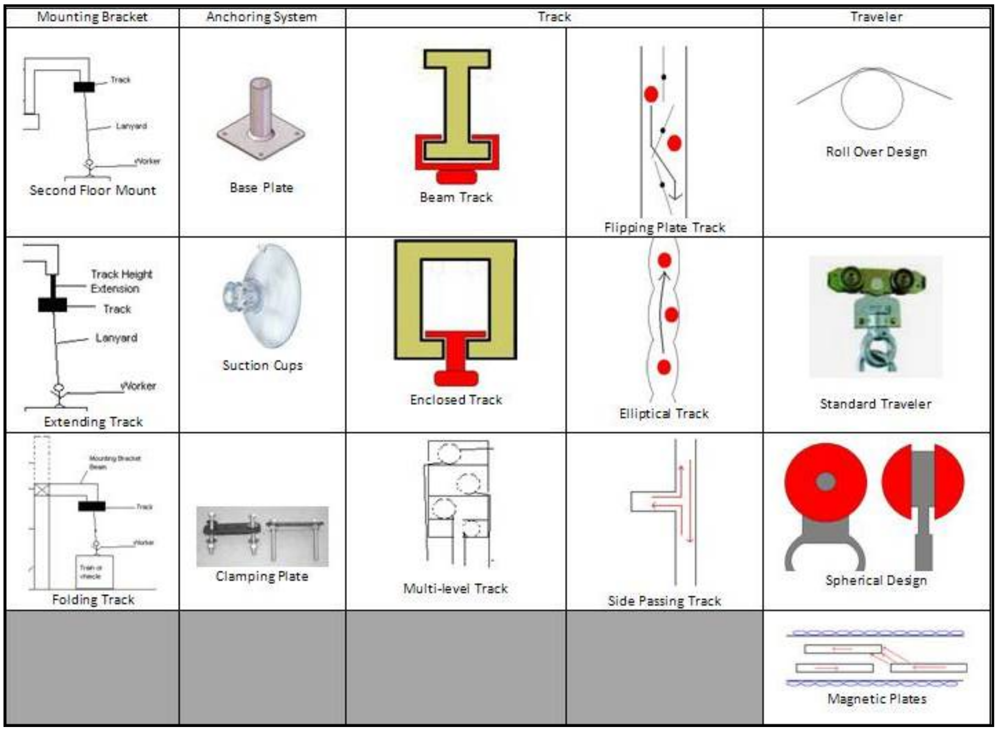


Figure 8.6: A conceptual morphological chart of a safety lanyard

Students developed different and alternative formats for their projects' morphological charts, reflecting the design-specific information they needed to incorporate in their solution. Figure 8.7 illustrates several conceptions of a design for a diffused air stripper unit.

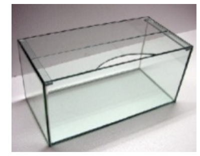
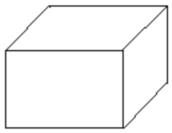
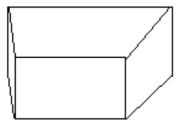
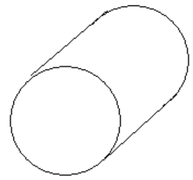
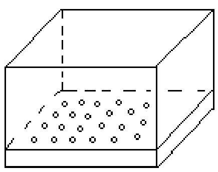
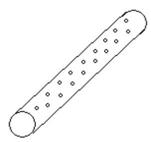
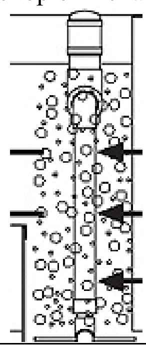
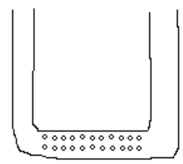
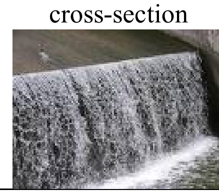
Tank Material	PVC 	Stainless Steel 	Coated Steel 	Plexiglas 
Tank Shape	Rectangular 	Trapezoidal 	Circular/Cylindrical 	
Air Diffusion Method	Have a sheet in the bottom of the tank which has holes drilled into it and bubbles air through 	Use horizontal tubing with holes drilled in it to diffuse air. These would sit near the tank bottom 	Use vertical tubes to diffuse the air which comes in through the top of the tank. 	Use a U-shape tube which brings the air in through the top but only diffuses air from the bottom 
Water Condition-ing	Heat the water inlet using steam or electrical tracing	Have water come in through a pipe	Have a "spill-over" entrance to the tank which spans the cross-section 	Place the water inlet at the top of the tank
	Use a variable flow rate – i.e. have the pump run at 25GPM for 45 seconds, and 5GPM for 15 seconds	Place the water inlet at the bottom of the tank	Place the water outlet at the top of the tank	Place the water inlet at the bottom of the tank

Figure 8.7: A detailed morphological chart for a diffused air stripper unit

This morphological chart represents ideas previously generated among the group members and reviewed according to the students' assessment of each idea's logic and plausibility. In the chart, ideas have been organized according to possible options for tank material, tank shape, air diffusion method, and water conditioning. The developed chart is simple and accessible, with both textual and graphical explanations. The project's client can see at a glance the different approaches students have considered. As well, students have a spatial representation that summarizes their findings, helping them justify their selection of one single solution to implement.

8.2.2.3 Decision making tables

Students needed to evaluate their identified design ideas based on specific criteria in order to select the design solution most appropriate to the project client's needs. Groups had to collaboratively choose between possible solutions or features to be incorporated into the final design, evaluating alternative designs by considering those objectives the design was supposed to achieve.

In order to make any kind of evaluation, students had to have a set of criteria based on the information gathered from the project client and from previous research carried out to discern the design objectives of their project. These evaluation criteria, which differed from project to project investigated in this research, included technical and economic factors, user requirements, safety requirements, and performance factors. Table 8.1 lists the evaluation criteria, based on customer needs, which students defined for a safety lanyard designed to prevent construction workers falling from great heights.

Table 8.1: Evaluation criteria for safety lanyard for fall protection

Customer Need	Definition
Adaptability	The ability of the component to be used in multiple locations or change to meet different environmental factors.
Aesthetics	The overall appearance of the system.
Cost effectiveness	The overall cost effectiveness of the component as part of the system.
Deflection	The overall deflection of the track when a load is applied to it.
Durability	The ability of the system to endure damage and forces not directly linked to a falling person.
Ease of installation / Uninstallation	The overall ease of installing or uninstalling the system. This includes the attachment or detachment to other components and the surrounding environment.
Ease of use	The ease a person can use this component. The less action the user has to take to use this component the better.
long running life	The estimated life of the component with proper maintenance.
Manufacturing ease	How simple the design is to manufacture.
Maximum load resistance	The estimated total load the component can bear compared to other components of similar size.
Number of people it can support	The number of personnel the system is able to support. Systems which would allow people to pass each other received a higher score.
Reliability	The length in between maintenance checks.
Safety	The overall safety of the system considering the chance it could fail catastrophically.
Horizontal / Vertical systems	The ability of the system to be converted for use in a vertical or a horizontal system.

In a next step, students collaboratively determined relative weights for different evaluation criteria, as they related to the project, and listed them in a rank order of importance. Consequently, students developed a weighted evaluation matrix (Figure 8.8) based on the ranked criteria for the alternative design options and the quantitative score of each design option was calculated. The design option with the highest score was selected as the most feasible solution to pursue based on the identified criteria.

		Engineering Specifications											System components		
Customer Needs	**Weighting**	Transporation Cost	Design Cost	environment of use	Attachment Mechanism	Tracks	Load	materials	rust proof	Dimensions	Manufacturing Cost	Meets standards	*Hercules*	*Pristine (non-rigid)*	*Spanco*
Adaptable to different Structures	9		3	3	9	3	3			3	1	1	4	5	5
Aesthetics	2		1	1	3	9		1	1		3		3	5	5
Cost Effectiveness	10	3	9	9	3	9	9	9	3	3	9	9	4	4	4
Durability	9		3	3	1	9	9	9	3		1	3	4	4	5
Ease of Installation	7		3	3	9	3		1		9			3.5	4	3.5
Ease of Use	9		9	1	3	9				1		1	5	5	5
Long Running Life/Rust resistant	10		1	9	1	9	3	9	9		3		4	5	3
Number of people it can support	9		9	1	9	9	9	9		3		9	1	4	2
Manufacturing Ease	3		3	1	3	9		9	3	9	9		4	2	4
Reliability	8		3	9	3	9	9	3	3	1		9	4	3	4
Safety	15		9	9	9	9	9	9	3	1	3	9	5	4	5
Deflection	5		9	3	3	9	9	9		3	1	9	5	1	5
Can be used as both horizontal and vertical systems	2		9	3	3	9							1	3	1
Ease of uninstallation	2		3	3	9	3		1		9			2	4	2
	100												386.5	399	407.5

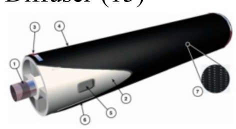
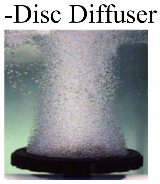
Figure 8.8: A constructed weighted evaluation matrix

The aim of the weighted evaluation matrix, as a constructed information object, was to help students collect and share information they may have identified during the design's idea-generation phase, that they might select the design to be implemented based on agreed evaluation criteria.

8.2.2.4 Cost analysis

Once a design solution was selected and approved by the project client, students needed to know the cost of necessary components and materials. Students approached different suppliers for these materials and made necessary calculations to estimate the overall cost of the design, especially when constructing a design prototype. Table 8.2 represents an example of cost analysis developed by students in a project to design a diffused air stripper unit.

Table 8.2: Cost analysis of a diffused air stripper unit

Component	**Potential Options**	**Pricing**	**Price Range**
Air Diffuser	- PVC with manually drilled holes	Piping - $25.80/10ft, 2 lengths (13) Labor - 2hrs @ $60/hr = $120 Total = $171.60	$171.60 - $402.00
	-Silicon Diffuser Hose (14) 	RFQ Pending	
	-Fine Bubble Membrane Tube Diffuser (15) 	RFQ Pending	
	-Disc Diffuser (16) 	$44.95/each, 6 needed Total = $269.70	
	-Air Tube Diffuser (16)	$67.00/each, 6 needed Total = $402.00	
Tank	-254 Gallon Polyethylene Tank 48" x 48" x 24"H (17)	$556.27, fittings and shipping extra	$340 - $697.75
	-200 Gallon HDPE Tank 58" x 30" x 30"H (18)	$398, fittings and shipping extra	
	- 225 Gallon Rectangular Tank 60" x 24" x 36"H (19)	$340, fittings and shipping extra	
	-Dedicated Plastic Tanks 228 Gallon Rectangular Tank 60" x 30" x 30"H (20)	$446.75 for tank, $156.00 for two bulkhead fittings, $95.00 shipping Total = $697.75	
Pipe, Fittings, and Accessories	PVC Pipe	$25.80/10ft, 2 lengths (13) Total = $51.60	$66 - $91 (High range for multiple elbows and couplings)
	Elbows, Couplings, Caps	Elbow - $7.00/ea (13) Coupling – $3.94/ea (13) Cap - $3.46/ea (13)	
Total Price Range			**$577 - $1191**

Based on information students were able to acquire from different suppliers and from examining existing designs similar or related to theirs, the table shows an estimated cost analysis of the unit to be developed. A developed cost analysis will typically include such information as type of materials required, components, dimensions and measurement, and expected performance. The calculated cost analysis was found to be an important information object for all groups to develop, allowing them to estimate the total cost of their project and thus be evaluated against the allocated project budget.

8.2.2.5 Developed surveys

In some projects, students needed to gather information about potential users and their preferences as part of the evaluation of possible design ideas for the developed product. Students asked some customers who were using a product similar to the one under development to complete a survey. Figure 8.9 shows a developed survey sent to construction workers using various fall-arrest systems, in order to get an understanding of current and potential users' trends and preferences. In addition to respondents' opinions about existing systems, the survey elicits open-ended suggestions for improvement, generating potentially valuable information that could be incorporated in the students' design solution.

est System Survey

1. Which do you use more?

a. horizontal fall arrest system b. vertical fall arrest system

2. Have you been saved by a fall arrest system within the last 2 years? Yes No

If yes how many times?

3. How many people typically work on the same section (Anchor to Anchor) of a fall arrest system?

a. yourself only b. 2 c. 3 d. 4 or more

4. Which part of the fall arrest system do you find slows you down in working the most?

a. Lanyard b. Harness c. Carbineer/Hook d. moving around anchor points

e. Other

Why? ____

5. Have you used a fall arrest track system before? Yes No

If yes did you find it better than a fall arrest cable system? Yes No

Why? __________________

6. What do you like about the current fall arrest system you use?

____

____

7. What major changes would you like to see in a fall arrest system?

____

____

If you so wish, place you name here to enter into a draw for a $10 Tim Horton's Gift Card

Figure 8.9: A developed survey on the use of fall arrest systems

8.2.2.6 Technical drawings

Technical drawings are a commonly used technique in engineering projects to represent the specifications, components, or dimensions of a developed product. Drawings range from rather general descriptions, such as plans, elevations, and general arrangement drawings, giving an overview of the developed artifact, to more specific drawings, such as sections and details that would give precise information as to how the artifact would be designed and manufactured. Students collaboratively developed many technical drawings to describe their developed design solutions. They used various formats that were constructed, based on agreed codes and conventions, to communicate precise design information with minimal likelihood of misunderstanding.

Technical drawings present spatial representations of different types of design information, with such necessary annotations of additional information as the dimensions of different parts or sections, as shown in Figure 8.10.

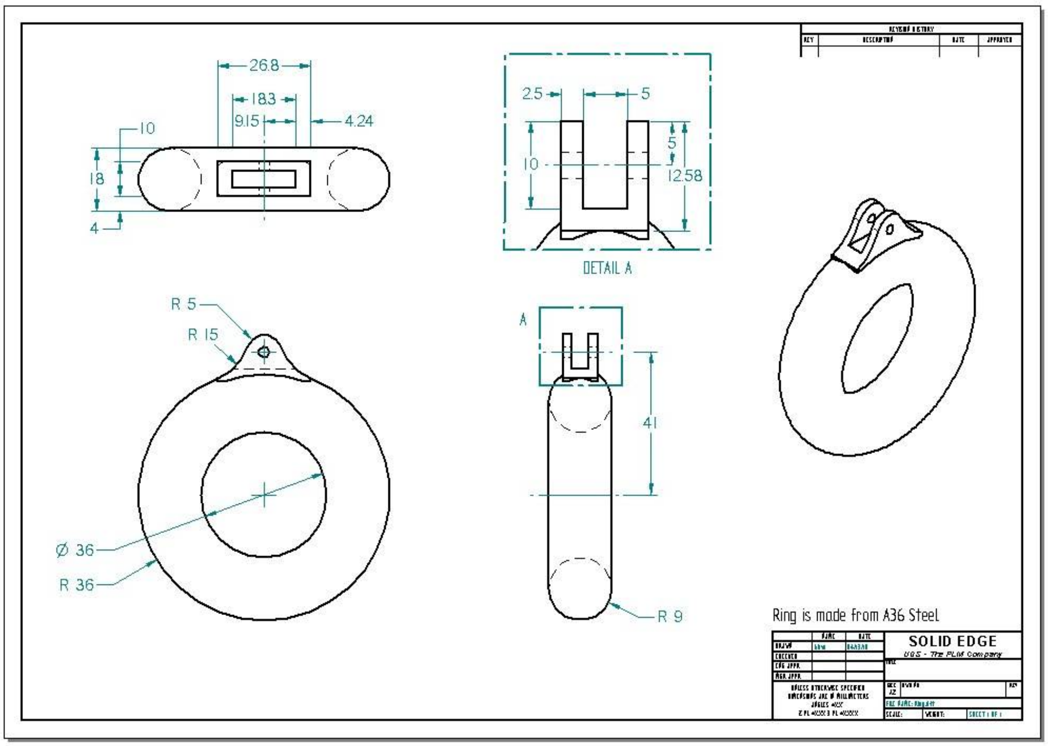


Figure 8.10: An example of a technical drawing

This example shows a ring as one component of a design solution. The artifact is represented in different views giving all necessary perspectives. The drawing also specifies the material to be used in the ring, in this case A36 steel. To produce these illustrations, students used a technical-drawing software application with which they were familiar from work done in their previous courses.

The drawings had to be high-quality representations, conveying a precise understanding of what the final product would look like and providing all information necessary for the project client to manufacture the product successfully.

8.2.2.7 Engineering prototypes

Students developed prototypes (models) for their final design solution based on the requirements of each project. These prototypes were either a virtual, computer-assisted representation or a physical model using components that could be tested and evaluated to measure the performance of the product. Figure 8.11 shows an example of a physical prototype of a mechanical component students developed to measure the performance of a rotary motor. Attaching different loads to it, they were able to decide the motor's operational range in its final design solution.

Figure 8.11: An example of an engineering prototype

8.3 Conceptualization of the information objects dimension

This chapter has shown the variety of information objects students collected and developed during their projects. These objects touch on many types of information that are dependent mainly on a given project's nature and objectives. Information objects were collected from different channels such as books, handbooks, databases freely available information on the Internet, and information gained from people who had more expertise and knowledge than did the students about the project topic.

At the same time, students had to collaboratively develop new information objects, based on what they were able to gather and learn about their project, in order to select and implement a solution to their given design problem. These developed information objects constituted a major portion of the course deliverables, which in turn reflected student progress in achieving their learning task objectives and project requirements.

Based on the analysis of students' deliverables and on the interviews, the represented categories of collected and developed information objects in this chapter cover those information objects employed by the project groups. These developed information objects reflect the analysis, synthesis, and development phases in the design process, during which students had to create new information relevant to the performed task. Figure 8.12 shows a conceptualization of the findings with respect to information objects as they relate to students' collaborative information behavior.

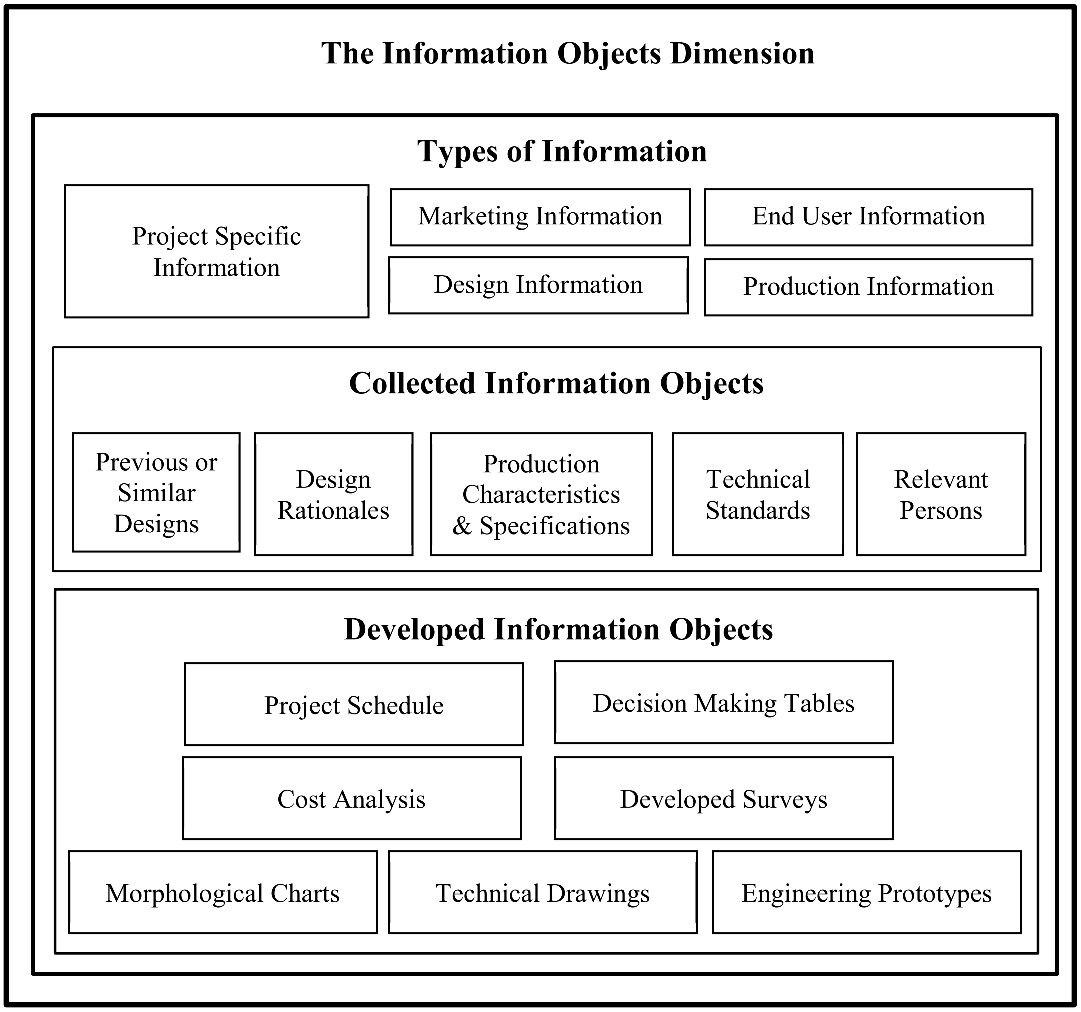


Figure 8.12: A conceptualization of the information objects dimension

The following chapter will detail further discussion of findings related to the main dimension of collaborative information behavior along with a suggested conceptual framework of collaborative information behavior of engineering students in learning tasks based on the findings of this study.

9 BRINGING IT TOGETHER: A CONCEPTUAL FRAMEWORK OF COLLABORATIVE INFORMATION BEHAVIOR

While it is evident that people collaborate when they seek information and when they use it in the performance of different tasks, there is little understanding of the characteristics of collaborative information behavior and its relation to the nature of performed tasks, particularly in educational settings. The collaborative information behavior of students as they undertake their assigned learning tasks has not been previously explored in detail or to a satisfying point of conceptual understanding.

The overall purpose of this dissertation has been to "open the black box" of collaborative information behavior and to break down its characteristics within learning tasks. The research focused on the investigation of collaborative information behavior of engineering students within their assigned learning tasks. The research goals were to provide a complete investigation of the main features of both the learning task and collaborative information behavior. This dissertation was motivated by Wilson (1999), emphasizing the need for adequate representations of the reality sought by information behavior research; I conducted a longitudinal investigation that used two interrelated studies, each of which drew upon a variety of data source formats in order to gain a greater understanding of the phenomenon under investigation.

The first step in this research required an in-depth literature review (Chapter 2) of related ideas from these two disciplines. The next step involved the selection of an appropriate research methodology (Chapter 3) that required me to perform a pilot study in order to create a conceptual framework for the research (Chapter 4). The research findings were analyzed according to the main concepts within the research framework and spread out over Chapters 5, 6, 7 and 8. The findings in these four concepts were brought together in Chapter 9, in which a conceptual framework of collaborative information behavior in learning tasks is suggested.

Collaborative information behavior in learning tasks was found to be of a dynamic nature that changed according to different subtasks' requirements and objectives. Information seeking, searching and use are essential and embedded parts of the design process that cannot be separated from whatever method a team has found appropriate to solve their assigned problem. The process can be seen to be a journey over which designers have full control when selecting appropriate pathways to follow; designers are like explorers searching for buried treasure, as Jones (1992) describes it:

> A new problem is like an unknown extent, in which the explorer searches by making a network of journeys…Design methods are like navigational tools, used to plot the course of a journey and maintain control over where he goes. Designing, like navigation, would be straightforward if one did not have to depend on inadequate information in the first place. Unlike the navigator's, the designer's landscape in unstable and imaginary, it changes form according to the assumptions he makes. The designer has to make as

> much sense as he can of every fragmentary clue, so that he can arrive at the treasure without spending a lifetime on the search (p. 39).

Accordingly, collaborative information behavior in design projects varies from one project to another, especially given that design projects often start with an ill-defined or wickedly difficult problem (Dym & Brown, 2012). The analogy of the design process as a problem solving technique is commonly used in design methodology literature (e.g., Best, 2006; Breiing et al., 2009; Cross, 2008). Problem solvers select different strategies based on the nature of the given design problem. Koberg and Bagnall (2003) described designers as travelers in a problem solving journey who use information in finding the best ways to reach a destination:

> A general rule is to find and use methods which best fit the problem and the abilities of the problem solver. It's a task similar to that of selecting the route, side roads and overnight stops for an auto trip. Just as any competent trip planner would examine the alternative routes on a map, and read through several brochures, books, or articles before choosing a route for his trip, so should the problem solver review the methods available, and not be afraid to adopt any of them to his special needs (p. 151).

The information behavior of designers is not a static or a bounded phenomenon but a human behavior adaptable to every situation. It is based on designers' awareness of the situational requirement and allows them to select an appropriate strategy, as concluded by Bruce in the last interview, during which he constructed his information horizons map:

> As an engineer, I need to maintain a high level of consciousness of every aspect in the project that would affect possible design solutions. I like to

> think that I am carrying a toolbox that is full of possible tools to use in solving different problems and to select the appropriate tool based on the problem that I need to solve. A tool which I use today in my project may be different from what I used yesterday, or from what I would use tomorrow. If none of my tools would solve the problem, I would ask for help from other engineers who may have additional tools that I do not currently have.

There have been noticeable variations among students' trends in their collaborative information behaviors. These variations were not only among individual students but also for the same student at different stages and phases of the learning task. My findings represent indications of common trends captured during this research and do not necessarily suggest that all students under investigation experienced every identified aspect of collaborative information behavior.

The previous four chapters represent the findings from the main dimensions which constitute the components of collaborative information behavior in learning tasks. In this chapter, I bring these research findings together before presenting a conceptual framework of collaborative information behavior in learning tasks.

I set out to answer my research question in this dissertation: How does students' collaborative information behavior interact with assigned learning tasks associated with an engineering design project? The research findings answered this question by providing a holistic understanding of: (1) the characteristics of the learning tasks associated with the engineering design project, (2) the characteristics of student collaborative information behavior, and (3) the interaction between learning tasks and students' collaborative information behavior.

9.1 Characteristics of learning tasks

The investigated learning tasks in this research were structured to develop students' skills in engineering design by making them solve a given engineering problem that had many objectives and constraints. It has been found, as presented in Chapter 5, that learning tasks have salient characteristics that affect task performers' activities including their information behavior; these characteristics define a task's stages and its objective complexity.

Learning tasks were structured to be of a creative nature that required students to create a new original solution for a given problem. That creative process started with a convergent phase when students needed to collaboratively define the project problem and to agree on a problem statement. A divergent phase would follow in which students had to generate possible design solutions to the given design problem. This was followed by convergent phases in which students selected a design method, chose the most appropriate solution, and finally executed and constructed the selected solution.

These learning tasks were also designed to be self-regulated assignments (Zimmerman, 1990) that required learners to take deliberate control of their learning experiences during the lifespan of the task. However, it was noticed that the structure of the learning task included interventions from the course instruction team when needed to keep the learning task within the course educational objectives. Contextually, tasks had purposefully intended objective complexities accompanied by high cognitive and domain-specific demands that challenged students not only to use all possible skills that they had acquired during their engineering program but also to acquire any needed new skills and knowledge. Furthermore, learning tasks explicitly required that collaboration be maintained among group members in performing their assigned tasks; this collaboration had to be reported in students' weekly reports and during group meetings with the course instruction team.

9.2 Characteristics of students' collaborative information behavior

Collaborative information behavior, the main investigated phenomenon in this research, is defined to be the totality of human behavior when two or more people work together, in relation to sources and channels of information, and includes both active and passive information seeking and use. Given that research in this area is still emerging, the characteristics of collaborative information behavior were identified according to the definition above and within three main dimensions: (1) the learner's knowledge dimension (Chapter 6), (2) the learners' activity and interaction dimension (Chapter 7), and (3) the information objects dimension (Chapter 8).

Students' collaborative information behavior was found to be of a dynamic nature that encompassed both individual and collaborative activities. Individual activities were found to be performed by individual students in a project group but with a maintained coordination among group members, while collaborative activities and interactions were performed explicitly by two or more students to meet the task objectives and goals.

Students decided their pathways in pursuing collaborative or individual information-related activities in different situations during the project. They came to these decisions aware of situational requirements and having had collaborative metacognitive experiences in which they integrated individual and social levels of cognitive orientation in their information seeking, searching and use.

Students sought information from two main channels: people and documents. People as information channels were viewed by students to be experts, with knowledge in particular subject areas, who would help students with practical information needed for the task at hand. Documentary information sources were sought by way of active information searching that varied from exploratory search, in which students investigated possible useful information sources to learn more about particular subjects, to lookup searching for a particular information source such as a journal article or material specifications.

In order to sustain collaborative information activities in information behavior, students had to develop and maintain a common ground for the group. Collaborative grounding (Hertzum, 2008) was the product of students' interactions in their group meetings and their use of collaborative software tools. Students had to share collected information objects in order to use this information to develop a solution for their project's problem.

Students used large amounts of information that required them to collaboratively synthesize what they had found. They accomplished this by prioritizing information sources based on their usefulness to the task at hand, evaluating these sources by judging the relevancy of the information in relation to situational requirements, and building connections between these information sources in order to create a new understanding or develop a new information object such as a table, drawing or flowchart.

9.3 Interaction between learning tasks and students' collaborative information behavior

It has been clearly found that students' activities and interactions in information seeking and use are closely intertwined with their learning experience while performing assigned tasks. Students engaged in information seeking and use activities to meet the learning task objectives and outcomes; i.e., students did not carry out activities in information seeking, searching and use for their own sake but mainly for purposes related to their projects' demands.

The overall objective of a learning task associated with an engineering design project was to develop and create a solution to a given design problem. To successfully complete a self-regulated learning task, students had to set realistic goals, select effective strategies, monitor their understanding, and evaluate their progress towards their goals (Zimmerman, 1990). The activities in the design process were found first to diverge from a particular design problem before finally converging on one concluding, evaluated and detailed design solution. However, the design process itself was found to include both divergent and convergent activities (Figure 9.1) that triggered individual and collaborative activities related to students' information behavior.

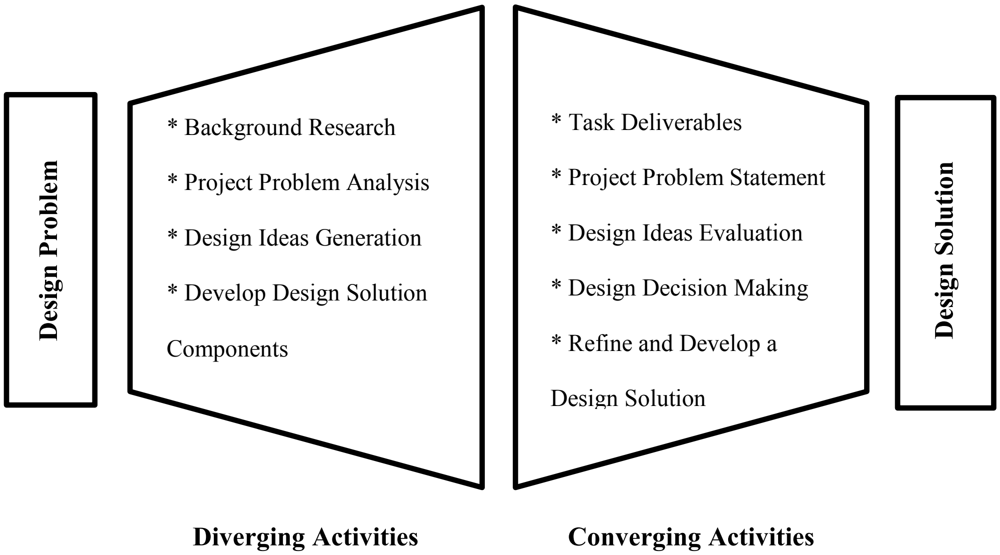


Figure 9.1: Examples of divergent and convergent activities during the learning task.

Information related activities were found to differ according to the learning task phases and depending on whether the activities were individual or collaborative. At the early beginning of the learning task, the identification of needed information was decided collaboratively in order to create a shared focus of the objectives of the learning task and to define the project's problem statement. Then, students delegated topics that needed information seeking and search to each group member. This resulted in divergent activity, requiring students to search for information individually, followed by convergent activity during which they worked collaboratively to synthesize what they had found to prepare a required task's deliverable report on the background research. Similarly, many groups reported that the generation of design ideas tended to be an individual activity, whereas the evaluation of these design ideas in order to select an appropriate design idea was a collaborative activity. This relationship shows that collaborative activities in information behavior depend on whether the nature of task activities is convergent or divergent. This finding is supported by the increasing intensity of collaborative activities seen in the last two months of the learning task, when engineering students had to collaboratively develop a selected design solution and represent it in a single prototype and a single report.

According to the findings in Chapter 5, learning tasks were structured as complex engineering design problems that required students to provide a detailed solution at the end of the project. In many situations, students in the same group perceived task complexity differently based on their knowledge, obtained in previous courses, of the content of the learning task and its requirements. These observed variations in students' perceived complexity of the task confirms Kuhlthaus's (2004, pp. 196-197) findings that variation in student's perception of task complexity is subject to the individual; the same task perceived to be complex by one student can be thought simple by another in the same group.

Variations in perceived task complexity among group members were negotiated in group meetings. The result was a shared collaborative metacognition regulating those cognitive processes needed to achieve the task goals. Collaborative metacognition led to the identification of information needs resulting from the distinct task to be performed in a particular situation and was a direct response to any of the following: ambiguity of information need, lack of domain-specific knowledge, anticipated cost of information seeking and searching, or unavailability of information. Once information needs were shared among group members, students were able to make decisions about possible pathways of information seeking, searching or use that might be executed individually or collaboratively.

Students perceived task complexity in many situations during their projects, and thus they collaboratively shared their knowledge of the situation and made decisions about information seeking, searching or use. Hence, the level of collaborative activity and interaction in information behavior was found to shift according to the converging or diverging nature of the task activity and the collaboratively perceived task complexity.

This research found that when students' perceived task complexity increased, their information behavior tended to be more collaborative. Students also preferred to seek information from people seen to be experts in the domain of the learning task rather than search for information themselves.

According to these findings, metacognitive experiences and regulation activities emerged in collaborative processes that could not be reduced to the level of the individual. In these metacognitive experiences, students shared experiences that were triggered by their learning experiences in constructing a joint problem-solving process and in using regulatory processes that were also metacognitive in nature. Students needed collaborative metacognition to regulate their cognitive processes in information related activities as they worked towards the common goal of their group project.

In association with the different learning task activities, students used various and different information sources according to the point at which they found themselves in the performance of a given task. The evaluation and use of information sources to fulfill task requirements was seen to be a more collaborative activity when the information sources were found by individual students than when the information was given to them by personal contacts.

Collaborative use of information sources ranged from the sharing of information objects in group meetings to the use of collaborative software tools that enabled them to build an information base for their projects. In addition, students used these different information sources to develop new information objects needed for the creation of knowledge shared by group members.

The engineering design projects under study required students to create an original solution to a design problem. In doing so, group members investigated and shared a large number of information sources. Students were engaged in many collaborative activities to synthesize information objects by: prioritization, judging relevance, and building connections between information sources, in order to construct a new shared understanding and awareness of any further information needed to accomplish the task at hand.

It has been found that there is a relationship between the learning task characteristics and students' collaborative information synthesis. Students found it difficult to judge the relevance of information at the start of the learning task when no focus and shared understanding had yet been formulated among group members. It was also easier to judge the relevance of information in simpler than in more complex and challenging subtasks, which required the evaluation and use of relatively more sophisticated relevance criteria with respect to associated information sources.

9.4 A conceptual framework of collaborative information behavior

The research findings demonstrate that there is a strong relationship between learning tasks and students' collaborative information behavior. The findings show that collaborative information behavior is a complex phenomenon that consists of many interacting aspects that change dynamically during different stages of the learning task and is affected by the level of the task complexity and its requirements.

To summarize the findings of this research, I constructed a conceptual model of collaborative information behavior in learning tasks (Figure 9.2). The model brings together the main identified aspects detailed in the previous four chapters in a holistic representation of the phenomena investigated in this dissertation.

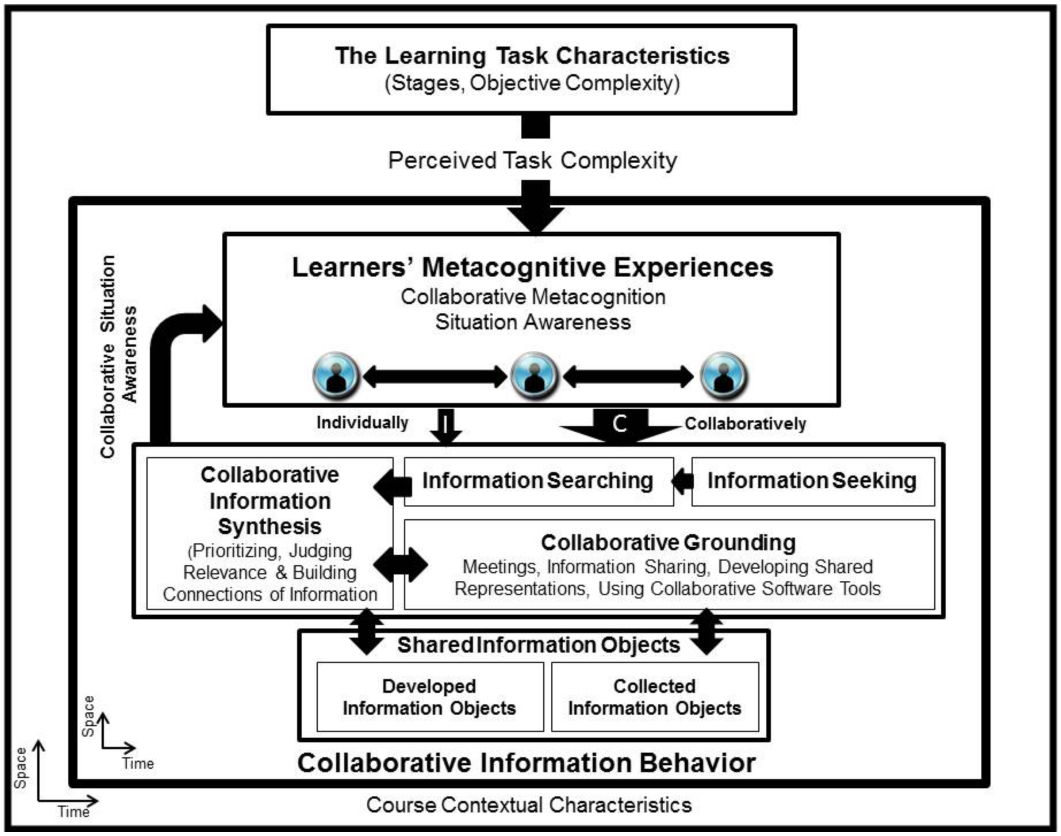


Figure 9.2: A conceptual framework of collaborative information behavior in learning tasks.

As revealed in the conceptual framework, collaborative information behavior involves shifts between collaborative and individual activities depending on the different topics and complexity of project subtasks. Collaborative information behavior is enabled by the collaborative grounding that group members had to develop during the learning task: working together, they generated the common ground of understanding needed to make decisions as a group in information seeking, searching and use.

At the vertical level of the developed conceptual framework, the four main dimensions exist parallel to each other. This means that the various dimensions dynamically interact with each other during the learning task performance process. The nature of theses interactions changes in time and space depending on the characteristics of the learning task and its performers. To sustain collaborative strategies in assigned learning tasks, students had to maintain collaborative situation awareness during task performance. This collaborative situation awareness acts as a feedback loop in which students' activities and interactions inform their decisions regarding anticipated collaborative or individual activities in the next stages of the project.

The constructed conceptual framework assumes that the learning tasks prompting collaborative information behavior take place within the contextual characteristics of the educational course in which learning tasks are performed. These larger contextual characteristics were purposely left unidentified so that the conceptual framework can be studied in other educational courses that are not necessarily project-based learning courses in engineering but can be in any other educational domain.

9.5 Conclusion

The findings in this dissertation make important contributions to our conceptual understanding of collaborative information behavior in learning tasks. Because learning tasks were found to be germane to students' information behavior, our understanding of students' information behavior cannot be separated from a considered analysis of those learning task components that trigger students' activities and interactions.

The research results showed a strong relationship between learning tasks' phases, combined with their objective complexity, and students' collaborative information behavior. Collaborative information behaviors dynamically occur in different stages of the project through different levels depending on the corresponding project tasks that trigger different collaborative information activities. Students' collaborative information behavior was found to be centrally triggered by shared understanding of the project requirements and subtasks to be performed, creating a collectively understood meaning of the needed and acquired information; these activities shifted the balance from individual to group understanding.

It was found that students played several roles during their learning experiences as they sought and used information, and that these roles varied among different projects in the same course. The findings also showed that engineering students' information behavior is similar to that of professional engineers, with regard to accessibility and cost of information sources, timeliness, and preference to seek information from people rather than from documentary information sources. Students' perceived task complexity was found to be an important factor triggering their collaborative use of different types of information sources, with preference for easily accessible resources, such as people as information channels.

The study elaborates on current understanding of the different ways learners seek and create meaning through collaborative synthesis of information to reach some conclusion or decision. It also extends what is already known about how learners monitor their information seeking and use through collaborative situation awareness over long time intervals.

9.6 Study contributions

To arrive at this conclusion, the underlying theoretical and empirical framework has led to a detailed conceptual analysis and modeling of collaborative information behavior that can be seen as a methodological contribution to studies of collaborative information behavior, in particular in group-based academic settings.

9.6.1 Contribution to information behavior research

This dissertation views collaborative information behavior to be an overall human behavior in relation to information seeking, searching and use in a natural setting. Unlike previous research that took apart the constituents of collaborative information behavior to concentrate only on collaborative information seeking or collaborative evaluation of information sources, this dissertation investigates information behavior holistically in all key dimensions and with respect to the significant relationships among them.

The research design has mainly rested on the Sense-Making approach (Dervin, 1983), implying that many influencing factors affect people's decisions in information seeking and use. Another useful finding of this dissertation is that Allen's (1996) person-in-situation approach helped me understand the different effects of situational factors on individual and groups information behavior.

This dissertation reports on original research into task-based collaborative information behavior of undergraduate students. It followed a grounded theory approach that resulted in the discovery of different aspects of collaborative information behavior and how they are interrelated. This research expands our conceptual understanding of collaborative information behavior by providing detailed insights into the occasions and characteristics of collaborative information behavior in learning tasks.

I provided a detailed account of how and why collaborative activities and interaction have occurred in the context of learning tasks. I also presented a conceptual framework of collaborative information behavior in which I extend important concepts that were covered to a lesser extent in previous research. These include collaborative metacognition, collaborative situation awareness, collaborative grounding, and collaborative information synthesis, my focus being the role they play in collaborative information behavior.

Although this dissertation focused on collaborative information behavior in learning tasks associated with engineering design projects, I believe the research findings and the developed conceptual framework to be useful for other studies of undergraduate students' collaborative information behavior in group-based learning tasks in disciplines other than engineering.

This dissertation corroborated previous research that found that task complexity is an important factor in understanding information activities (viz., Byström & Järvelin, 1995). I approached and analyzed objective task complexity as being part of the learning task dimension, while students' perceived task complexity was regarded as part of the learner's knowledge dimension. The conceptual descriptions of both objective and perceived task complexity in this research explain how they were related to students' information activities in task performance.

During the last four years, while conducting this research, I was able to present my research objectives and some preliminary results from the pilot study in four conferences in the field of information science, where I received positive feedback about the research and reinforcement that such studies are needed in the fields of information sciences and engineering education. I presented at many annual conferences of professional associations in information science, including the American Society of Information Science and Technology (Saleh & Large, 2011) and the Canadian Association of Information Science (Saleh & Large, 2010, 2012). I also presented a position paper at an international workshop on collaborative information seeking (Saleh, 2011b).

This dissertation moves forward existing research in collaborative information behavior by detailing its components and bringing to light the relationships among them. My research provides valuable insights into how people interact with each other during information seeking activities and how both individual and group sensemaking evolves during these interactions.

9.6.2 Contribution to engineering education

This dissertation's results have practical implications in the field of engineering education particularly in project-based learning, which has recently become a common trend to follow in engineering programs, as detailed in Section 2.5. This dissertation explores the role of information in engineering design tasks through investigation of information seeking, searching and use as ongoing activities during engineering projects. Students' collaborative information behavior is embedded in their experience in the design process and is essential to their learning in engineering courses.

In engineering programs, students need to develop their knowledge and skills in information seeking and use, as guided by the ideal attributes of an engineering graduate. The research results of this study show that information synthesis, among other collaborative activities, was essential to the design process when students had to evaluate the found information in order to create new knowledge needed to progress in the project.

Students' awareness of information sources and ability to use different search tools were found to be important factors affecting performance of their assigned learning tasks. Knowing this, academic engineering librarians need to continue to acquire the most up-to-date information sources, whether in print or through subscription in electronic databases, and make these resources available to students to use. It was found that many students were not aware of the availability of some useful sources for their projects or did not know how to use some of these databases efficiently. The research findings of this study would be of practical use to librarian-faculty collaboration in engineering design courses. Librarians can provide invaluable instruction in the types of information sources needed in design projects and on how to access and use library databases effectively.

As this study is related to research and practice in engineering education, I presented in the following annual conferences of professional associations in engineering education: the Canadian Design Engineering Network (Saleh, 2008), the Canadian Council of Engineering Education (Saleh, 2009), and the American Society of Engineering Education (Saleh, 2011a). During these conferences, my research was welcomed and identified as an area of engineering education research and practice needing further exploration.

9.7 Methodological reflections

All methodological decisions can be traced to my early decision to conduct the study in a real-life educational context. This decision was taken not only because it allowed examination of students' information behaviour but also because it allowed me to study information activities as part of another action, learning task performance. I have followed a constructivist approach in conducting this study by using grounded theory as a research methodology, as described in Chapter 3. The main challenge in using grounded theory was in building a theoretical framework that would guide my data collection and analysis; the partial use of the web-based survey in Study 1 as a pilot study was helpful in creating a theoretical framework, as represented in Chapter 4.

I selected grounded theory as a research methodology and found it to be useful in investigating a complex phenomenon that had had little previous empirical research before I started my study. As an inductive methodology, grounded theory is an efficient way to explore research findings in conjunction with relevant literature. The result was an accumulation of detailed findings that together constituted the main dimensions of a complex phenomenon without the influence of prior assumptions or hypotheses.

One of the strengths of this research is its use of multiple data sources. By examining actual students' deliverables in their learning tasks, irrespective of the tedium attached to data preparation and analysis of a large number of documents, I acquired a rich and varied pool of information. The interviews in Study 2 provided me with further insight into students' actual experiences in collaborative information behaviour. The change of protocol in the last interview helped me to better understand students' collaborative activities and interactions, especially through the use of the information horizons method for data collection, a tool that enabled interviewees to think aloud about and map their overall information practice during their projects.

9.8 Limitations of the study

It may be difficult to generalize the findings from this research to other forms of group-based learning in other disciplines, given that the study focused on one particular course in a specific discipline (engineering) in a Canadian University. The number of participants in Study 2 was limited to eight students who voluntarily chose to participate in this research, and I was unable to recruit students who were in the same project group. Doing so would have given me more insight into different perspectives of students' experience, from those who were working on the same project. Hence, I would say that the findings presented in this dissertation demonstrate indications rather than absolute measures of students' collaborative information behavior in learning tasks.

The study was investigated at one university (Queen's University) in one country (Canada) which would make the research results to be limited to that particular course. However, given that capstone group-based design courses become mandatory courses in engineering programs worldwide; the context of the course under investigation in this research can have similarities with group-based design courses in other engineering education programs particularly in countries that have comparable accreditation criteria for their engineering programs such as the United States, the United Kingdom, Australia, and New Zealand.

The inclusion of students' quotations in this dissertation might be viewed as excessive, given the considerable length they add to the thesis. I justify their use by pointing out that, there having been relatively few qualitative studies in collaborative information behavior; I wanted to provide a detailed and thorough depiction of students' experiences in information related activities as a necessary requirement to have a credible trustworthy qualitative study.

Another limitation is that the research has focused on a knowledge-based approach in collaborative information behavior without detailed investigation of other dimensions, identified in previous research in information behavior, such as the affective dimension in information seeking (Kuhlthau, 2004), personality types (Hyldegård, 2006b), or information searching skills (Eskola, 2005). Finally, the dissertation did not focus on the more technical aspects of collaborative information seeking, especially those that deal in greater detail with collaborative software tools. My research focus was to understand collaborative information behavior as primarily a human endeavor.

I work at the university at which the research was conducted; this has been an advantage for me as a researcher to be familiar with context of the engineering program and the design courses but this has limited me with the selection of data collection method as I could not use observational methods because my presence with students while they see and use and information would be deceptive to the nature of my work at the university. However, I was not involved in the course under investigation during the two years of research data collection, but I perceive a limitation to this research that some survey respondents and interviewees have already known me during their first year engineering design course and that might have affected some student's answers to my questions regarding their actual experience in information seeking, searching, and use.

Finally, the research data constituted self-reported data representing students` perceptions as provided through their responses to the survey and during the interviews. Meanwhile, the project deliverables in Study 1 only represented the experiences that students have reported as course requirements and do not necessarily represent all of their information related activities and interactions during their projects, especially given that students were not provided with a definition of what was meant by collaboration compared to team working.

9.9 Recommendations for future work

I have an interest to further investigate the dimensions of students' collaborative information behavior, particularly collaborative information synthesis, which is the heart of the design process. I am interested in how students take large amounts of information and turn it into new information objects and new knowledge as they proceed with their projects.

I would also like to continue my research in the area of student perception, specifically the variation in perceived task complexity during the execution of their projects. I want to examine these variations within groups to see how differences in perceived task complexity among group members affect their collaborative information behavior.

I am also interested in how the activities of collaborative information behavior can be supported with particular software tools and how these tools could improve collaborative grounding by enhancing communicability, information sharing and collaborative information synthesis among group members.

I plan to continue this research in the next year by testing my findings in a different engineering design course. This time I will observe students enrolled in a course taken during the first year of their engineering program, one considered a cornerstone of engineering design. I want to examine the collaborative information behavior of first-year engineering students and compare it to that of senior engineering students, as presented in this dissertation. Another research I plan to pursue in the near future is to test the research findings in another senior disciplinary engineering design course, one in which group members belong to the same engineering department. The course under investigation for this dissertation was a multidisciplinary course in which students came from different engineering departments. Comparing collaborative information behavior in the two groupings will broaden and deepen my understanding of the phenomenon.

I do recommend that other researchers in information science test and investigate my research results, doing so in group-based learning environments in other disciplines, to compare my findings into students' collaborative information behavior with those in different educational domains.

Concluding, this dissertation provides evidence in support of more research in the field of collaborative information behavior in particular contexts. I hope that my contribution encourages more researchers in the field of information science to become engaged in this area of inquiry.

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11.APPENDICES

11.1 Appendix A: Web-based survey for Study 1

The following pages contain the web-based forms used in Study 1 in the academic year 2009/2010:

- Invitation letter to students for the web-based survey.
- Letter of information for the web-based survey.
- The survey questions.
- Letter of information for the use of students' deliverables.
- Consent form for the use of students' deliverables.

Invitation letter to students to participate the research study

Dear Student,

The purpose of this survey is to gain insight into the ways students collaboratively explore and use information resources for their senior design project. It is part of a research study to understand students' experience in using information and then develop solutions and services that will support students in the discovery of information while they work on their projects. Participation in this survey is completely voluntary.

The survey has two objectives to:

1. Capture information about how students collaboratively search for information for their capstone engineering design project,
2. Understand the way in which the project task affects students' information-related activities.

All students registered in (ENG495: Multidisciplinary Design Project) are invited to participate in this survey. It contains a number of multiple choice and open-ended questions that will take approximately 15 minutes to complete and the student may choose to skip any questions that she/he does not wish to answer. Individual student responses will remain confidential and will not affect the course grade or project evaluation.

As students participated in a project group, the survey participants will be asked to provide the project number so that I can match your responses to the responses of other students in the same group. Please note that data will only be used in aggregate. No individual responses will be identified and all identifying information will be removed from the aggregated data. Your instructor will not know whether you participated in this survey or not.

Should you have any questions, concerns or complaints regarding the survey please do not hesitate to contact Nasser Saleh, Integrated Learning Librarian, at Queen's University Engineering and Science Library, Kingston, ON K7L 3N6, or by phone at 613-533-6848 E-mail: nasser.saleh@queensu.ca Alternatively, you may contact the General Research Ethics Board at Room 301, Fleming-Jemmett, Email: chair.GREB@queensu.ca, Phone: 533-6081

I would like to take the opportunity to thank you for your time and consideration.

Sincerely,
Nasser Saleh

If you voluntarily accept to participate in this survey, please click at the survey link "link to the survey".

Letter of information for the Web-based Survey

LETTER OF INFORMATION

This research study is being conducted by Nasser Saleh, Integrated Learning Librarian at Queen's University in Kingston, Ontario, Canada.

The study will examine the effect of the project task on information-related activities for a group of students in a senior engineering design course. You will be asked to fill in the following survey asking for items such as your conceptions of the project and its complexity, and how you identified your information needs and searched for information for your project. It will take you about 20 minutes to complete

Participation is completely voluntary. You are free to withdraw at any time for whatever reason without penalty by just exiting the survey before the end. You are not obliged to answer any questions that you find objectionable. You will not be identified in any way if the results are published and nothing will connect you to your responses. All data will be stored in a secure computer file accessible only to the researchers until published, at which point the files will be erased from the computer.

If you have any complaints, concerns, or questions about this research, please feel free to contact Nasser Saleh, email: Nasser.saleh@queensu.ca or Dr. Joan Stevenson, Chair of the General Research Ethics Board, email: chair.GREB@queensu.ca

Thank you again for your participation,

Nasser Saleh

If you consent to participate in this study, click "Continue." Otherwise, you may exit the survey.

Survey questions for Study 1

Information About Your Project

Questions 1 - 2

Please provide the following information:

Project number:

Your department:

Questions 3 - 7

Please indicate your level of agreement with the following statements:

	Strongly agree 5	Moderately agree 4	Neither agree nor disagree 3	Moderately disagree 2	Strongly disagree 1
I had an interest in the project topic before I was assigned to it.	○	○	○	○	○
At the beginning of the project, I felt that I had prior knowledge about the project topic.	○	○	○	○	○
At the beginning of the project, I felt that the project topic was clear to me and I could easily find the needed background information.	○	○	○	○	○
Finding relevant information for my project has been an easy process.	○	○	○	○	○
Finding relevant information for my project improved with my understanding of the project scope.	○	○	○	○	○

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Information Resources for the Project

Question 8

Please indicate your level of agreement with the following statement:

The nature of my project required me to look for relevant information from many different sources.

- ○ Strongly agree
- ○ Moderately agree
- ○ Neither agree nor disagree
- ○ Moderately disagree
- ○ Strongly disagree

Question 9

What different information resources did you use for your project? (Check all that apply)

- ☐ Books
- ☐ Handbooks and manuals
- ☐ Technical reports
- ☐ Journal articles
- ☐ Standards and codes
- ☐ Patents
- ☐ Government reports
- ☐ Statistics
- ☐ Company information and catalogues
- ☐ Business reports
- ☐ Laws and by-laws
- ☐ Data and/or surveys
- ☐ Other (please specify)

Question 10

What types of information resources did you use for this project? (Check all that apply)

- ☐ Print
- ☐ Electronic
- ☐ Multimedia
- ☐ Other (please specify)

Question 11

For this project, did you use information that you got from other people?

- ○ Yes (please explain)
- ○ No

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Question 13

Please indicate your level of agreement with the following statement:

Finding and using information for my project was an ongoing activity.

- ○ Strongly agree
- ○ Moderately agree
- ○ Neither agree nor disagree
- ○ Moderately disagree
- ○ Strongly disagree

Question 14

Can you describe a critical stage in your project when there was a high need for information? And what you did?

- ○ Yes (please explain)
- ○ No

Question 15

For this project, how did you look for information? (Check all that apply)

- ☐ Group
- ☐ Individually

Questions 16 - 20

Please indicate your level of agreement with the following:

We worked together in a group to look for information because . . .

	Strongly agree 5	Moderately agree 4	Neither agree nor disagree 3	Moderately disagree 2	Strongly disagree 1
It is a requirement for this course to work as a team	○	○	○	○	○
The information needed for the project is complex	○	○	○	○	○
It is easier to look for information as a group rather than as an individual	○	○	○	○	○
The needed information requires searching expertise that I do not have as an individual	○	○	○	○	○
The needed information was not available to any of us	○	○	○	○	○

Question 21

Are there any other factors that caused you to work together as a group to find information?

- ○ Yes (please explain)
- ○ No

Question 22

When you looked for information as a group, how often did you find the information that the group was seeking?

- ○ Always
- ○ Often
- ○ Occasionally
- ○ Rarely
- ○ Never

Question 24

What medium did you use when collaborating with your teammates to look for information? (Check all that apply)

- ☐ E-mail
- ☐ Face to face
- ☐ File sharing tools, e.g., Google Docs, Qshare, Drop Box (please specify)
- ☐ Instant messaging
- ☐ Telephone
- ☐ Social networking sites, e.g., Facebook, MySpace (please specify)
- ☐ Other (please specify)

Question 25

How did you share the found information among your group?

Question 26

Did your project group ask for help in finding information when it could not find what it was looking for?

- ○ Yes
- ○ No
- ○ Sometimes

Question 27

Who did you contact for help? (Check all that apply)

- ☐ Teaching assistant/project manager
- ☐ Course instructor/faculty sponsor
- ☐ The project client representative
- ☐ Last year's students who worked on a similar project
- ☐ Librarian
- ☐ Other library service (e.g., e-mail, help desk)
- ☐ Other people at Queen's (please specify)
- ☐ Other people outside Queen's (please specify)

Question 28

How would you describe your style of looking for information as an **individual** for this project?

Question 29

How would you describe the group style of looking for information as a **group** for this project?

Question 30

When you were searching for information on your project as a group, what did you do to make it an easy and enjoyable process?

Question 31

When you were searching for information in your project as a group, what aspects affected your performance?

Question 32

During your group experience looking for information for your project, can you describe some of the advantages you felt about working as a group?

Question 33

During your group experience searching for information for your project, can you describe some of the challenges you faced?

Press “Submit” to end the survey.

[A new window appears]

Thanks for your participation in the survey.

The study would benefit from the analysis of the documents you submitted as deliverables for this course. The analysis of documents will be performed during the next year and all of the identifying information will be removed from the documents.

If you agree to the use of your project’s documents as secondary data source for this study, click “Continue” Otherwise, you may click “Exit” to exit the survey.

Letter of information for the use of students' deliverables

LETTER OF INFORMATION

This research study is being conducted by Nasser Saleh, Integrated Learning Librarian at Queen's University in Kingston, Ontario, Canada. It will examine the effect of the project task on information-related activities for a group of students in a senior engineering design course

What is this study about? The purpose of this research is to understand the impact of project tasks on the information behavior of students in a group-based engineering design course: how do students define the information they need for their project and how do they search for it. I would like to collect your weekly memos, progress reports, and final report.

Is my participation voluntary? Yes. Although it will not possible to access a group's deliverables without the consent of all group members, it would be greatly appreciated if you can discuss participation in this study among your group.

What will happen to our reports and memos? I will keep your reports and memos confidential. Only the researcher will have access to this information in a password-protected computer. The results may be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. Should you be interested, you are entitled to a copy of the findings.

What if I have concerns? In the event that you have any complaints, concerns, or questions about this research, please feel free to contact Nasser Saleh, email: Nasser.saleh@queensu.ca or Dr. Joan Stevenson, Chair of the General Research Ethics Board, email: chair.GREB@queensu.ca

Again, thank you. Your interest in participating in this research study is greatly appreciated.

If you agree to the use of your project's document as secondary data source for this study, click "**Continue**" Otherwise, you may "exit" the survey.

Consent form for the use of students' deliverables

Name	[text box]
Project #	[text box]

1- I have read the Letter of Information and have had any questions answered to my satisfaction.

2- I understand that I will be participating in the study called **Assessing the effect of the learning task on the collaborative information behavior of engineering students**. I understand that this means that I give consent to the researcher for using the group deliverable materials that were submitted during the course.

3- I understand that my participation in this study is voluntary and I understand that every effort will be made to maintain the confidentiality of the data now and in the future. Only the researcher will have access to this data that will carry no identifying information. The aggregated data may also be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. Should I be interested, I am entitled to a copy of the findings.

4- I am aware that if I have any questions, concerns, or complaints, I may contact In the event that you have any complaints, concerns, or questions about this research, please feel free to contact Nasser Saleh, email: Nasser.saleh@queensu.ca or Dr. Joan Stevenson, Chair of the General Research Ethics Board, email: chair.GREB@queensu.ca

I have read the above statements and freely consent to participate in this research:

If you consent to the use of your project's document as secondary data source for this study, click "**I give consent to the use the project's documents**" Otherwise, you may exit the survey.

11.2 Appendix B: Interviews for Study 2

The following pages contain the forms and interview protocols used in Study 2 in the academic year 2010/2011:

- Invitation letter to students to participate in interviews.
- Letter of information for the interview.
- Informed consent form from each participant.
- Interview questions for interviews 1, 2, and 3.

Invitation letter to students to participate in interviews

Dear Student,

The purpose of this survey is to gain insight into the ways students collaboratively explore and use information resources for their senior design project. It is part of a research study to understand students' experience in using information and then develop solutions and services that will support students in the discovery of information while they work on their projects. Participation in this survey is completely voluntary.

The survey has two objectives to:

3. Capture information about how students collaboratively search for information for their capstone engineering design project,
4. Understand the way in which the project task affects students' information-related activities.

All students registered in (ENG495: Multidisciplinary Design Project) are invited to participate in 4 interviews during the academic year. Each interview will last 60 minute. Individual student responses will remain confidential and will not affect the course grade or project evaluation. All identifying information will be removed from the interview data. Your instructor will not know whether you participated in this study or not.

Should you have any questions, concerns or complaints regarding the survey please do not hesitate to contact Nasser Saleh, Integrated Learning Librarian, at Queen's University Engineering and Science Library, Kingston, ON K7L 3N6, or by phone at 613-533-6848 E-mail: nasser.saleh@queensu.ca Alternatively, you may contact the General Research Ethics Board at Room 301, Fleming-Jemmett, Email: chair.GREB@queensu.ca, Phone: 533-6081

I would like to take the opportunity to thank you for your time and consideration.

Sincerely,
Nasser Saleh

If you voluntarily accept to participate in the study interviews, please email me "link to the email address".

Letter of information for interviews in Study 2

LETTER OF INFORMATION
(given to students before each interview)

This research study is being conducted by Nasser Saleh, Integrated Learning Librarian at Queen's University in Kingston, Ontario, Canada. It will examine the effect of the project task on information-related activities for a group of students in a senior engineering design course

What is this study about? The purpose of this research is to understand the impact of project tasks on the information behavior of students in a group-based engineering design course: how do students define the information they need for their project and how do they search for it. I would like to conduct 4 interviews during the academic year.

Is my participation voluntary? Yes. And the interviews will be with individual students, although it will not be possible to understand how a group search for information without the participation of all group members, it will be greatly appreciated if you can discuss participation in this study with among your group. Your signature in the consent form indicates that you understand that your participation is voluntary and that you are free to withdraw at any time.

What is the nature of the interview? Each participant will be invited to four interviews, the first interview will be in September, the second will be near the end of November, the third will be in February before the reading week and the final interview will be near the end of your project. The selection of time and location will be determined according to your schedule. Each interview will take no longer than 60 minutes. You are not obliged to answer any questions that you find objectionable or which make you feel uncomfortable.

What will happen to my answers? During the interview, the researcher plans to record the interview using a digital recorder to record the interview for the purpose of analysis. You will have the right to get a copy of the recorded interview at the end of the interview. The researcher will keep the recorded interviews confidential. Only the researcher will have access to this information in a password-protected computer. The results may be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. Should you be interested, you are entitled to a copy of the findings. Your agreement below indicates that you understand these provisions around confidentiality and anonymity.

Is there compensation for my time? You will be given a $15 Campus Bookstore gift certificate for each interview or a $75 gift certificate at the end of the four interviews.

What if I have concerns? In the event that you have any complaints, concerns, or questions about this research, please feel free to contact Nasser Saleh, email: Nasser.saleh@queensu.ca or Dr. Joan Stevenson, Chair of the General Research Ethics Board, email: chair.GREB@queensu.ca Again, thank you. Your interest in participating in this research study is greatly appreciated.

Informed consent form each interview in Study 2

Name (please print clearly): ____

Project # ____

1- I have read the Letter of Information and have had any questions answered to my satisfaction.

2- I understand that I will be participating in the study called **Assessing the effect of the learning task on the collaborative information behaviour of engineering students**. I understand that this means that I give consent to the researcher for conducting interviews with me for the purpose of this study.

3- I understand that my participation in this study is voluntary and I understand that every effort will be made to maintain the confidentiality of the data now and in the future. Only the researcher will have access to this data that will carry no identifying information. The aggregated data may also be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. Should I be interested, I am entitled to a copy of the findings.

4- I am aware that if I have any questions, concerns, or complaints, I may contact In the event that you have any complaints, concerns, or questions about this research, please feel free to contact Nasser Saleh, email: Nasser.saleh@queensu.ca or Dr. Joan Stevenson, Chair of the General Research Ethics Board, email: chair.GREB@queensu.ca

I have read the above statements and freely consent to participate in this interview:

Signature: ______________________________ Date: _______________________

Interview questions for interviews 1, 2, and 3

1. At this stage of your project, are you still interested in the project that you are assigned to?

2. At this stage of your project, how do you assess your understanding of your project topic, its objectives, and its constraints?

3. At this stage of your project, has your understanding of the project objectives changed or improved since our first interview? [interviews 2 and 3]

4. If your understanding of the project objectives has changed or improved, please give examples and explain what affects your understating of the project topic and objectives? [interviews 2 and 3]

5. At this stage of the project, how would you describe your style of looking for and using information for this project?

6. At this stage of your project, has your style of looking for and using information for this project has changed or improved since our first interview? [interviews 2 and 3]

7. If your style of looking for and using information for this project has changed or improved, please give examples and explain what affects your style towards information searching and use? [interviews 2 and 3]

8. At this stage of the project, how would you describe your style of looking for and using information for this project as **a group**?

9. At this stage of your project, has your style **(as a group**) of looking for and using information for this project changed or improved since our first interview? [interviews 2 and 3]

10. If your style (**as a group**) of looking for and using information for this project has changed or improved, please give examples and explain what affects your style towards information searching and use? [interviews 2 and 3]

11. Are there any other factors that caused you to work together as a group to find and use information?

12. Can you describe a critical stage (or more than one stage) in your project when there was a high need for information? And what you did?

13. For this project, did you use information that you got from other people? Please describe.

14. What other information do you feel that you still need for your project? And how you plan to get this information?

Appendix C: Interview 4 in Study 2

The following pages contain the forms and the interview protocol used in interview 4 in Study 2 in the academic year 2010/2011:

- Interview structure and questions.
- Data collection forms for student's reflections on their collaborative activities in information seeking and use.
- Constructing an Information horizons map.

11.3 Appendix C: Interview 4 structure and questions

Participant #____________________________

[This information to be shared with each participant before the interview]

1. The interview will take about 60 minutes
2. The structure of this interview will be different than the previous interviews as this will be more interactive
3. Feel free to think aloud while you answer the survey questions to explain why you chose these answers
4. The audio recorder will be on during the whole interview to capture your comments and then your answers to some questions.

[Students were asked to answer some of the questions that were given to students as a part of the survey in Study 1 in order to check the reliability of students' replies in the former academic year]

[The questions are given to students in papers with enough space in which students could provide any additional notes]

Questions 4 - 8

Please indicate your level of agreement with the following statements:

	Strongly agree 5	Moderately agree 4	Neither agree nor disagree 3	Moderately disagree 2	Strongly disagree 1
I had an interest in the project topic before I was assigned to it.	○	○	○	○	○
At the beginning of the project, I felt that I had prior knowledge about the project topic.	○	○	○	○	○
At the beginning of the project, I felt that the project topic was clear to me and I could easily find the needed background information.	○	○	○	○	○
Finding relevant information for my project has been an easy process.	○	○	○	○	○
Finding relevant information for my project improved with my understanding of the project scope.	○	○	○	○	○

Notes/ Comments:

Question 9

Please indicate your level of agreement with the following statement:

The nature of my project required me to look for relevant information from many different sources.

○ Strongly agree
○ Moderately agree
○ Neither agree nor disagree
○ Moderately disagree
○ Strongly disagree

Question 13

Please indicate your level of agreement with the following statement:

Finding and using information for my project was an ongoing activity.

- ○ Strongly agree
- ○ Moderately agree
- ○ Neither agree nor disagree
- ○ Moderately disagree
- ○ Strongly disagree

Question 15

For this project, how did you look for information? (Check all that apply)

- ☐ Group
- ☐ Individually

Questions 16 - 20

Please indicate your level of agreement with the following:

We worked together in a group to look for information because . . .

	Strongly agree 5	Moderately agree 4	Neither agree nor disagree 3	Moderately disagree 2	Strongly disagree 1
It is a requirement for this course to work as a team	○	○	○	○	○
The information needed for the project is complex	○	○	○	○	○
It is easier to look for information as a group rather than as an individual	○	○	○	○	○
The needed information requires searching expertise that I do not have as an individual	○	○	○	○	○
The needed information was not available to any of us	○	○	○	○	○

Notes/ Comments:

Question 10

What different information resources did you use for your project? (Check all that apply)

- ☐ Books
- ☐ Handbooks and manuals
- ☐ Technical reports
- ☐ Journal articles
- ☐ Standards and codes
- ☐ Patents
- ☐ Government reports
- ☐ Statistics
- ☐ Company information and catalogues
- ☐ Business reports
- ☐ Laws and by-laws
- ☐ Data and/or surveys
- ☐ Other (please specify)

You can add other sources that you used here:

Did you use informaiton from other people: Yes ☐ No ☐

If yes, can you list the people that you contacted for information here:

Students' reflections on their collaborative information behavior

[Each of the following tables was given to student in a separate page and instruction about the structure of the tables were explained to interviewees]

Can you approximate the percentage (%) of individual vs. group activities regarding the followings:

Identifying the needed information for the project	
Individually	**As a Group**

Searching for the needed information for the project	
Individually	**As a Group**

Evaluating the relevance of the found information for the project	
Individually	**As a Group**

Using the found information for the project	
Individually	**As a Group**

Follow up questions to the interviewee:

1. Can you describe to me why the perscentage has changed/ remained the same among the four tables?
2. What were the factors that imapcted groups activities from individual ones?

[This table was given to students after they filled the previous tables]

Can you approximate the percentage (%) of individual vs. group activities that are related to information search andf use in followings months during your project:

As a Group **Invidually**								
	September	October	November	December	January	February	March	April

Follow up questions to the interviewee:

1. Can you describe why the perscentage has changed/ remained the same among the four tables?
2. What were the factors that imapcted groups activities from individual ones?

Constructing an information horizons map

[This information was shared with every interviewee]

1. One other thing that we're trying in this study is that we're asking you if you could draw what we are referring to as information horizon or information horizon map: to put yourself on a piece of paper, and then draw in the people and resources that you typically accessed when you were seeking information for your project.
   5.
2. You may refer to the resources and people that you have used to get information that you have indicated previously during this interview.

3. And if you could indicate which ones you preferred to go first, or you could go to several simultaneously, or which ones you prefer – and talk about it as you're drawing it.

4. You can refer to the information sources and the people you have consulted for your project from previous questions while you construct your map in the attached sheet

Follow up questions:

[Participants were also encouraged to talk about and explain their drawing as they created it. Follow up questions encouraged participants to provide details about their information horizons]

1. When, or why, would you go to this particular resource after/before going to this other one?
2. Do any of these resources proactively provide you with information? Or suggest other information resources to you?
3. Previously, you mentioned xyz resource. Would you include them/it on your information horizon? Where? Or, why not?

11.4 Appendix D: Examples of students' deliverables

The following pages contain examples of students' deliverables in Study 1 in the academic year 2009/2010 [All identifying information were removed and pseudonyms are used for students' names]:

- Group memos
- Group project progress reports

Examples of group memos

WEEKLY TEAM MEMO

Group A
Date: Oct 10 2009
Time: 11:30 am
Location: ILC
Previous action items

- Research for industrial specifications
- Issues related to scaling and efficiency of the prototype
- Dimensional Analysis to be used as part of the modeling process

New Business

Item #1	Gather Background information on current Thermal Energy Systems
Discussion	The project time scale from now until December and what might go wrong.
Action Item:	All team members need to cross check with the gaunt chart and the progress schedule that has been given to the client, and work their tasks in order to avoid the inconvenience of time, setbacks if the theory does not work accordingly.
Responsible/Date:	All team members ☞ Ongoing ☞ Need to review the Gantt chart time and again

Item #2	Background review from Discussing with project supervisor (potential market)
Discussion	Fields associated with heat storage include, transportation of hot metals in industries, or materials of high thermal capacities, and mostly power plants might be the target market.
Action Item:	Gather more information on the possible application of the project, the environmental aspects related to heat storage and materials used.
Responsible/Date:	Sophie And Daniel ☞ Report regulations and codes in the next meeting, find ANSI codes for pressure and material handling

Item #3	Client Satisfaction
Discussion	How to deal with a client in order to meet the demands of the two parties. Mainly the communication of ideas and advice, as well as getting information from a client without misunderstanding.
Action Item:	Need to explore the market limits, how other companies convey their projects and always update the client according to the set time scale.
Responsible/Date:	All team members ☞ Every one need to find out ways of addressing issues to the client, and Paul will make sure he keeps the client informed of the changes made.

Item #4	Efficiency and Scale Up
Discussion	Boundaries within which to define the prototype efficiency, and consideration of material properties when scaling down the design.
Action Item:	Use of dimensional Analysis to model the system and its efficiency, as well as taking into consideration the economics (such as the market value of the efficiency).
Responsible/Date:	Peter and Paul ☞ Need to estimate the required efficiency of the prototype and the rest of the team has to help scaling down with the material estimates.

Budget Update:

Category	*Current Expenditures*	*Total Expenditures*
Components	$0	$0
Services	$0	$0
Equipment	$0	$0
Travel	$116.89	$116.89
Grand Totals	$116.89	$116.89

A brief description of expenditures in each category for the week

Agenda for Next Meeting

- Report on the market Analysis
- Discussion of the codes and Standards as well as the limitations that are being faced by the group
- Review of the communication with the client, as well as conducting another conference call with the client

WEEKLY TEAM MEMO

Group A
Date: November 12 2009
Time: 1:30 pm
Location: ILC 325
Previous action items

- Tank Design
- Insulation Material
- Valve selection
- Measurement

New Business

Item #1	Create Heat Transfer model
Discussion	Now that the system has been designed, engineering models must be created in order to quantify important engineering properties of the system. In order to quantify insulation requirements, a model of the heat transfer from the fluid to the environment must be created.
Action Item:	A model will be created that uses engineering calculations to quantify heat losses to the environment from 12 L of fluid in a 21.5 L propane tank. This model will find the heat flux across the insulation boundary as well as the thickness of insulation required. To check the validity of the model, two separate models will be created.
Responsible/Date:	Peter Will create model and send it to the group by Sunday, November 15 ☞ Will present findings to at least one group member on Monday, November 16, 2009 or Tuesday, November 17 Sophie ☞ Will create model and send it to the group by Sunday, November 15 ☞ Will present findings during team meeting on Thursday, November 19

Item #2	Computational Fluid Dynamics model
Discussion	A model must be used to understand heat transfer and fluid dynamics within the system as the prototype is filled and fluid is discharged. As well, internal heat transfer must be found while the fluid is stored.
Action Item:	A CFD model will be created using Fluent. The model will show heat transfer within and outside the prototype. If possible, it will also show transient conduction within the prototype.
Responsible/Date:	Paul ☞ Model will be created and graphs presented to the group on Thursday, November 26

Item #3	Solid Edge model of the prototype
Discussion	A visual model of the prototype is required in order to size parts and create representations of the model. The program that can perform both of these functions is Solid Edge, where 3-Dimensional objects can be properly modeled.
Action Item:	A Solid Edge model of the prototype will be created in order to understand interactions between parts, as well as ensure that no part of the system has been missed. The model will be used to create visual representations of the prototype.
Responsible/Date:	Daniel ☞ Daniel will build the Solid Edge model and have output graphics by Thursday, November 26

Item #4	Dimensional Analysis
Discussion	The ability to scale results of the system is very important to this project, in that the prototype is only relevant insofar as the output data can be used by the client. Therefore, an understanding of the scale-up requirements for the prototype is needed.
Action Item:	An analysis of the scaling considerations for the prototype from a 1 kWh system to a 50 MWe x 8 hour system will be created.
Responsible/Date:	Paul and Peter ☞ Dimensional analysis will be performed and results summarized and presented to group by Monday, November 23

Item #5	Pipe losses
Discussion	A quantitative analysis of energy losses in the pipes leading to and from the system is required. Specifically, filling times and pumping requirements must be found.
Action Item:	An excel model will be created that shows the relationship between pipe diameter (for all three of the pipes in the model), filling time, and pumping energy required.
Responsible/Date:	Sophie ☞ Model will be sent to the group by Monday, November 23

Budget Update:

Category	*Current Expenditures*	*Total Expenditures*
Components	$0	$0
Services	$0	$0
Equipment	$0	$0
Travel	$0	$116.89
Grand Totals	$0	**$**116.89

We will likely incur expenditures when we give our final presentation to the client in the second week of December.

Agenda for Next Meeting

- Discuss and create framework for final report
- Discuss and create 2 presentations: one to fill course requirements, and one that will actually be given to the client
- Updates on model progress and discuss space and safety requirements

Weekly Team Memo

Group A
Date: Tuesday 26 Jan
Time: 7:30 pm
Location: ILC
Previous action items

- List of materials
- Insulation of the system
- Piping and Instrumentation
- Detailed Working drawing

New Business

Item #1	Cost analysis and financial flow until present time
Discussion	Updating the teams budget and current spending
Action Item:	Daniel, as finance person, has to update the finances and send them to Sophie. Add the cost of the 2 propane tanks, and also fill out a reimbursement form for the admin assistant.
Responsible/Date:	Daniel ☞ Ongoing ☞ Need to cross check costs with the gaunt chart time and tasks

Item #2	Ordering the hot oil pump
Discussion	Specs for the pump have been used to find the pump, and a 34 HL model pump, with flow capacity ranging from 0-365 m3/hr, a pressure rating of 0-14 bars, viscosity range of 0.1 to 1McSt and a temperature range of -50 to 345 C, was found to fit the prototype, but its cost was not revealed by the company website.
Action Item:	The gas pumps at Princess Auto (although not rated at such high temperatures) will have to be considered. - Call Lavac Supplies or Brofasco, the two companies recommended to us by a Princess Auto salesman. - Asphalt pumps has to be contacted for pricing and quotations
Responsible/Date:	Paul ☞ Will follow up on the quotation of the pump and report to the group on Feb 2nd.

Item #3	Pipe threading and measurement
Discussion	Fitting the pipes to compose the entire arrangement has been looked at, and we are considering doing threading for smaller pipes and find out if the technique will work out fine.
Action Item:	The main piping from the storage tank to the sink tank will be used for sampling the technique.
Responsible/Date:	Sophie and Peter ☞ Will check with the machine shop, and proceed with the threading on week 4. ☞ Sophie has to find the right scale to get sensitive weight readings (around 0.05 Kg), with a maximum of 8kg.

Item #4	Workspace allocation
Discussion	All the work that is to be done at the machine shop is limited to be done this week because of the bookings.
Action Item:	The pipes will be threaded and, more hours have to be allocated for working on the project.
Responsible/Date:	All team members ☞ Have to be at the machine shop with the right gear, at the right time

Budget Update:

Category	*Current Expenditures*	*Total Expenditures*
Components		
2 propane tanks	$58.35	$58.35
Services		
	$81.45	$139.80
Equipment		
	$0	$0
Travel	$116.89	$256.69
Grand Totals		**$**256.69

A brief description of expenditures in each category for the week

Agenda for Next Meeting
Broken down by timing (from Gantt chart):
- Visit the machine shop. Ask about:
1) Attaching something to the small propane tank
2) Cutting- open the large tank
3) Advice on what kind of pump might work?
- Find a pump
- Find working valves
- Buy valves, first pieces of pipe, T-junction
- Get thermocouples. I've attached a presentation about making them, and emailed the prof in charge of MECH 215 about making them with the MECH 215 class. Does anyone know who the replacement for this professor is? We need someone with measurement expertise to let us know how to set up the DAS.
- Buy a scale and finish insulation purchase order - I'm working on a second quote, and will fill out the form and order this

Examples of project progress reports

THERMAL ENERGY STORAGE PROGRESS REPORT

Group A

Date: October 8, 2009
Time: 8:30 am
Location: ILC 229
Prepared by: Daniel, Peter, Sophie, Paul

Issues Resolved

Issue	**Resolution**
Uncertainty about IP and NDAs	The client will have control over any IP generated through this project
Unknown industry benchmarks	Used previous solar thermal storage facilities to find reasonable benchmarks for large-scale designs
Scope was not fully defined	Wrote work scope document submitted to the client on 8 October. Scope has been narrowed to exclude chemical reactions catalyzed by thermal energy
Lack of expertise concerning solar thermal power	Worked to prepare background research covered in Brief #1. Created a problem definition statement as well as an overview of current and future research to be conducted.

New Issues

Issue	Description	Action plan
Difficulty obtaining exact specifications	Outside of some material supplied to the team by the client, most industry knowledge on this subject is not available to students	Will continue internet research, specifically in academic papers where calculations and data may be more readily available. Will also consult Queen's Library website
Scaling issues	Estimating efficiency of the project will be difficult because temperature change is related to the surface area to volume ratio, which is much higher for small projects (~6) than commercial systems (~0.25)	Have made engineering assumptions for the time being. Will complete dimensional analysis for more accurate answer, then create computer model for interim report.
Efficiency definition	Efficiency of this system is hard to define because of the boundary problems inherit to power systems design	Will use thermal energy storage textbook to create list of possible alternatives, then choose the alternative best suited for a small prototype
Market analysis	Because the market for this product is very small, it is difficult to conduct a numerical market survey. In addition, the field of thermal energy storage is relatively new and as such utility expectations may be undefined	Will conduct qualitative surveys of industry to determine requirements

Critical Path

- At this point the team feels that the project is on track and the issues we have found do not impact the critical path of our project, especially since we are addressing them early.
- The largest problem we are currently dealing with is the difficulty finding information about storage facilities described in new issues above.
- A possible barrier in the future will be the relative novelty of constructing a functioning prototype. As such, the team will endeavor to order parts and supplies in December 2009 rather than during February 2010 so that there is time to deal with design flaws.

THERMAL ENERGY STORAGE PROGRESS REPORT

Group A

Date: November 18, 2009
Time: 6:30 pm
Location: ILC 109

Issues Resolved

Issue	Resolution
Design Selection	A prototype has been selected by breaking the design into components and evaluating each component individually. A detailed account of this process can be found in Brief 4.
Design Thermal Flux	An excel model of the expected thermal flux through the prototype walls has been created. This is a resolved portion of the previously mentioned design modeling issue.

New/ongoing Issues

Issue	Description	Action plan
Detailed Design	Although the prototype design has been chosen on a component basis, dimensions and specifics on component interactions still need to be detailed.	Daniel is in the process of creating a Solid Edge model of the design and all of its composite parts. This design will guide materials sourcing efforts.
Design Fluid Modeling	Determining the flow properties in the tank as well as through the piping is important to the understanding of this prototype and potentially how it compares to a $50MW_e$ system.	Paul is using a computational fluid dynamics program to assess the fluid properties throughout the proposed system.
Safety Approval	Queen's University has a very intensive safety approval process for any design on campus, and the group must be proactive in engaging the EH&S department.	This is an ongoing issue that will need to be considered throughout the rest of the project with the aid of Queen's EH&S as well as the course instructor. Peter will act as the team's primary contact with Queen's EH&S.
Space for Design	Engineering design and storage space is needed for the design. Because the heaters will require a significant power draw, there must also be an electrical conduit in the design space. On Wednesday the team was informed that there is a potential site in the same lab as the heat pipe team, however nothing has been confirmed.	The team will continue to pursue any leads until a project space has been confirmed.
Construction Options	At this point the team is still unconfident in how the best way to construct the prototype is, and if we require aid from a machine shop, what they will require from us.	The team will contact the shop in the McLaughlin Hall to learn the shop's capabilities, draw from the experience of the foremen and learn what they would require from the team if we do need their help.

Issue	Description	Action plan
Scaling	There are many foreseen differences between a prototype's functionality and that of a full scale system. Understanding this relationship is of key importance in maximizing the utility of the prototype.	Peter is conducting a dimensional analysis to quantify the differences.
Pipe Loses	The prototype's design relies on gravity as the driving force. In order to achieve a steady output, the team will need to assess the pipe losses.	Sophie is conducting an analysis of the pipe losses in the proposed system.

Critical Path

- At this point the team feels the project is on track. Although there have been issues that threatened the critical path, it appears that they are all being resolved early enough to not slow the team.
- The team has still not contacted specific suppliers about products; however the chosen materials at this point are standard. Steel piping, off the shelf container and high temperature wool insulation.

THERMAL ENERGY STORAGE PROGRESS REPORT

Group A

Date: January 28, 2010
Time: 8:30 am
Location: ILC Design Studio

Issues Resolved

- Circulation Heater is ordered
- Heat Transfer Oil has been delivered
- 'Pig' oil absorbent, source located
- Propane tank valve removed
- Piping method determined – steel threaded

New Issues

- Locating a suitable pump
- Determining how to best attach a valve point to the propane tank

Critical Path

- The main issue at the moment is securing a suitable pump. Initially it was assumed that the client would provide a pump suitable for the application. However this has been altered in recent weeks. The client will pay for a pump however it is essential that the team find one which is suitable and identify it to the client. The difficulty in locating a pump is due to the fact that high temperature pumps are not very common and high temperature low flow pumps are even less common. The idea flow rate for the system is lower than what so far has been found.
- Also critical is preparing the propane tanks for use. One tank has had the valve removed. The other tank needs to have the valve removed and prepped for attachment of another valve. The method for attachment is undetermined at the moment. There is a threaded flange at the top of the tank which the team may be able to use to attach a short length of pipe.
- The lead time on the pump and heater are likely to be the determining steps on our critical path.