The Pennsylvania State University

The Graduate School

College of Education

SCAFFOLDING STUDENTS' PROBLEM-SOLVING PROCESSES
ON AN ILL-STRUCTURED TASK
USING QUESTION PROMPTS AND PEER INTERACTIONS

A Thesis in

Instructional Systems

by

Xun Ge

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 2001

We approve the thesis of Xun Ge.

Date of Signature

Susan M. Land
Assistant Professor of Education
Thesis Adviser
Chair of Committee

Kyle L. Peck
Professor of Education

Steven B. Sawyer
Associate Professor of Information Sciences and Technology

Edgar P. Yoder
Professor of Agricultural and Extension Education

Alison A. Carr-Chellman
Associate Professor of Education
In Charge of Graduate Program in Instructional Systems

ABSTRACT

Complex, real-world problem solving is an essential component of learning. Based on previous research (e. g., Bransford, Brown, & Cocking, 2000; Bransford & Stein, 1993; Jonassen, 1997), engaging students in complex, ill-structured problem-solving tasks not only help them to apply knowledge in real-world situations, but also facilitate knowledge transfer. However, previous research has also pointed to students' deficiencies in problem-solving skills, for instance, failing to apply knowledge learned in one context to another, especially when solving problems on ill-structured tasks (Gick and Holyoak, 1980; Gick, 1986). While students' difficulties in problem solving are partly attributed to misconceptions or shallow conceptions of domain knowledge (P. J. Feltovich, Spiro, Coulson, and J. Feltovich, 1996), they are, to a greater extent, due to a lack of metacognitive knowledge (Brown, 1987).

Therefore, it follows that supports should be provided to students during problem solving in cognition and metacognition through various scaffolding strategies, such as coaching through prompts (King, 1992; Scardamalia, Bereiter, & Steinbach, 1984; Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989; Schoenfeld, 1985), modeling through reciprocal teaching or peer-regulated learning (e.g., Palincsar & Brown, 1984), and guiding students to self-generate questions (King, 1991a). These strategies were found to be effective in fostering comprehension, monitoring cognitive thinking, and facilitating general problem solving (e.g., Palincsar & Brown, 1984; Scardamalia et al., 1989).

The purpose of the study was to investigate the effects of question prompts and peer interactions in scaffolding college students' problem-solving process on an ill-structured task. Although these two strategies had been studied in previous research, few studies were focused on their use to support students' problem solving on ill-structured tasks. Hence, this study was focused on the use of question prompts and peer interactions to support college students' problem-solving processes on an ill-structured task, especially in the processes of *problem representation*, *solution*, *justifications*, and *monitoring and evaluation*.

A mixed study design, combining an experimental study with a comparative, multiple-case study, was applied. The experimental study was conducted to measure the students' problem-solving *outcomes* on an ill-structured task, as demonstrated by the four problem-solving processes, in four different treatment conditions: individuals with question prompts (IQ), individuals without question prompts (IC), peers with question prompts (PQ), and peers without question prompts (PC). The comparative, multiple-case study, through observation, interviews, and think-aloud protocols, was carried out to gain insights into students' problem-solving *processes*, especially their cognition and metacognition, as influenced by question prompts or peer interactions.

115 college students participated in the experimental study, and 19 of them participated in the comparative, multiple-case study. The result of the experimental study showed that the students working with peers and question prompts (PQ) significantly outperformed the other treatment groups, especially the students without question prompts (either working individually or with peers), in all the four problem-solving processes. At the same time, the students working individually and with question

prompts, though they did less well than the PQ group in problem representation, significantly outperformed the PC and IC groups in problem representation, justifications, and monitoring and evaluation. There were no significant differences between the PC and the IC groups in any of the four problem-solving processes. It appeared that question prompts were a superior scaffolding strategy over peer interactions in supporting students' problem solving on an ill-structured task. However, the comparative, multiple case study revealed the complexity of the peer interaction context and the relationship between question prompts and peer interactions. While this study confirmed the findings of previous research on the effectiveness of question prompts in facilitating students' cognition and metacognition, it also showed the benefits of peer interactions, which were contingent upon group members' active and productive engagement in peer interactions, that is, questioning, explaining, elaborating and providing feedback among peers. The study implied that, in order for students to gain full benefits from peer interactions, the peer interaction process itself need to be scaffolded, especially when students were novice learners in problem solving; and question prompts, through expert modeling, may serve to facilitate this process.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Great is the Lord and most worthy of praise! He is my rock, comfort, and source of energy and wisdom. Praise be to the Lord who sustained me through countless days and nights during this research process and helped me understand who I am - my strengths and my weaknesses. Praise be to the Lord for his rich blessings through the abundant assistance I have received from many people, to whom I am deeply indebted.

My heartfelt thanks go to my thesis advisor and mentor, Dr. Susan Land, for her warm personality, continual encouragement, support, and perseverance in guiding me through the entire research and dissertation-writing process. Dr. Land, your magic calendar has taught me how to plan and push ahead to achieve my goals.

Special thanks also go to my committee members. Dr. Peck, thanks for your input and feedback on the scoring rubrics and many helpful insights to my dissertation draft. Dr. Yoder, thanks for your patience and assistance in guiding me through the statistical analysis, and for the selflessness and the passion you pour into teaching and advisement. Dr. Sawyer, the past two years I worked under your guidance were some of the most enjoyable times during my graduate studies at the Penn State; I enjoyed the IST 110 labs we developed together, through which I derived inspiration for this thesis. Thanks for helping me refine the research design and develop materials and instruments for this study. Dr. Barbara Grabowski, my former thesis advisor, I can never forget your advisement and help in developing research ideas for this thesis. Thanks for informing me of "mountains and valleys" ahead on my research journey; now I have seen, traversed and explored some of the "mountains and valleys", the scenery was breathtaking, and the experience was thrilling!

My gratitude is due to the faculty in School of Information Sciences and Technology (IST) for their support by allowing me to use the IST 110 classes, recruiting their students, and providing valuable suggestions to this study. The following people are especially worth mentioning: Dr. Gerry Santoro, who shared his expertise and contributed greatly to the development of the materials used for this study; Dr. Amanda Spink, who let me use her class for my study sessions; Seda Ozmutlu, without whose assistance, the successful implementation of the study would have been impossible; Dr. Michael McNeese, who was always there to provide intellectual and morale support, and whose sharing of knowledge in problem solving has provided insightful perspective to this study; and Dr. Larry Spence, who also provided great help in developing materials for the study, and who gladly carried out conversations with me on problem-based learning, which have helped to shape this study.

I am grateful to my colleagues in Instructional Systems for their friendship over the past few years and the immense help during my research process. Thanks to Wei-Fan Chen, Wenyi Ho, Ting-Ling Lai, Ikseon Choi, and Ke Zhang for their valuable feedback and suggestions to my research, as well as various helps they provided, ranging from recruiting participants, videotaping to data rating.

My acknowledgement is also extended to the Alumni Society, College of Education for the Research Initiation Grant. The grant means a lot to me; it is not only a financial, but also a morale support!

I would also like to express my particular thanks to my pastors and friends at the Chinese Alliance Church and the International Christian Fellowship at the Penn State, whose prayers, fellowship, and support have played an essential part in my spiritual life.

Last but not least, my affectionate thanks go to my family for their unfailing love, continual understanding, and selfless support: Zhenhua Ge (father), Shiyi Chen (mother), Jie Ge (sister), Dan Ge (sister), Keqin Wang (husband) and En Wang (son). Dad, thanks for starting my English lessons at home when I was still a little girl, and at a time when China was still closed to the outside world; and thanks for encouraging me to study for Ph. D., a dream that you have wanted to, but have not had a chance to fulfil. Mom, your diligence and perseverance, as I remembered since my childhood, has made a great impact in my life wherever I go and whatever I do. Dan, thanks for your financial support that have pulled me through the most difficult time of my first two years in the States. Jie, though at a distance, your help was endless. Keqin, thanks for accompanying me through the journey and sharing my load, with sacrificial support, patience, encouragement, and understanding. En, you have been a source of inspiration, delight and help, and I owe you for your help with the video transcription!

My thank-you list could go on and on if I had more space. Lord, may you bless all those people who have helped me!

CHAPTER 1

INTRODUCTION

The importance of complex, real-world problem solving has been increasingly emphasized in education (e.g., Bransford, Brown, & Cocking, 2000; Bransford, Sherwood, & Sturdevant, 1987; Bransford & Stein, 1993; Jonassen, 1997; Schmidt, 1989). This emphasis is reflected in National Science Education Standards (1996), which state that students must be educated to experience the richness and excitement of knowledge about the natural world, to solve difficult real-world problems, and to use appropriate scientific processes and principles in making personal decisions. In higher education, more and more undergraduate and graduate programs have initiated a problem-based learning approach for their curricula, aimed at developing students' problem-solving skills to deal with complex, authentic problems (e.g., Barrows, 1996; Stinson & Milter, 1996).

A complex, real-world problem is often ill-structured, which differs from a well-structured problem in many ways. A well-structured problem consists of a well-defined initial state, a known goal state, and constrained set of logical operators (Greeno, 1978). Many mathematics- or physics- related, practice-type problems, such as those found in textbooks, are examples of well-structured problems. With an ill-structured problem, however, one or more aspects of the problem situation are not well defined, the problem descriptions are not clear, and the information needed to solve it is not contained in the problem statement (Chi & Glaser, 1985). There may be multiple solutions, solution paths, or no solution at all (Kitchner, 1983). For example, for a real-world business case, the problem descriptions may be vague, and the information needed to solve the problem, such as the contextual environment, organization culture and other potential factors, is not always clear. There may be several solutions to the problem, each having its strengths and limitations, which require justifications. By comparison, ill-structured problems are more complicated than well-structured problems, and thus are more open-ended and difficult to solve.

The rationale for complex, real-world problem solving is that it is an essential learning process for knowledge acquisition and transfer. Reviewing the research on expertise, Bransford et al. (2000) noted three key principles that help people develop expertise: (a) recognizing meaningful features and patterns, (b) organizing knowledge around core concepts or "big ideas", and (c) having a vast repertoire of knowledge that is relevant to their domain or discipline, which is "conditionalized" and can be retrieved for a specific task. Therefore, it is necessary to create learning environments for students to experience the kinds of problems and opportunities experts in various areas encounter and the knowledge that these experts use as tools (The Cognition and Technology Group at Vanderbilt [CTGV], 1990). Real-world problems provide "anchored instruction" (CTGV, 1990), which helps students to understand facts and concepts in the context of a conceptualized framework, to organize knowledge in ways that facilitate retrieval and application, and to transfer what has been learned from one context to another (Bransford et al., 2000). In addition, real-world problem solving allows students to acquire other important skills, such as generating hypotheses, employing inquiry strategies, formulating problems, evaluating information and making appropriate decisions (Schmidt, 1989).

The perceived value of problem solving in learning and instruction has driven many educators and researchers to study the nature of problem solving as well as instructional strategies for developing students' problem-solving skills. Similarly, this study is also driven by the demand to explore effective instructional strategies and to improve students' problem-solving skills, especially of complex, ill-structured tasks.

Problem Statement

Although problem solving has been recognized as an important learning component, research on problem solving indicates that learners often fail to apply what they have learned to real-world situations, even though they are able to retrieve knowledge from school-based contexts (Bransford et al., 1987). Gick and Holyoak (1980) found that students failed to apply knowledge learned in one context to another without providing explicit prompts or hints. P. J. Feltovich, Spiro, Coulson, and J. Feltovich (1996) noted two deficiencies associated with learning in complex and ill-structured domains: (a) the problem of knowledge transfer and (b) the problem of prevalent misconceptions. First, the more complex and ill-structured the domain, the greater the difficulty people have in applying their knowledge to novel situations (Feltovich, Coulson, Spiro, & Dawson-Saunders, 1992; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). Second, achieving sound and accurate understanding of subject matter in ill-structured domains is difficult for learners (Coulson, Feltovich, & Spiro, 1989; Feltovich, Spiro, & Coulson, 1989).

Students' difficulty in knowledge transfer is also due to their lack of metacognitive strategies. A study of history experts by Wineburg (1998) showed that an important characteristic involved in ill-structured problem solving is "metacognition" -- the ability to monitor one's current level of understanding and decide when it is not adequate (Bransford et al., 2000). Bruning (1994) commented that many college students were surprisingly unaware of their thinking and learning processes, and thus were unable to direct their learning in productive ways.

Therefore, merely exposing students to ill-structured problems does not necessarily mean that students will effectively engage in problem solving. It is necessary to provide guidance to students when necessary, such as "pay attention to students' interpretations" when students are constructing new knowledge based on their previous knowledge in ill-structured problem solving tasks (Bransford et al., 2000, p. 11). It is also important to improve student's knowledge transfer by helping them become more aware of themselves as learners who actively monitor their learning strategies and resources and assess their readiness for particular tests and performance (Bransford et al, 2000).

In other words, guidance should be provided to support both cognition and metacognition. Cognition refers to domain-specific knowledge and strategies for information and problem manipulation (Salomon, Globerson, & Guterman, 1989; Schraw, 1998), and metacognition includes knowledge of cognition and regulation of cognition (Cross & Paris, 1988), such as planning, evaluation and monitoring (Jacobs & Paris, 1987). The two constructs are interrelated. Although metacognitive knowledge may be able to compensate for absence of relevant domain knowledge, its development may also depend on having some relevant knowledge of the domain (Garner & Alexander, 1989).

The Role of "Scaffolding" for Ill-Structured Problem Solving

Over the past decade, researchers (e.g., Palincsar & Brown, 1984; Wood, Bruner, & Ross, 1976) have investigated the role of "scaffolds", or temporary supports, to facilitate learner comprehension and reflection on complex tasks. In the studies of Palincsar and Brown (1984), Palincsar (1986), and Palincsar, Brown, and Martin (1987), scaffolds involved modeling and dialogue to enhance comprehension monitoring and strategy use. Scardamalia, Bereiter, and Steinbach (1984) provided coaching through question prompts, while King's studies (e.g., 1991a; 1992) modeled and guided students to self-generate questions. All these scaffolding strategies were shown to improve students' cognition by activating their schema, retrieving knowledge, and enhancing comprehension and metacognition by making their thinking explicit and guiding them to monitor their understanding.

Based on a problem-solving model for ill-structured domains by Voss and Post (1988), the ill-structured problem solving process involves (a) problem representation, (b) solution generation, and (c) evaluation, which has both cognitive and metacognitive requirements. It is argued that the instructional strategies aimed at scaffolding cognition and metacognition can also be applied to support students' problem-solving activities on an ill-structured task. Although most of the previous research on scaffolding has been focused on improving learner's comprehension, some research has been conducted to support students' problem solving by scaffolding their cognitive and metacognitive thinking (e.g., King, 1991a, 1992; Schoenfeld, 1985).

Scaffolding Problem Solving Using Question Prompts

Previous research has shown that questioning strategies helped students to focus attention on their learning process and to monitor their learning through elaboration on the question asked (Rosenshine, Meister, & Chapman, 1996; Wager & Mory, 1993). A review of studies on questioning strategies by Rosenshine et al. revealed that students who were provided with prompts made considerably greater gains in comprehension than did students in control groups. King (1994) showed that question prompts designed to access prior knowledge or experience were more effective in enhancing comprehension. Other studies showed that questioning strategies also helped students to monitor problem-solving performance of well-structured tasks. For example, Schoenfeld (1985) found that asking and answering metacognitive questions helped students to focus on the process of problem solving and consequently improved their performance. Two other studies by King (1991a, 1992) indicated that guided, student-generated questioning promoted students' critical thinking and problem-solving success by teaching them how to ask for and provide task-appropriate elaboration during problem solving. In sum, questioning strategies have been found to foster the following important functions: focusing attention, stimulating prior knowledge, enhancing comprehension, monitoring thinking and learning processes, and facilitating problem-solving processes. Another critical role that question prompts play in supporting problem solving is to elicit thoughtful responses such as explanations and inferences (King & Rosenshine, 1993) and to construct cogent arguments (Kitchner & King, 1981).

Scaffolding Ill-Structured Problem Solving Using Peer Interactions

In addition to question prompts, peer interaction is also been identified as a powerful strategy to scaffold problem solving, especially ill-defined tasks. Peer interaction refers to students who learn by interacting with each other, rather than only with the teacher (Webb, 1989b). According to Webb, peer interaction occurs within small groups of students who are given material to learn, or a problem or set of problems to solve. All students in the group are expected to master the material. Students are expected (and usually instructed) to help each other learn the material or solve the problem. Although students may have different abilities and background experiences, they are not given specific roles, and they are expected to master the material.

Central to the notion of peer interactions is Vygotsky's zone of proximal development, that is, "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (p. 86). Through social interactions, more highly-skilled learners or peers can provide modeling of higher-level thinking and more sophisticated ways of constructing arguments, understanding textual materials, and solving problems, and thus may collectively reach levels that none could have reached alone (Resnick & Klopfer, 1989).

Some empirical evidence supports the effectiveness of peer interactions in scaffolding cognitive and metacognitive thinking. For instance, Palincsar and Brown (1984) found that "reciprocal teaching" involving dialogue between the teacher and the student helped to foster comprehension and comprehension monitoring activities. In another study, Palincsar, Brown, Martin (1987) found that peer interaction resulted in equal gains in reading comprehension comparable to the interactions between the teacher and the students. The benefits of dialogue in reciprocal teaching lie in the following: (a) extensive modeling of the comprehension-fostering and comprehension-monitoring activities by the teacher; and (b) task requirements for students to ask and respond to questions, which made their thinking explicit. Webb's studies (Webb, 1982, 1989b) showed that when learners were required to give explanations and ask questions to each other, learning was enhanced. The process of explanation presumably requires learners to clarify concepts, reorganize thinking, and reconceptualize the material. Naturally, the elaboration process through peer interaction can assist students to define the goals and understand the nature of the problem. King's studies indicated that peer questioning engaged students in more explanation and inferences on problem solving performance and knowledge construction (King, 1991b; King & Rosenshine, 1993).

Another role that peer interaction plays is to support reflection through social discourse (Lin, Hmelo, Kinzer, & Secules, 1999). According to Lin et al., multiple perspectives and distributed expertise during peer interaction supports students' reflection and helps them notice new things that they might otherwise overlook. This helps to "engage the learner in considering each point of view and selecting the best one based on reasoning and evidence" (Jonassen, 1997, p. 86), and thus supports argument construction. Greene and Land's (2000) study indicated that peer interaction during open-ended learning was effective when group members offered suggestions, negotiated ideas, and shared their experiences. The attribute of reflective thinking in peer interaction leads to the conclusion that peer interaction can facilitate ill-structured problem solving in monitoring problem solving processes, assessing problem solutions, and constructing sound arguments.

Given those findings, peer interactions could scaffold students' problem solving by defining problems, constructing the problem space, and articulating contextual constraints. It also allows peers to negotiate meanings, share knowledge and experience, construct arguments and develop justifications. Above all, peer interactions may prompt students to regulate and reflect on their problem-solving processes.

Purpose of the Study

Despite the justification for the use of question prompts to facilitate problem solving activities, the relationship between questioning strategies and ill-structured problem solving has been insufficiently studied. The review by Rosenshine, Meister Chapman (1996) revealed that a majority of the studies in the area of questioning strategies in the past was focused on activating prior knowledge and improving comprehension. King's studies (King, 1991a, 1991b, 1992, 1994; King & Rosenshine, 1993), primarily focused on the effect of guided, student-generated questions on metacognitive skills, knowledge construction and problem solving of children, have made significant advances in the research of questioning strategies. Nevertheless, her research represents a start to future work of extending the research on questioning strategies beyond the scope of well-structured problems and to a wider population (e.g. college students).

As an anecdotal account, the strategies of question prompts and peer interactions had been tried out by the researcher on undergraduate students enrolled in the IST 110 course "Introduction to Information Sciences and Technology". It was found that students had difficulties solving the ill-structured problems without appropriate guidance. This anecdotal teaching experience showed that the strategies of question prompts and peer interactions seemed effective with most of the students in guiding them through the problem solving processes. Yet, as the strategy of question prompts was combined with that of peer interactions, it was not clear to what extent each of those two scaffolding strategies had effects on facilitating ill-structured problem solving processes, and which aspects of learning each of the strategies facilitated most effectively. Thus, this study was carried out to investigate the effects of question prompts and peer interaction, as well as their interactions. On the other hand, the effects of the two strategies were not as apparent with some students who tended to ignore the question prompts or did not collaborate productively with peers. This problem also called for further exploration in the present study.

Thus, the purpose of this study was to investigate the effects of the following strategies in support of undergraduate students' problem-solving processes on ill-structured tasks: (a) question prompts; (b) peer interactions; and (c) the combination of question prompts and peer interactions. The definitions of question prompts and peer interactions for this study are described below:

Question prompts refer to a set of static questions, both content-specific and metacognitive types, which are designed to serve both cognitive and metacognitive functions and guide students through the problem solving processes.

Peer interactions are defined as verbal interactions (King, 1991a) of students working together in small groups of three or four to engage in a task of ill-structured problem solving. All students in the group are expected to engage in the problem-solving task and produce a problem-solution report at the end of the study session. They are also expected to collaborate on problem solving by helping and learning from each other. Although they may have different abilities and background experiences, they are not assigned specific roles. To sum up, peer interactions in this study embodies meanings of group collaboration and collaborative learning.

The problem solving processes under investigation were (a) problem representation, (b) problem solutions, (c) justification for solutions, and (d) monitoring and evaluation of solutions, which were commonly discussed in the literature on ill-structured problem solving (e.g., Sinnott, 1989; Voss & Post, 1988). As justification is an important skill in solving ill-structured problems (Jonassen, 1997; Kitchner & King, 1981), the researcher purposely separated this process to be examined as one of the dependent variables for measuring ill-structured problem-solving processes and outcomes, in addition to the other three dependent variables: problem representation, problem solution, and monitoring and evaluating ill-structured problem-solving processes.

Research Questions

This study is concentrated on the effect of using question prompts and peer interaction to scaffold undergraduate students' problem-solving processes in an ill-structured task in (a) problem representation, (b) developing solutions, (c) making justification, and (d) monitoring and evaluating solutions. The study, intended to examine both problem-solving outcomes as well as processes, was focused on the following questions:

Question 1. Does the use of question prompts have an effect on students' problem solving on an ill-structured task in problem representation, developing solutions, making justifications, and monitoring and evaluation of solutions?

Question 2. Does the use of peer interaction have an effect on students' problem solving on an ill-structured task in problem representation, developing solutions, making justifications, and monitoring and evaluation of solutions?

Question 3. Does the use of question prompts combined with peer interaction have an effect on students' problem solving on an ill-structured task in problem representation, developing solutions, making justifications, and monitoring and evaluation of solutions?

Question 4. How does the use of question prompts influence students' cognition and metacognition in the process of developing solutions to ill-structured problems?

Question 5. How does the use of peer interaction influence students' cognition and metacognition in the process of developing solutions to ill-structured problems?

A mixed study of quantitative and qualitative research methods was applied to seek answers to the questions. An experimental research design was conducted to examine Questions 1-3 while a qualitative case study design was carried out to explore Questions 4-5.

Hypotheses

Based on Questions 1-3, the following hypotheses were generated:

Hypothesis 1. Students working individually and also receiving question prompts will demonstrate better problem-solving skills on an ill-structured task than their counterparts who did not receive the question prompts in (a) problem representation, (b) developing solutions, (c) making justifications and (d) monitoring and evaluating solutions.

Hypothesis 2. Students working with peers, with or without question prompts, will demonstrate better problem-solving skills on an ill-structured task than students working individually, with or without question prompts, in (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions.

Hypothesis 3. Students working with peers but also receiving question prompts will demonstrate better problem-solving skills on an ill-structured task than all the other treatment groups (PC, IQ, and IC) in (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions.

Significance of the Study

The research on questioning strategies to scaffold ill-structured problem solving is meaningful as the educational paradigm has shifted. The information age has challenged educators to reexamine the role of the learner and of instruction from a constructivist perspective. As the learner's role changes from a passive knowledge recipient to an active meaning constructor, self-regulation, self-direction and metacognitive skills have a significant value in instruction, particularly in solving ill-structured problems. Because of the complexity of an ill-structured problem, questioning strategies must be focused on helping students monitor the epistemological nature of the problems they are solving and the truth value of alternative solutions, not just the comprehension-monitoring metacognitive strategies that serve well-structured problem solving (Jonassen, 1997).

It is hoped that the findings of the study will contribute to further understanding of the role of questioning strategies in knowledge acquisition, scaffolding complex ill-structured problem solving tasks, and supporting collaborative problem solving. If the use of questioning prompts proves effective in facilitating the problem-solving process, instructors will have additional instructional strategies that can be used to support students' complex, ill-structured problem solving, especially novice learners (e.g. college students). In addition, the results of the study will be informative to those who attempt to seek effective and efficient tools to scaffold students' problem solving and make the class interactive in a large-sized class.

CHAPTER 2

LITERATURE REVIEW

The literature review focuses on the scaffolding strategies associated with ill-structured problem solving processes, specifically question prompts and peer interactions. After a discussion and comparison of well-structured and ill-structured problems, the review deals with the process of solving ill-structured problems and the essential components needed for solving ill-structured problems. The theoretical framework for the scaffolds, such as question prompts and peer interactions, is presented.

Ill-Structured Problem-Solving Processes

The Nature of Ill-Structured vs. Well-Structured Problems

Real-world problems have been referred to as ill-structured problems that we encounter in everyday life and that are typically complex and ill defined, not well circumscribed. They are generally problems in which one or several aspects of the situation are not specified. The general nature of these problems is that the goals are vaguely defined or unclear (Voss & Post, 1988), their descriptions are not clear, and the information needed to solve them is not entirely contained in the problem statements; consequently, it is not obvious what actions to take in order to solve them (Chi & Glaser, 1985). Ill-structured problems entail multiple solutions, solution paths, or no solutions at all (Kitchner, 1983).

In contrast to well-structured problems are application problems found at the end of textbook chapters, requiring the application of finite number of concepts, rules, and principles being studied to a constrained problem situation (Jonassen, 1997). Greeno (1978) categorized these types of problems as *transformation problems* that consist of a well-defined initial state, a known goal state, and constrained set of logical operators. Well-structured problems have single solutions, optimal solution paths, and structured goals (Sinnott, 1989), with limited amount of information or constrained knowledge based on the materials presented in the text. Problems such as theorems in logic or geometry and word puzzles are some examples of well-defined problems.

Making this distinction between well-structured problems and ill-structured problems is important because well-structured problem solving in school contexts has shown to have limited relevance and transferability to authentic problems in everyday life. Thus, educators should expose students to ill-structured problems, and instructional strategies should be developed to support students' skills in solving ill-structured problems.

Ill-Structured vs. Well-Structured Problem-Solving Processes

Traditionally, problem solving has been defined as a guided search through a cognitive space of possibilities, with the search guided by various heuristic methods or rules of thumb. It is based on information processing models, such as the classic General Problem Solving (GPS) (Newell & Simon, 1972) and IDEAL problem solver (Bransford & Stein, 1993). GPS generally specifies two sets of thinking processes: understanding processes and search processes. It was intended to provide a core set of processes that could be used to solve a variety of different types of problems. The critical step in solving a problem with GPS is the definition of the problem space in terms of the goals to be achieved and the transformation rules. The IDEAL model for solving problems involves identifying problems and opportunities, defining goals, exploring possible strategies, anticipating outcomes and acting, and looking back at learning (Bransford & Stein, 1993). Gick (1986) simplified the IDEAL model to include problem representation, search for solutions, and implementation of solutions. In general, these models require the problem solver to construct a problem representation, activate known problem schema or search for solutions, and then implement the solution. However, these processes are more applicable to well-defined problems, in which the goals of the problems are clearly specified, and problem solving is characterized by algorithm or means-ends-analysis, that is, breaking a problem into subcomponents (subgoals) and solving each of those.

Everyday problem solving is often ill-defined, in which the goals are vague. Sinnott (1989) proposed solving ill-structured problems based on her study of think-aloud protocols. Sinnott's model consists of five main components: (a) processes to construct the problem space; (b) processes to choose and generate solutions; (c) monitors; (d) memories; and (e) noncognitive elements. In this model, she emphasized the specific processes for choosing and generating solutions, arguing that the essence of a problem must be selected; then the goals; and finally a solution must be selected or generated from among many solutions. Since ill-structured problem solving may generate a large number of possible goals, Sinnott insisted that the solvers must have a mechanism for selecting the best goal or solution.

Voss and Post (1988) conducted a study on a political science problem. In their study, they found problem representation an extremely important process for determining the solutions of ill-structured problems. They argued that problem representation involves processes of examining the concepts and relations of the problem, isolating the major factor(s) causing the problem and its constraints, and recognizing divergent perspectives. Once the representation is developed, solutions can be derived by finding ways to eliminate the causes of the problem, and then corresponding procedures to implement the solutions can then be developed. Then, evaluations are carried out to assess if the proposed solution would work and to justify the solution. To summarize, Voss and Post's model involves (a) problem representation, (b) stating a solution, and (c) evaluation.

Hong (1998) summarized and combined the models of Sinnott (1989) and Voss and Post (1988) into three processes: (a) representation problems, (b) solution processes, and (c) monitoring and evaluation. A representation problem is established by constructing a problem space, including defining problems, searching and selecting information, and developing justification for the selection. The solution process involves generating and selecting solutions. Finally, the monitoring and evaluating process requires assessing the solution by developing justifications for it.

By comparison, well-structured problem solving processes parallel ill-structured problem solving processes. However, there are some major differences. Because of the complexity and ill-defined nature of ill-structured problems, justification skills, monitoring and evaluation are critical processes. The following is a comparison between well-structured and ill-structured problem-solving processes in the processes of problem representation, solution processes and monitoring and evaluation.

Problem Representation

When solving a well-structured problem, the goal of the problem can be easily defined, so the process of problem representation focuses on problem decomposition and classification of the type of problem. Whereas, in solving ill-structured problems, when problem descriptions are not clear or the goals are not well defined, an ill-structured problem may have multiple representations or understandings. Therefore, determining an appropriate problem space among the competing options is the most important process of an ill-structured problem (Jonassen, 1997). Then based on the information selected and evaluated, the solvers may depict the cause of the problem in a problem statement. Solvers must develop justification or an argument for supporting the rationale behind their selection of a particular cause.

Solution Process

Since a well-structured problem has a constrained set of logical operators and a single correct solution, solving a well-structured problem requires means-ends analysis guided by various heuristic methods or rules or thumb. According to Gick's model and IDEAL model, after a problem has been identified and goals defined, the problem solver searches for or generates possible solutions to the problem, which are then implemented and tested. The solver continues the process until a successful solution is found. When solving an ill-structured problem, however, opposing or contradictory evidence and opinions exist, and there is no single solution that can be determined by employing a specific decision-making process (Kitchner, 1983). In this case, the preferred solution should be represented in the form of an argument grounded on relevant and sufficient evidence and backed up with supportive facts or conjectures (Voss, 1988). The best solution is the most viable one that is justified with a cogent argument by the problem solver.

Monitoring and Evaluation

In solving well-structured problems, after a solution has been generated, the solver must implement the solution and evaluate the result. If a solution is successful, the problem-solving process concludes. The problem solver looks back at the strategies he or she has used to solve the problem and evaluates what works and what does not, and thus learns from the problem-solving experience (Bransford et al., 1987). In this aspect, monitoring and evaluation activities are carried out in order to search for a solution in the process of solving a well-structured problem. By comparison, monitoring and evaluation activities in solving ill-structured problems are conducted in order to justify selections and solutions. As a problem solver must select a good solution from among the many viable solutions, he or she must provide the most viable, the most defensible and the most cogent argument to support their preferred solution, and defend it against alternative solutions (Jonassen, 1997; Voss & Post, 1988). In addition, the problem solver must also evaluate his or her selection by examining and comparing other alternatives. In fact, the monitoring and evaluation processes already start as soon as the problem solver is involved in problem representation process of identifying the essence of the problem and selecting the best goal for solving the problem (Sinnott, 1989). Sinnott noted that during the process of solving an ill-structured problem, problem solvers monitor their own processes and movements from state to state, as well as select information, solutions, and emotional reactions.

Components of Ill-Structured Problem Solving

Cognition

Solving ill-structured problems requires domain-specific knowledge. Jonassen (1997) argued that although individuals may have the ability to solve problems, they may not transfer the prior problem-solving skills to other domains without appropriate content knowledge. Voss and Post (1988) found that experts consciously used domain knowledge in solving ill-structured problems. Voss, Wolfe, Lawrence, Engle (1991) found that expertise in solving ill-structured problems is highly domain-specific. Better-developed domain knowledge may enhance problem-solving ability in any domain. If the individual does not have and employ substantial knowledge of the domain in a problem, the applications of the methods will lead to inadequate solutions (Voss et al., 1991).

In addition to domain-specific knowledge, solving ill-structured problems also requires structural knowledge. Structural knowledge is knowledge of how concepts within a domain are interrelated and requires integration of declarative knowledge into useful knowledge structures (Jonassen, Beissner, & Yacci, 1993). Knowledge structure is an organized network of information stored in semantic or long-term memory (Champagne & Klopfer, 1981) and used to develop procedural knowledge for solving domain problems (Jonassen et al., 1993).

The importance of structural knowledge can be found in the processes of solving ill-structured problems. The representation is established by organizing appropriate elements in which a schema guides selection, instead of recognizing and classifying problem types (Voss & Post, 1988). In Johnson's study of house officer ratings, the data showed experts are likely to have clear-cut stop rules, such that a search is terminated as soon as enough information is obtained (Voss et al., 1991). For example, as in constructing problem space, experts have a well-defined routine for searching out critical information and have the ability to terminate after immediately collecting a sufficient amount of cogent information (Voss et al., 1991). Furthermore, experts have suitable conceptual knowledge of a problem domain, especially large amounts of problem-related information, stored in long-term memory rather than constrained by the content domains being taught in lecture (Voss et al., 1991).

In summary, domain-specific knowledge plays an important role in ill-structured problem solving. The domain-specific knowledge must be organized or assembled in a meaningful way, using some type of rule, with other concepts to result in a unique solution.

Metacognition

The term metacognition involves thinking about thinking. Some perspectives emphasize the individual's knowledge about cognition and strategy use. Others emphasize both the knowledge and regulation of cognition (Brown, 1987). Since ill-structured problems have no clear goals and require the consideration of alternative solutions as well as competing goals, solving an ill-structured problem requires the learner to regulate the selection and execution of a solution process. That is, when goals or action alternatives are ill-defined, solvers have to organize and direct their cognitive endeavors in different ways. Individuals cannot solve a problem in a straightforward way as in a well-structured problem. Complex, real-world problems require the learner to use metacognitive skills to monitor problem-solving processes, to reflect on the goals and solution processes and to construct cogent arguments for their proposed solutions.

In a study of history experts, Wineburg (1998) found that metacognition helped one to solve an ill-defined problem in the absence of domain knowledge. This study showed that one of the history experts, who was not a specialist in Lincoln, was able to successfully recognized the insufficiency of his initial attempts to explain the issues required by the task. The expert stepped back from his own initial interpretation and searched for a deeper understanding of the issues. As a consequence, he adopted the working hypothesis that he needed to learn more about the context of Lincoln's times before coming to a reasoned conclusion. The success of the history expert indicated that both knowledge of cognition and knowledge of regulation were essential elements of metacognition. In the first place, the history expert recognized the insufficiency of his domain-specific knowledge; in the second place, as soon as he was aware of his limitation of knowledge, he was able to adopt a working hypothesis that helped him to learn more about the context of Lincoln’s times. Hence, the metacognitive skills addressed in this study involve both knowledge and regulation of cognition.

Knowledge of cognition. The key components of metacognition are (a) knowledge about and awareness of one's own thinking and (b) knowledge of when and where to use acquired strategies (Pressley & McCormick, 1987). Knowledge about one's thinking includes information about one's own capacities and limitations and awareness of difficulties as they arise during learning so that remedial action may be taken. Knowledge of when and where to use acquired strategies includes knowledge about the task and situations for which particular goal-specific strategies are appropriate. As it has been discussed, domain-specific knowledge is required for solving ill-structured problems. In the absence of domain-specific knowledge or lack of information in various content areas, a problem solver often needs to apply general strategies, which can be applied to the problems, regardless of their content. In the social science study conducted by Voss et al. (1991), they found that experts were flexible in that they take into account more factors than do novices in searching for information. Additionally, experts used strategies of argumentation more often than novices did. They concluded that argumentation may be an important strategy in solving ill-structured problems (Gick, 1986).

Regulation of cognition. The three components in regulation of cognition descried by Jacobs and Paris (1987) are planning, evaluation, and monitoring. Planning consists of setting goals, activating relevant resources, and selecting appropriate strategies. Evaluation involves determining one's level of understanding. Monitoring, the third component in regulation involves checking one's progress and selecting appropriate repair strategies when originally-selected strategies are not working. Ill-structured problem-solving processes require all three components in regulation of cognition.

Planning is a primary everyday problem solving activity. Problem solvers must make decisions and predetermine a sequence of actions aimed at defining a problem and accomplishing a goal. The planning activity helps the problem solver to engage in the processes of problem representation and problem solution.

Monitoring is a critical component of ill-structured problem solving. When ill-structured problems represent states of uncertainty, individuals often fail easily to solve a problem because they lack the necessary knowledge needed to act in such a situation. In searching for solutions, this uncertainty requires monitoring of one's own cognitive efforts, the effects of these efforts, the progress and the success of solution activity, as well as keeping track of the solution activity and conflicts between different goals (Kluwe & Friedrichsen, 1985). Furthermore, the execution of plans must be monitored and regulated in order to insure that one's actions are directed toward the desired goal state.

During the problem-solving processes, a problem solver has to evaluate the information constantly as well as his or her problem solving processes. First, when information is obtained, either internally or externally, it is necessary for the solver to evaluate the information with respect to its usefulness in solving a problem (Kluwe & Friedrichsen, 1985). The solver must use evaluation skills when determining the extent to which obtained information may be effectively used in the solution process, the quality of the solution, and which selected goals may be important in a given situation (Kluwe & Friedrichsen, 1985).

The regulation of cognition is important not only in assisting learners with problem representation, solutions, and monitoring and evaluation of ill-structured problem-solving processes, but also in helping them develop justification skills. In the process of ill-structured problem solving, the learner is required to identify many possible perspectives, views and opinions which may occur in the problem situation, and to evaluate these perspectives to develop and argue for a reasonable solution (Voss & Post, 1988; Voss et al., 1991).

Scaffolding Ill-Structured Problem-Solving Processes

Scaffolds are forms of support provided by the teacher (or another student) to help students bridge the gap between their current abilities and intended goals. Central to the notion of scaffolded instruction is Vygotsky's (1978) zone of proximal development, that is, "the distinction between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (p. 86). According to Vygotsky (1978), scaffolds serve as aids during the initial learning of a complex skill or cognitive strategy and are gradually removed as the learner becomes more proficient. Scaffolds may be tools, such as cue cards, or techniques, such as teacher modeling, questioning, and explanation (Rosenshine & Meister, 1992). The seminal study by Palincsar and Brown (1984), characterized by reciprocal teaching, modeling, questioning and dialog, was representative research on scaffolding instruction. Procedural prompting by Scardamalia and Bereiter (1985) is another kind of scaffold, which supplied the learner with specific procedures or suggestions that facilitate the completion of tasks. Learners can temporarily rely on these hints and suggestions until they create their own. The following review specifically examines question prompts and peer interactions as two scaffolding strategies to support ill-structured problem solving.

Scaffolding Ill-Structured Problem Solving Using Question Prompts

Theoretical Perspectives on Questioning

The effect of questioning strategies can be explored from information-processing theory, schema theory, as well as cognitive development theory. From the point of information-processing theory, questions can direct and maintain learner's attention, and facilitate information encoding and retrieval. As a result, questions can direct students' attention to important information, or alternative perspectives which students may have ignored. From the perspective of schemata theory, questions allow a learner to elaborate his or her thought process and develop one's understanding. Mayer (1991) argued that problem solving depends on how knowledge is organized in memory, and that it was possible to discuss retrieval as problem solving. He observed that human beings are capable of answering a wide variety of complex questions, and that we do so not always by direct recall, but by working on a series of subquestions that bring us progressively closer to the answer (Mayer, 1991). Pressley et al. (1992) found that the "why" questions activated the students' prior knowledge related to the new concepts. Therefore, it is believed that questioning strategies can help to activate one's schemata and thus enable him or her to retrieve information, elaborate knowledge and represent understandings of the problem to be solved.

Viewed from Piaget's cognitive-development theory (Piaget, 1985), questions play a critical role in enhancing cognitive development of young children. The basic notion is that questions make cognitive demands on the child that create cognitive discrepancies and provide motivation for resolving them. The causal sequence begins with a teacher question that generates tension while creating the discrepancy, which in turn causes disequilibrium, and the child then strives to resolve the discrepancies via mental activity. In this case, questions challenge one to change a cognitive structure to make sense of the environment, to think about alternative solutions and consider various perspectives.

Questions provide also provide scaffolding to make the task explicit. Rosenshine, Meister, and Chapman (1996) categorized generic question stems and generic questions as one of five types of procedural prompts. In a series of studies conducted by King (1991a, 1991b, 1992, 1994), students were given generic question stems. The following are examples of generic question stems used in the studies by King: "how are …and…alike?" "What is the main idea of …?" "What are the strengths and weakness of…?" "How is this related to…" "What conclusion can you draw about?" Whereas, in Weiner's (1978) study, specific generic questions were provided, such as "How does this passage or chapter relate to what I already know about the topic?" and "What is the main idea of this chapter or passage?" Formulating and answering such questions forces students to identify the main ideas and the ways the ideas relate to each other and to the students' prior knowledge and experiences. The study results showed significant results on comprehension tests in almost all studies that provided generic questions or question stems.

The Influence of Question Prompts on Cognition and Metacognition

King's (1991a, 1991b, 1992, 1994) and Weiner's (1978) studies showed that questioning strategies could facilitate learners' understanding of domain knowledge by activating prior knowledge and elaborating their thought processes. Palincsar and Brown's (1984) study of reciprocal teaching revealed that, by providing modeling, feedback, and practice to students at a level that appeared to match the students' current need, helped them to play an active role and initiating role in the learning process. Osman and Hannafin's (1994) study showed a positive effect of advance questioning in science learning. Engaging in these active processes may lead to improved comprehension and enhanced recall of information, particularly of the central features of a passage. It is obvious that questions can assist the learner to organize the new material, integrate the information with existing knowledge and guide the encoding of schema.

Pressley et al. (1992) note that questions that affect only selective attention or maintenance rehearsal do not require transformation of the material. Questions should be used as cognitive strategies for comprehension fostering and active processing, as well as comprehension monitoring (Rosenshine et al., 1996). Wong (1985) noted that teaching students to ask questions might help them become sensitive to important points in a text and thus monitor the state of their reading comprehension. Palincsar and Brown (1984) indicated that in generating and answering questions concerning the key points of a selection, students might find that problems of inadequate or incomplete comprehension could be identified and resolved. van Zee and Minstrell's (1997) study described "a reflective toss" through a question-answer cycle between the teacher and the students, which revealed the influence of a teacher's questions on a student's reflective thinking process. It is evident that questions can serve to facilitate metacognition in planning by activating prior knowledge and attending to important information, in monitoring by actively engaging students in their learning process, and in evaluation through reflective thinking.

Regulation of cognition typically involves at least three components: planning, monitoring, and evaluation (Jacobs & Paris, 1987; Kluwe, 1987). These components closely parallel the problem-solving model (e.g., Bransford & Stein, 1993; Gick, 1986). Planning is an essential executive strategy and provides evidence of metacognition. It is necessary to make a problem-solving plan intentionally and to carry out that plan for all kinds of problems in order to identify and define the problem. To explore possible strategies, a problem solver must constantly regulate his or her own problem-solving performance by self-generating feedback. For an ill-structured problem, students have to decide if the problem is solvable and whether strategies or processes exist for solving it (Jonassen, 1997). Evaluation helps students to reflect on their problem solutions or alternatives so as to direct their future steps.

King (1991a) grouped metacognitive questions into three executive levels or categories—planning, monitoring and evaluating. These questions were designed to help students to clarify the problem and access their existing knowledge and strategies when relevant. For example, to identify the problem (or redefine the problem, which is often necessary during problem solving process), questions such as, "What are we trying to do here?" can be asked which are expected to help students determine the nature of the problem more precisely. Questions such as "What information is given to us?" would presumably help students to access prior knowledge, whereas the question "Is there another way to do this?" would foster greater access to known strategies (King, 1991a). A question to monitor problem solving may be "Are we getting close to our goal?" Above all, questions prompt students to reflect on their problem solving process, for instance, to articulate the steps they have taken and decisions they have made, facilitating their understanding of the reasons behind actions (Lin et al., 1999). When dealing with ill-structured problems where the context is complex and there may be more than one solution, students need to observe and analyze the complexity of their own reasoning and behaviors from multiple perspectives. Jonassen (1997) argued that it is important that learners be able to articulate the differing assumptions in support of arguments for whatever solution that they recommend. Therefore, scaffolding such as prompts and questions should be made to support learners making reflective judgements about what can be known and what cannot. Questions such as "What is your justification for that solution?" would help students to construct cogent arguments for their point of view (Jonassen, 1997).

Question prompts are especially important for those learners who tend to jump immediately into finding solutions when faced with the task of solving complex problems (Lin et al., 1999). King's (1991a) study on the relationship between guided questioning and problem solving suggested that many children may lack the ability to engage in effective thinking and problem solving on their own; thus the use of the guided questioning strategy may induce higher-order thinking and provide them with tools that they did not already possess. In sum, question prompts guide students' attention to specific aspects of their learning process, helping students to organize, monitor and evaluate their own problem-solving processes while learning (Lin et al., 1999).

Question Prompts to Scaffold Ill-Structured Problem-Solving Processes

Although many studies were conducted on the functions of questions to foster and monitor comprehension, studies on question prompts to scaffold ill-structured, complex problem solving are rare. Schoenfeld (1985) and King (1991a) each did a study on the effect of self-generated questions on children's math problem solving. The results showed that providing students with question stems facilitated the students' knowledge construction and problem solving processes. Even though the problems being solved in these studies were well-structured problems, it is predicted that questioning strategies can also facilitate ill-structured problem solving processes.

Problem representation. Problem representation means constructing a problem space that includes defining problems, searching and selecting information, and developing justification for the selection. Based on information-processing theories of problem solving, two types of strategies are generally applied in problem representation: schema-driven strategies and search-based strategies (Gick, 1986). While constructing a representation of the problem, the solver extracts the given and goal information and attempts to "understand" the problem or connect it to existing knowledge so that an integrated representation can be formed. During this stage, certain features of the problem may activate knowledge in memory. A schema for that particular type of problem may then be activated. The schema is a cluster of knowledge related to a problem type, which contains information about the typical goals, constraints, and solution procedures useful for that type of problem. King and Rosenshine (1993) found that guiding students to ask questions with prompt cards elicited explanation that, in turn, enhanced knowledge representation. It is inferred that question prompts can also facilitate problem representation.

Developing solutions. In the absence of appropriate schema activation, the problem solver proceeds to the second step and a search strategy is invoked (Gick, 1986). Search strategies may involve the comparison of problem states to the goal state and the use of information gathering strategies. During the stage of developing solutions, various questioning procedures play an important role in activating prior knowledge and mapping the problem onto the existing problem schema through eliciting elaborated explanations (King & Rosenshine, 1993; Mayer, 1991). When faced with a problem, it is natural to search memory for a similar, previous experience. If the learner can be prompted to recognize the similarities between the previous and current problem, he or she may recall the solution method used in the previous problem (Jonassen, 1997). While searching for solutions, questions may direct students' attention to some important information or specific features of a problem. They may also prompt students to recall the solution to a similar problem situation, to identify discrepancies between the current state and the goal state, or to break down a problem into subproblems (Jonassen, 1997).

Making justifications. Questions prompt students to elaborate and articulate their thoughts and make them aware of their own decision and actions. In turn, this function serves to support students' reasoning and help them to make justifications for a solution they have selected or generated. Chi, Bassok, Lewis, Reimann, and Glaser (1989) found that guiding students to self-generate explanations facilitated problem solving, and question prompts were expected to elicit explanations from the students. Lin and Lehman's (1999) qualitative results showed that reason justification prompts directed students' attention to understanding when, why, and how to employ experiment design principles and strategies, which helped students to transfer their understanding to a novel problem.

Monitoring and evaluation. During this process, questions can potentially guide students' attention to specific aspects of their learning process (Rosenshine et al., 1996), by reminding them of the initial conditions of the problem and helping them to reflect upon the solutions by comparing the initial conditions and the solutions (Jonassen, 1997). In this case, question prompts serve to regulate their learning process (Palincsar & Brown, 1984). Questions may prompt students to articulate the steps they have taken, the decisions they have made and facilitate their reasoning behind actions (Lin et al., 1999), which can help them to evaluate their solution process, make viable argument for the solution, or seek for ways to overcome limitations in their solutions. In fact, Davis and Linn (2000) found that reflective prompts were more effective and successful to support knowledge integration than other activity prompts, which only served to guide the inquiry process.

Scaffolding Ill-Structured Problem Solving Using Peer Interactions

Theoretical Perspectives on Peer Interactions

Constructivism holds that cognition is an outcome of social processes, and that knowledge or meaning results from individuals' interpretations of their experience in particular contexts. However, experience refers not only to direct experience but also to learning that occurs through interactions with others (Webb & Palincsar, 1996). Based on sociocultural theory, one's cultural development appears twice, first on the social or interpsychological plane between people and later on the individual or intrapsychological plane within the person (Vygotsky, 1978). A key concept in Vygotsky's theory is the *zone of proximal development*, which is defined as "the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (p. 86). Social interactions allow the learner to activate not yet fully developed cognitive functions that enable him or her to perform on a higher cognitive level (Salomon et al., 1989). Eventually, learning becomes internalized and the learner is able to perform on a higher cognitive level independently.

Why are the social interactions among the peers important when interactions between the adult, such as a teacher, and the student is available? Empirical research has shown that social interactions among peers had advantages over the interactions between the adult and the student. A study conducted by Brown and Palincsar (1989) compared teacher modeling of four text comprehension strategies (questioning, summarizing, predicting, and clarifying) to reciprocal teaching among students in which students used the same strategies with each other. Although the comprehension assessments indicated some improvement among students who watched the teacher engage in the think-aloud modeling condition and responded to the teacher-generated questions, the performance of the students in the reciprocal teaching condition was significantly better. A study by Graesser and Person (1994) showed that peer interactions during the tutoring sessions encouraged the students to ask and answer questions and overcame some of the barriers found in class interactions between the instructor and students.

Peer interactions have been found to work effectively in combination with questioning strategies. The use of peer interaction provides a context for students to ask questions, provide explanations, receive elaboration, and construct argumentation. Elaboration, interpretation, explanation, and argumentation are central to the activity of the group, in which learning is supported by other individuals (Webb & Palincsar, 1996). While previous research provides different theoretical perspectives on the benefits of peer interactions, for example, shared cognition, group information processing, and social construction of knowledge, this study mainly focuses on the theoretical framework of social constructivism, and addresses the influence of peer interactions on cognition and metacognition and how peer interactions can be used to scaffold ill-structured problem solving.

The Influence of Peer Interactions on Cognition and Metacognition

Previous research supports the effectiveness of peer interactions in scaffolding cognitive and metacognitive thinking. For instance, Palinscar and Brown (1984) found that "reciprocal teaching" involving dialogue between the teacher and the student helped to foster comprehension and comprehension monitoring activities. In another study, Palincsar, Brown, and Martin (1987) found that peer interaction resulted in equal gains in reading comprehension comparable to interactions between the teacher and the students. The benefits of dialogue in reciprocal teaching lie in the following: (a) extensive modeling of the comprehension-fostering and comprehension-monitoring activities by the teacher; and (b) task requirements for students to ask and respond to questions, which made their thinking explicit. Webb's (1982, 1989b) studies showed that when learners were required to give explanations and ask questions to each other, learning was enhanced. The process of explanation presumably requires learners to clarify concepts, reorganize thinking, and reconceptualize the material. Naturally, the elaboration process through peer interaction can assist students to define the goals and understand the nature of the problem. King's studies indicated that peer questioning engaged students in more explanation and inferences during problem solving (King, 1991b; King & Rosenshine, 1993).

Another role played by peer interaction is to support reflection through social discourse (Lin et al., 1999). According to Lin et al. (1999), multiple perspectives and distributed expertise during peer interactions support students' reflection and help them notice new things that they might otherwise overlook. This helps to "engage the learner in considering each point of view and selecting the best one based on reasoning and evidence" (Jonassen, 1997, p. 86), and thus supports argument construction. Recently, Cockrell, Caplow, and Donaldson (2000) found that group collaboration contributed to students' metacognitive awareness of their self-directed learning activities in problem-solving tasks, and as a result, the students demonstrated greater clarity in their reasoning, analysis, and problem-solving skills. Greene and Land's (2000) study indicated that peer interaction during open-ended learning was effective when group members offered suggestions, negotiated ideas, and shared their experiences. The attribute of reflective thinking in peer interaction leads to the conclusion that peer interaction can facilitate ill-structured problem solving in monitoring problem solving processes, assessing problem solutions, and constructing sound arguments.

Given those findings, it is believed that peer interactions may scaffold students' problem solving on an ill-structured task by defining problems, constructing the problem space, and articulating contextual constraints. It also allows peers to negotiate meanings, share knowledge and experience, construct arguments and develop justifications. Above all, peer interactions can also prompt students to regulate and reflect upon their problem-solving processes.

Peer Interactions to Scaffold Ill-Structured Problem-Solving Processes

According to social constructivism, peer interactions in the form of negotiation and meaning sharing, is an essential learning process for knowledge construction. The power of peer interactions in learning lies in asking questions, and in providing explanations, elaboration, and feedback (Webb, 1989b), which facilitate the process of negotiation and meaning sharing. Through negotiation, students correct their misunderstandings and construct new knowledge; and through meaning sharing, students develop their cognition and metacognition as a collective group. McNeese (2000) noted three features in collaborative learning: collective induction, generative learning, and metacognitive learning. How these features will influence problem solving specifically is examined below.

Problem representation. Through seeking information, giving explanations and receiving information during peer interactions, students may fill in gaps in their understanding, correct misconceptions, and strengthen connections between new information and previous learning (Wittrock, 1990). Peers may also be able to direct other students' attention to the relevant features of a problem they do not understand, and can explain concepts in familiar terms (Brown & Palincsar, 1989; Noddings, 1985). Hence, when active peer interaction occurs, it can help individual students to represent the problem space.

Problem solution. When students are actively engaged in discussion, explanation, providing feedback rather than passively receiving information, they gain new insights, ideas, knowledge and strategies, which they could not have learned on their own. In the collaborative learning environment, cognition is distributed among the group members (Pea, 1993). Through interactions, such as questioning, explanations, elaboration, and reflective feedback, different ideas, expertise, and perspectives can be generated from the members. Thus, students collaboratively construct knowledge and develop solutions, which is expected to be the product of collective induction and generative learning.

Argumentation and justifications. Similarly, peer interaction supports argumentation and justification through questioning, explanation, elaboration and feedback. The findings by Chi et al. (1989) indicated the effectiveness of self-explanation in problem solving, whereas Lin and Lehman (1999) also found that the prompts eliciting arguments and justification facilitated students to integrate knowledge. When working together on a problem, if students are actively engaged in negotiation and meaning sharing, they will ask questions which will challenge one's thinking and require explanations, elaboration or justifications. In such an environment, peer interaction creates a venue for students to construct arguments and make justifications. Students may ask other students questions related to the goals, how an idea worked with solving the problem, and why they have selected a solution.

Monitoring and evaluation. Monitoring and evaluation are two most important attributes of metacognitive knowledge characterizing problem-solving processes, especially on an ill-structured task (Jonassen, 1997). They help students to plan, monitor and evaluate their problem-solution processes. Two aspects of peer interactions facilitate the monitoring and evaluation process: multiple perspectives and articulating one's thoughts. Peer interactions provide students with multiple perspectives and lead them to see things they might have overlooked (Lin et al., 1999). Such a characteristic helps students to reflect on their own thinking, actions, and decisions, and as a result, they would modify their thinking, plan remedial actions, evaluate their solutions, check their solution steps, and monitor their solution process (e.g., going back to reexamine the goals of the problem). The other aspect of peer interactions is articulating one's thoughts through the cycle of questioning, explanation, and elaboration. Articulating one's thoughts makes one's thinking visible, so that students can examine and reflect on their reasoning on a problem solution, an action, or a decision they make, so that they construct arguments to justify their position or make modification of their own understanding.

Conditions for Peer Interactions

Although a few studies have reported positive relationships, some other studies have shown no significant relationship between peer interaction and students' achievement (Webb, 1989a, 1989b, 1991). Summarizing previous research, Webb (1989b) pointed out that levels of questions (high vs. low) may influence levels of elaboration or help received; and use of elaboration or feedback for problem solving will yield a high level of elaboration, which in the end leads to greater academic achievement. In another study, Webb, Troper, Fall (1995) showed that students' level of constructive activity, that is, showing and explaining how to solve problems using concepts stated or implied in the explanations received, was correlated to the benefits from the peer interactions. Therefore, benefits of peer interactions are contingent upon a high level of peer interaction, that is, active engagement in asking questions and providing elaborations and feedback, which in turns is dependent upon group dynamics where group members are willing and see the need to engage in such a knowledge construction activity.

CHAPTER 3

RESEARCH METHOD

Participants

The sampling unit was students enrolled in an introductory course (IST 110) in Information Sciences and Technology in a major land-grant university in the northeastern United States. The majority of the students taking this course planned to major in Information Science and Technology (IST). The approximate age range of the students was 18-20, and the ratio between males and females was 3 to 1. Most of the students had some limited previous experience with ill-structured problem solving in the domain of information science and technology, as determined by a survey distributed by the researcher.

The potential subject pool consisted of approximately 150 students enrolled in three of the four IST 110 (Introduction to Information Sciences and Technology) sections. Each of the three professors taught a class section of IST 110. Two teaching assistants (TA) worked closely with the three professors, with each TA attached to two class sections respectively, and one TA being the researcher of this study. The TAs were responsible for teaching computer laboratory sessions and grading the course assignments. All the three class sections shared a common curriculum and a core textbook.

In compliance with the university's regulations, the researcher went to two of the class sections to recruit the participants herself, while for the class section she was teaching, she sent a third party to recruit the participants. The purpose of the study, a brief description of the procedure, and the benefits for participating in the study were explained to about 150 students in the three IST 110 class sections in order to seek their consent. Approximately 125 students signed the human subject consent form (Appendix A) in the lab a week before the study, however, only 115 students actually showed up and participated in this study. In addition, 8 cases (19 participants) were selected for in-depth, qualitative study.

The Context of the Study

IST 110 (Introduction to Information Science and Technology) was a course designed not only to introduce basic concepts and principles in information sciences and technology, but also to incorporate both collaborative learning and problem-solving experiences. IST 110 consisted of both lecture and laboratory sessions. The lecture sessions, held twice a week and each lasting 75 minutes, had in-class presentations by the professor, discussions among the students, and a variety of graded assignments (including individual or group projects), as well as mid-term and final examinations. The laboratory sessions, held once a week and 115 minutes in length, were primarily designed to provide the students hands-on experience. They were conducted by a teaching assistant and were mainly focused on two aspects: (a) developing basic information technology (IT) skills through skill module exercises, such as word processing, spreadsheet, database management systems, and Web page design and development; and (b) developing problem-solving and collaboration skills through case studies. About two thirds of the laboratory sessions were devoted to IT skill development while the remaining lab sessions were intended for students to work in groups on some ill-defined, problem-based cases. When students were working on a comparative case study, the instructor (teaching assistant) usually provided instruction on the task requirements during a lab session, answered students' questions regarding the cases, or clarified meanings or misunderstandings. The instructor provided little formal instruction on problem-solving strategies or skills.

By the time this study was conducted, the students had some exposure to problem-solving tasks at various degrees. The students in two classes had worked on two problems (case studies) related to IST in the preceding two labs. However, those were more structured problems, for which the students were told exactly what to do and how to arrive at the solutions. Besides, during the same period when the study was conducted, those students were also working on a group project for a class assignment outside of the class time. In the other class, the students had not been exposed to problem-solving tasks similar to those done by other two classes in the labs, but they had just completed a group project on problem solving related to the IST domain for a class assignment. Therefore, the three classes were considered roughly equivalent in terms of their prior experience in problem solving as far as the IST 110 course was concerned. Despite various problem-solving experiences the students had gained from IST 110, the participants were still considered novice learners, especially in solving problems on ill-structured tasks. In this study, the problem scenario, the content, the format, and the nature of the problem-solving task (Appendix B) were different from what the participants had done in the past.

Research Design

The research questions are stated in Table 3.1. Given those questions, the researcher chose a mixed research design approach, integrating quantitative with qualitative methods. The quantitative method was intended to measure students' problem-solving *outcomes* on an ill-structured task through an experimental study. The purpose of the quantitative study was to examine the relationship between the instructional interventions -- the *independent variables* (question prompts and peer interactions) and ill-structured problem-solving outcomes -- the *dependent variables* (problem representation, developing solutions, making justifications, and monitoring and evaluation). However, the experimental study might not yield the contextual information about students' problem-solving process, such as if they had used the treatment material, how they had interacted with each other during problem solving or how the treatment material had influenced their thinking during problem solving. Besides, through the experimental study alone, the researcher would not have access to students' attitudinal information either, such as their perception about their problem-solving abilities, their attitudes toward working with peers, or their motivation to engage in a problem-solving task.

Therefore, a qualitative study, using a comparative, multiple-case study design (Yin, 1989), was conducted to analyze students' problem-solving *process* and the influence of question prompts and peer interactions on their cognitive thinking and metacognitive skills. Through think-aloud protocols, observations, and interviews, the researcher intended to examine students' thoughts, actions, decision-making, as well as their feelings during the problem-solving process, and thus gain insight into students' problem-solving process on an ill-structured task, in conditions with or without the influence of question prompts and peer interactions. Think-aloud protocols were intended to provide the researcher insights into students' cognitive and metacognitive aspects while they were engaged in problem solving. They also allowed the researcher to understand how question prompts influenced their thinking process, actions taken, decision making, and problem-solution paths. Observations provided the researcher an opportunity to query the interaction process when students were working with peers on the problem-solving task, such as their dialogues, questions and responses, and how such interaction processes influenced their cognitive thinking and metacognitive knowledge. The observation data were also expected to provide information on how and when the students used the question prompts while they were working with peers and how those questions had influenced their interaction process. The follow-up interviews were intended to serve two purposes: first, to clarify any questions that the researcher may have regarding think-aloud protocols or observation data; and second, to gain insights into the participants' self-reflection of their problem-solving processes in different treatment conditions.

It was expected that the comparative case studies, through different data sources (think-aloud, observations, and interviews), would provide rich data to understand the influence of the two instructional strategies (question prompts and peer interactions) on students' cognitive and metacognitive aspects during their problem-solving process in-depth. The multiple case studies were also expected to help the researcher to interpret the experimental study results, which would be triangulated with the qualitative data to yield new findings and meanings, and to explain paradoxes and conflicts emerged from findings.

According to Greene, Caracelli, and Graham (1989), mixed study methods help a researcher to seek triangulation of the results from different data sources, examine overlapping and different facets of a phenomenon, discover paradoxes, contradictions, and fresh perspectives, and expand the scope and breadth of a study. These purposes of mixed methods justify the use of mixed methods for this study.

Table 3.1 summarizes the five overall study questions covered by both the experimental study and the comparative case study, including techniques, tasks, materials, instruments and data sources.

Table 3.1
Overall study questions, data collection techniques, instruments and data sources

Research Question	Techniques	Tasks/Materials/Instruments	Data Sources
1. Does the use of question prompts have an effect on students' problem solving on an ill-structured task in problem representation, developing solutions, making justifications, and monitoring and evaluation?	• Experimental study combined with comparative case study: • Think-aloud protocols • Observation • Interviews	• Ill-structured problem-solving task • Rubrics for rating the problem-solving report	• Problem-solving reports triangulated with • Audio transcription of think-aloud protocols and interviews • Video transcription of peer interactions and interviews
2. Does the use of peer interaction have an effect on students' problem solving on an ill-structured task in problem representation, developing solutions, making justifications, and monitoring and evaluation?	• Experimental study combined with comparative case study: • Observation • Interviews	• Ill-structured problem-solving task • Rubrics for rating the problem-solving report	• Problem-solving reports triangulated with • Video transcription of peer interactions • Audio and video transcription of interviews
3. Does the use of question prompts combined with peer interaction have an effect on students' problem solving on an ill-structured task in problem representation, developing solutions, making justifications, and monitoring and evaluation?	• Experimental study combined with comparative case study: • Observation • Interviews	• Ill-structured problem-solving task • Rubrics for rating the problem-solving report	• Problem-solving reports triangulated with • Video transcription of peer interactions • Audio and video transcription of interviews
4. How does the use of question prompts influence students' cognition and metacognition in the process of developing solutions to ill-structured problems?	• Comparative case study • Think-aloud protocols • Observation • Interviews	• Ill-structured problem-solving task	• Audio transcription of think-aloud protocols • Video transcription of peer interactions • Audio and video transcription of interviews
5. How does peer interaction influence students' cognition and metacognition in the process of developing solutions to ill-structured problems?	• Comparative case study • Observation • Interviews	• Ill-structured problem-solving task	• Video transcription of peer interactions • Audio and video transcription of interviews

The Experimental Study

The experimental study was designed to answer Questions 1-3 (see Table 3.1) by investigating the relationships between (a) question prompts and problem-solving skill outcomes; (b) peer interactions and problem-solving skill outcomes; and (c) interactive effect of question prompts and peer interactions and problem-solving skill outcomes. The independent variables of this study are (a) question prompts and (b) peer interactions. The ill-structured problem-solving skill outcomes were measured in the areas of (a) problem representation; (b) developing solutions; (c) making justifications; and (d) monitoring and evaluation, which are commonly identified in the general models of solving ill-structured problems (Bransford & Stein, 1993; Gick, 1986; Jonassen, 1997; Kitchner, 1983; Voss & Post, 1988).

The Experimental Study Design

The experimental study design employed for this study was "posttest-only control group design". It was designed to compare the treatment groups with the control groups on solving ill-structured problems in two dimensions, the individual and the peer conditions respectively. The experimental study design is illustrated in Table 3.2.

Table 3.2
The experimental study design

	Peer	Individual
Treatment (Question Prompts)	XO	XO
Control (No Question Prompts)	CO	CO

In Table 3.2, O stands for observation, X stands for treatment, and C stands for control condition. In this study, the observation would be made on students' problem-solving performance on an ill-structured task, the output of which would be a problem-solution report. There were two types of treatments: question prompts and peer interactions. Each treatment group had its control counterpart. In the dimension of question prompts vs. no question prompts, the comparison was made between the peers and individuals. Viewed from another dimension, that is, peers vs. individuals, the comparison was between those who received question prompts and those who did not receive question prompts.

As illustrated by Table 3.2, there were four conditions to this study, which is displayed in Table 3.3.

Table 3.3
Four different treatment conditions for the experimental study

	Peer	Individual
Treatment (Question Prompts)	Condition PQ	Condition IQ
Control (No Question Prompts)	Condition PC	Condition IC

- PQ Condition: Students receiving question prompts and working in groups of 3 or 4.

- PC Condition: Students receiving no question prompts but working in groups of 3 or 4
- IQ Condition: Students receiving question prompts but working individually
- IC Condition: Students receiving no question prompts and working individually

Sampling and Treatment Assignment

In order to study the students' problem-solving performance in a naturalistic setting of the classroom, the study was incorporated into the IST 110 curriculum, with the professors' approval. Therefore, the problem-solving task was conducted in a 115-minute laboratory session, and each class section was randomly assigned to one or more than one conditions as an intact group. As there were only three classes for four different treatment conditions, one class had to be divided into two individual conditions. Class A was randomly assigned to Condition PQ, and Class B was randomly assigned to Condition PC, and Class C was randomly assigned to Conditions IQ and IC, in which some participants were assigned to Condition IQ and the other participants were assigned to Condition IC. The treatment assignment of the participants is illustrated in Figure 3.1.

There were 13 groups of 48 participants in Class A, who were assigned to Condition PQ, and 11 groups of 38 students in Class B, who were assigned to Condition PC. The groups in the two classes were previously formed by the professors who taught the classes to fulfil a class project. The normal size of the groups were four students; however, due to the absence of some group members or the decision of some students not want to participate in the study, some variations to the group size resulted. In Condition

PQ, there were ten 4-person groups, two 3-person groups, and one 2-person group. In Condition PC, there were three 4-person groups, seven 3-person groups, and one 5-person group. It is worth noticing that there were less participants in Condition PC than in Condition PQ, which might be due to the early class session for Class B (Condition PC), whose lab started at 8 A. M. in the morning. Class A's lab started at 2:30 P.M. in the afternoon, while Class C's lab started at 10:10 A.M. in the morning. Due to attrition, six students in the PC condition, 2 students in the PQ condition, and 2 students in the IQ condition did not participate in the study.

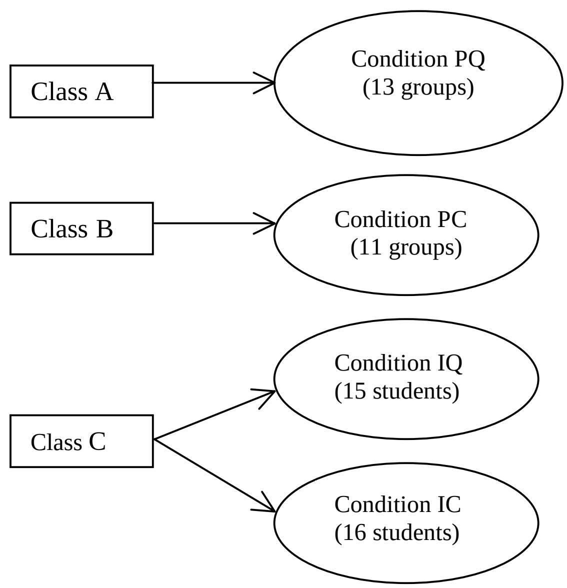


Figure 3.1. Assigning participants to the four different treatment conditions.

Materials and Instruments

The materials and instruments used for the experimental study include the material for the ill-structured problem-solving task (Appendix B), the question prompts treatment material (Appendix C), and scoring rubrics (Appendix D).

The ill-structured problem-solving task material. The ill-structured problem-solving task material (Appendix B) was a complex, real-life problem related to the domain of information science and technology and developed by IST 110 professors. The problem-solving task first presented a problem and then described the task that the students must complete during the 115-minute problem-solving session. The material had been validated by an instrument (Appendix B), which incorporated the major attributes of an ill-structured problem defined by the literature (Chi & Glaser, 1985; Jonassen, 1997; Kitchner, 1983; Sinnott, 1989; Voss, 1988; Voss & Post, 1988). The participants' task was to generate solutions to the problem and develop a 2-3 page problem-solution report. In addition, in order to satisfy the lab requirement, the students were also told to produce a prototype of the database system they designed and reported in the solution proposal.

Treatment material: Question prompts. The treatment material (Appendix C) for the problem-solving task was a list of 10 questions generated by the IST professors, the subject matter experts, according to the problem solving task. These problems were categorized by the researcher into the following groups of question prompts:

1) Problem Representation Prompts: "How do I define the problem?" (There are 3 questions and 4 sub-questions to Question #3 in this category.)
2) Solution Prompts: "How do I generate the solutions?" (There are 3 questions in this category.)
3) Justification Prompts: "What are my reasons and argument for the proposed solutions?" (There are two general questions in this category, with 1 sub-question to each question.)

4) Monitoring and Evaluation Prompts: "Am I on the right track?" (There are 2 questions and 3 sub-questions to Question #10.)

The question prompts are closely paralleled to the ill-structured problem-solving processes. They consist of questions supporting cognitive thinking and metacognitive skills, such as "what", "how" and "why" as well as strategic questions that are found in King's generic question stems (King, 1991b, 1992). These questions are designed to facilitate students' understanding of domain knowledge and the nature and the complexity of the problem and to develop students' metacognitive thinking, such as planning, monitoring and evaluation processes. The participants in the IQ and the PQ conditions were instructed and reminded frequently to think about the questions, and use the questions to facilitate them through the problem-solving process.

The question prompts treatment material was mainly based on the questions generated by two IST 110 professors, which were then compiled and categorized by the researcher. The researcher first approached the two professors by asking them what kind of questions they would ask as an expert if they were going to solve that problem. Then, the researcher sought input from some other IST 110 professors as well as some professors and doctoral students in the program of Instructional Systems. The modification was made based on the feedback and suggestions. Before formally conducting the study, the treatment material was pilot tested to a group of participants who were not part of the formal study. Further revision was made to the question prompts based on the information the researcher obtained from the pilot study.

Scoring rubrics. An analytical rubric system (Appendix D), developed by the researcher based on performance criteria, was used to score the result of the posttest – the problem-solving reports. The research on ill-structured problem solving (Chi & Glaser, 1985; Jonassen, 1997; Kitchner, 1983; Sinnott, 1989; Voss, 1988; Voss & Post, 1988) was used as a framework for developing the rubrics. In developing the rubrics, the researcher also referred to the literature by Barn (1994) and Blum and Arter (1996), as well as the rubrics developed by Hong (1998), who validated her rubrics on ill-structured problem solving through a construct validity test.

Four major constructs, which tightly corresponded to the dependent variables of this study, were identified as important for measuring ill-structured problem-solving skills for this study: (a) problem representation, (b) developing solutions, (c) making justifications for generating or selecting solutions, and (d) monitoring and evaluating the problem space and solutions. Each of the constructs was subdivided into specific attributes. For instance, the third construct "(3.0). Making justifications for selecting/generating a solution" was examined by two specific attributes: "(3.1). Constructing argument" and "(3.2). Providing evidence". Each attribute was assigned an ordinal value on scales such as 0-1-2-3 or 0-2-4, based on the performance description and specific criteria. For example, in measuring "providing evidence", if the evidence provided to support the argument is obvious and relevant, a score of "3" would be assigned to this attribute. On the contrary, if the evidence provided to support the argument is weak or irrelevant, a score "1" would be assigned. If no evidence is provided, a "0" would be assigned. The earned points for both 3.1 ("constructing argument") and 3.2 ("providing evidence") were summated to give an overall score for the construct "making justifications".

The rubrics were reviewed by professors teaching IST 110 and professors in Instructional Systems, and were tried out on scoring a few problem-solving reports by the three raters, who provided feedback on the rubrics, before the rubrics were finalized and used for scoring the problem-solution reports.

The Comparative, Multiple-Case Study

As is previously mentioned, a comparative, multiple case study design, for which two samples were selected from each of the four treatment conditions, was used in addition to the experimental study. According to Yin (1989), the multiple cases were analyzed for the purpose of theoretical replication, which either (a) predicts similar results or (b) produces contrasting results but for predictable reasons. The development of a rich, theoretical framework is an important step in all of these replication procedures (Yin, 1989). In this multiple-case study, case results were compared against and explained according to the previously developed theories on using questioning strategies and peer interactions to scaffold students' cognitive and metacognitive knowledge.

In particular, the multiple case studies across the four treatment conditions were used to (a) answer Questions 4-5 (see Table 3.1), which were designed to investigate the relationship between question prompts and the ill-structured problem-solving processes as well as the relationship between peer interactions and the ill-structured problem-solving processes; (b) triangulate with the experimental study data in order to study the research questions in-depth; (c) confirm the experimental study results; and (d) explain or interpret paradoxes or conflicts between findings of different data sources.

In this study, a case is an individual student or a group of students. Four individuals who worked separately with the presence of the researcher on an ill-structured problem-solving task represented four separate cases. In addition, four groups of 3 or 4 students working together on an ill-structured problem-solving task in the natural setting of the classroom represented the other four cases. Depending on the treatment conditions they were assigned to, they were provided or not provided with the question prompt material when they were working on the problem. Figure 3.2 illustrates the cases sampled from different treatment conditions.

PQ 2 groups (of 4)	IQ 2 participants
PC 2 groups (of 3 or 4)	IC 2 participants

Figure 3.2. Case sampling from the four different treatment conditions.

The following was a brief overview of the sampling approach and data collection technique used for the comparative case study.

Sampling Approach

A sample was taken from each of the four conditions for the comparative case study. Selective (discriminative) sampling (Strauss & Corbin, 1998) was used to maximize the representation of cases (Stake, 2000) and opportunities for comparative analysis across different conditions. For the four peer groups, selection was made during the same session when the problem-solving task was given, which was based on the researcher's observation and quick assessment of students' interactivity at the beginning of the session. The selection of the individual cases (PQ and PC) were based on their usual class performance. The four individuals selected (IQ and IC) were considered "good" students by their professor and thus selected for the study. As a result, eight cases were selected, with two from each of the four treatment conditions. Yet, it was found after the observation session that the data of two cases were unusable (see explanation below); thus two other cases were selected (post-hoc) after the problem-solving session, based on the quality of their solution reports, which, as judged by the researcher, were generally good.

The techniques of think-aloud protocols, observation, and follow-up interviews were applied to study the selected cases. Think-aloud protocols (Ericsson & Simon, 1996) were applied to the four selected individuals, with two from the IQ condition and the other two from the IC condition. Observation of peer interactions in the natural setting of the classroom was made through videotaping the four selected cases, with two from the PQ and the other two from the PC condition. However, due to some technical problems encountered during the videotaping process and also because one selected group was off task for the entire period, the videotaped data of two selected groups (PQ) became unusable, so these two cases were removed from the comparative case study. Interviews were designed for all the selected cases (individuals and groups) after the problem-solving task. The individuals who did think-aloud protocols were interviewed immediately after they completed the problem-solving task. As two cases were taken out of the comparative case study after the observation session, the follow-up interviews for the selected groups consisted of the two groups (PC) who were earlier observed through videotaping as well as two newly selected groups (PQ).

Data Collection Techniques

Think-aloud protocols. Think-aloud protocols were the verbalization of one's thinking process (Ericsson & Simon, 1996). For this study, think-aloud protocols (Appendix G) indicated students' verbalizations while they were engaged in solving the ill-structured task. Think-aloud protocols provided evidence of their thinking, reasoning, decision-making, monitoring and evaluating processes for the task in different treatment conditions, that is, with or without the question prompts. Specifically, think-aloud protocols provided information on how question prompts influenced students' cognition and metacognition during problem solving in the processes of problem representation, solution, making justification, and monitoring and evaluation. At the same time, think-aloud protocols were used to examine the problem-solving processes of the individuals who did not receive the question prompts. The think-aloud protocols from two different conditions were used to make comparisons of students' problem-solving performance in a condition with or without question prompts. According to Ericsson and Simon, verbalization would not interfere with the ongoing process of the students who were engaged in the task.

Observation. For this case study, the observation was the noting and video recording of the peer interaction process (e.g., verbalization, dialogues, and gestures) of a group of students (3 or 4) while they were engaged in the problem-solving task in a pre-assigned condition (PQ or PC). The recording was made through videotaping and on-site observation notes. Observations were expected to provide information on how differently the students solved the problem when working with peers and when supplied with or without question prompts. It was also intended to investigate if question prompts had any effect on peer interactions in supporting cognitive thinking and metacognitive skills during the problem-solving processes. The videotaped observation data were transcribed (see Appendix G) and analyzed subsequently.

Interviews. In this study, interviews were conversations between the researcher and the participants of the selected cases after they had completed the problem-solving task. Interviews served two purposes: first, to clarify what was not clear to the researcher from think-aloud protocols, observations or the problem-solving reports, such as intentions, actions, thoughts or decisions; and second, to probe into the students' reflection on their problem-solving processes, such as how they solved the problem, how they came up with solutions, or how the question prompts or peer interactions worked for them during the problem-solving process. For the latter purpose, structured interview questions (Appendix F), such as "what", "how" and "why", were used to make inquiries into students' problem-solving process, effects of question prompts, and effects of peer interactions.

The Self-Report Questionnaire

To test the assumption that the participants were equivalent, the participants were asked to complete a self-report questionnaire immediately after the problem-solving task. The questionnaire was focused on the participants' background information, including their prior experience in problem solving and the overall strategies used for problem solving. Rockwell & Kohn (1989) refer to such a self-report questionnaire as the "post-then-pre" method. This design was expected to account for changes in learners' knowledge by allowing participants to first report their present behaviors (post); and then rate how they perceived these same behaviors just before taking the test (then pre) (Rockwell & Kohn, 1989). Rockwell and Kohn found that the retrospective pretest at the end of a study was accurate and reliable.

The self-report questionnaire on problem-solving skills (Appendix E) was developed based on the work by Schoenfeld (1985) and Hong (1998). There were two primary parts in this evaluation. The first part sought participants' background information, such as major, the year in college, their prior experience with problem solving, and their computer skills. The second part of the questionnaire made inquiries into students' self-rating of their problem-solving skills. It consisted of 20 statements grouped into four areas. The first area (Questions 11-15) was focused on interpreting and problem representation; the second (Questions 16-20) area was focused on developing solutions and the monitoring of solution processes; and the third (Questions 21-25) on making justifications and evaluating their problem-solving processes. The fourth area (Questions 26-30) inquired about students' specific strategies for solving a problem.

The Implementation Procedures

The study procedures consisted of four primary steps: (1) recruiting participants; (2) developing and testing research procedures; (3) assigning participants to different conditions; (4) administering the research sessions, including the problem-solving task;

observations, think-aloud protocols, self-report questionnaire, and follow-up interviews. An outline of the procedures is diagrammed in Figure 3.3.

Step 1: Recruiting Participants

With the approval of the Office of Regulatory Compliance and the IST 110 professors, the researcher recruited participants from the three IST 110 class sections a week before conducting the study. Each of the IST 110 classes consisted of 45-50 students. The researcher explained the study purpose, described the task and general procedures of the study, and the benefits to the students. The students were also informed that the study would be carried out during a lab session and they would earn 2-3 extra credit points by participating in this study.

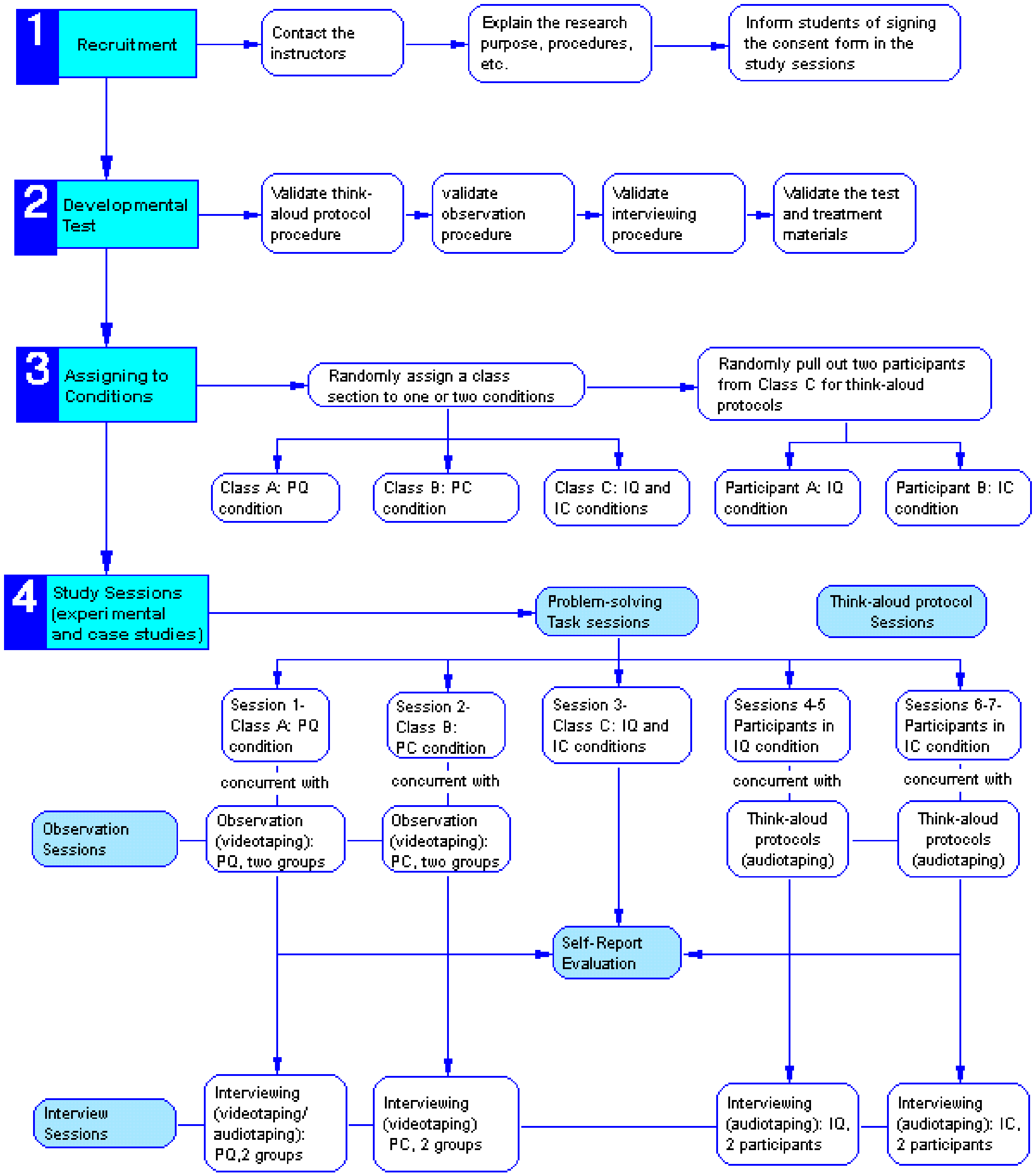


Figure 3.3. Flowchart of implementation procedures for the research.

Step 2: Developing and Testing Research Procedures

Prior to the formal study sessions, a developmental test was conducted to validate research procedures. The researcher recruited some participants from a fourth IST 110 class, who were not going to participate in the formal study. There were two purposes to the developmental test: first, to test the materials, including the problem-solving task material, the treatment material (the question prompts) and the questionnaire; secondly, to test the research procedures, such as think-aloud protocols, videotaping peer interactions, and conducting interviews. Three individuals did the think-aloud protocols with the comparative case study, and three groups were observed engaged in the same problem-solving task. Some individuals or groups were provided with the question prompts while solving the problem. The participants were randomly assigned to the four different conditions, depending on their schedules and availability for forming a group of 3 or 4. In the think-aloud session, the researcher explained to the individual participants how to talk aloud during problem solving. The interview session not only allowed the researcher to test the interview procedure and the interview questions, but also to get feedback on the problem-solving task and treatment materials. The problem-solving task session took 115 minutes, the same amount of time allowed for the following formal study sessions.

Step 3: Assigning Participants to Different Conditions

The three IST 110 classes were randomly assigned to one of the conditions as intact groups for two reasons. First, since the study was incorporated into the curriculum as a regular lab session, it was not realistic to mix the participants from the three classes and randomly assign them to one of the conditions. Second, carrying out the study in the natural setting of the class had a value in the research, especially for the comparative case study. Therefore, the participants in one class section were assigned to the PQ condition, those in the second class section were assigned to the PI condition, while the participants in the third class section were randomly assigned either the IQ or the IC condition. The participants of the three class sections participated in the experimental study within the same week, but at different class schedules. The two individuals selected for think-aloud protocols were pulled out of the class and completed the problem-solving task on two separate occasions.

Step 4: Administering the Study Sessions

The problem-solving sessions. The problem-solving task was administered in five separate sessions during the same week, with 115 minutes for each session:

- Session 1: The problem-solving task was given to the participants in the PQ condition.
- Session 2: The problem-solving was given to the participants in the PC condition.
- Session 3: The class was randomly divided into two halves, with some assigned to the IQ condition and others to the IC condition.
- Sessions 4-5: Two individuals (IQ) solved the problem separately in Session 4 and 5, during which they were audiotaped for think-aloud protocols and follow-up interviews immediately after they had completed the problem-solving task.

- Sessions 6-7: Two individuals (IC) solved the problem separately in Session 6 and 7, during which they were audiotaped for think-aloud protocols and follow-up interviews immediately after they had completed the problem-solving task.

In Session 1 and Session 2, the TA of the two classes helped the researcher to start the study session. She told the students to get into the preexisting groups (the same groups assigned by their professor for doing the class project), introduced the researcher, and explained the lab task (the problem-solving task for the study) and the number of extra credit credits the students could get by participating in the study and signing the consent form. For those students who did not sign the consent form in the previous lab, they were told to sign one in this lab if they wanted to participate in this study. Five minutes later, the researcher took over the class and explained the specific requirement and procedure for the problem-solving task. Throughout the session, the researcher attended to the students' questions, of which she only answered those related to the procedures and requirement for the study. No hints or assistance associated with problem solving were provided to the participants.

In Session 1, the participants assigned to the PQ condition were provided with the question prompt treatment material when the material was passed out, both of which were posted on the class web site. The printed materials were also passed out at the same time. They were reminded several times throughout the study session that they should use the question prompts as a guide to help them solve the problem. In Session 2, the same procedure was applied, but only the problem-solving task material was provided.

In Session 3, in which the participants were randomly divided into two conditions, the researcher first explained the purpose of the study and the extra points the students were going to earn by participating in this study. As the researcher was the TA of this class, the students in this class had already filled out the consent form a week earlier through a third party. The researcher projected to the screen the list of the students grouped into two different conditions. She told the students that they were going to be assigned to two different groups, with Group A moving to the right side of the classroom and Group B to the left side of the classroom. The students checked their names and moved to the appropriate side of the classroom according to instructions. Then the researcher passed out the problem-solving material. The materials for the two groups were color-coded, with Group A getting yellow sheets and Group B getting white sheets. The researcher explained to the students that the difference between the two materials was only a matter of a different version, and that the tasks and the requirements were all the same. The students were also reminded at the beginning that this was individual work only and that there should be no communication with other peers. The students in Group A (IQ) condition were reminded frequently to pay attention to the question prompts on the other side of the problem-solving task page.

Think-aloud protocols sessions. The four participants selected for think-aloud protocols were assigned to four different sessions (Sessions 4 and 5; IQ; Session 6 and 7, IC) outside of the laboratory session. During every session, the researcher explained to the individual how to talk aloud. She demonstrated the think-aloud procedure by talking aloud while using MS Word to write a paragraph. Then she showed another example of talking aloud while calculating a summation in her head. She made sure that the student understood how to do the think-aloud protocol before she turned on the tape recorder. Throughout the process, the researcher reminded the participant to continue talking or to raise his or her voice.

Observation of the problem-solving processes. Observation and the problem-solving task occurred concurrently in Session 1 and Session 2 while the PQ and the PC participants were completing the problem-solving task. After the instructions for the problem-solving task were explained to the students, the students started to work on the problem in groups. The researcher first did a quick assessment based on how verbally interactive a group was before deciding which groups she wanted to videotape; then she approached the two groups and asked them for approval for videotaping. Two colleagues of the researcher were helping with videotaping the sessions.

The self-report questionnaire. The self-report questionnaire was passed out to the participants after they completed the problem-solving task at the end of the session. Every participant was asked to fill out a questionnaire whether they were in individual or group conditions.

Follow-up interviews sessions. Each of the four selected individuals who completed think-aloud protocols, with two from the IQ and two from the IC conditions, was interviewed right after he or she had completed the problem-solving task. The two selected groups from Session 3 (PC), were interviewed separately three or four days later at separate sessions. Due to some problems in the observation session with Session A, which was mentioned earlier, the two previously selected groups from Session 1 (PQ) were excluded from the interview sessions. Instead, the researcher selected another two groups in their place based on the quality of their solution reports.

Except for one group, in which one member did not want to be videotaped, all the interviews with the selected groups were videotaped. All the interviews with the individuals who completed think-aloud protocols were audio-taped.

The interview sessions for the individuals lasted about 20-30 minutes, while focus-group interviews lasted about 30-40 minutes. The interviews with the individual participants were audiotaped, while the interview sessions with the groups were videotaped.

Data Analysis Procedure and Method

Quantitative data and qualitative data were first analyzed separately, then the results from the two data sources were triangulated. Quantitative data sources consisted of the evaluation results of students' problem-solution reports and their self-report questionnaire. The data sources for the qualitative data included think-aloud protocols and individual interviews from the audiotape and the observation and group interviews from the videotape. The following describes in detail the data analysis procedures and methods for both quantitative data and qualitative data.

Quantitative Data Analysis

Evaluation of the Problem-Solution Reports

The evaluation process. Three raters, including the researcher, evaluated the problem-solving reports. Before distributing the reports to the other two raters, the researcher removed the names of the participants from the reports and used an ID system in their place. Every report was labeled with an ID number so that the other two raters had no information of the treatment condition the participants were in when evaluating the reports. Then, the raters met to discuss the scoring rubrics. The researcher explained every construct, attribute, and scale of the scoring rubrics (Appendix D) to the other two raters with illustration of examples in order to reach a conceptual consensus on the evaluation among the raters. Next, the raters evaluated the comparative case study reports individually using the scoring rubrics. The researcher evaluated all the reports while the other two raters evaluated 3/4 of the reports. During this period, the researcher and the other two raters talked on the phone or met frequently to discuss any question regarding the rubrics or the students' reports during the evaluation process. Due to the time constraint, only a few items with great discrepancies were discussed. Thus, instead of taking the approach of reaching consensus among the raters on every item and for every report, the point values assigned by the three raters were calculated for measure agreement. Crosstabs was used for this procedure.

After all the reports were evaluated, the scores by the three raters were entered into the SPSS computer program by the researcher, who did an overall comparison of the scores by items among the three raters. If there were discrepancies among the three raters, the researcher would note them down, and then the three raters would meet again to review the reports and discuss the evaluation on specific items. After an overall agreement was reached on the evaluation of all the reports, the researcher finalized the scores in the data sheet of the SPSS program before computing the interrater consistency.

Interrater consistency. The scores of the problem-solving reports by the three raters were analyzed using the Crosstabs technique in the SPSS program, which calculates the measure agreement between raters (Huck, 2000). The Kappa value, an interrater reliability coefficient, was used for the Crosstabs. It takes into account base rates, which were the relative frequency of the behavior being rated in the study. A summary of the crosstabs results for measure of agreement among the three raters is presented in Appendix D. There was significant agreement among the raters for items 1.3 and 2.2 on all the point values assigned. For most of the items (1.1, 1.2, 1.4, 3.2, 4.1, and 4.2), there were significant agreement on most point values assigned, but with some variations on a few. However, for items 2.1 and 3.1, there was no significant agreement among the raters. In spite of some variations among the raters, in examining the Crosstabs results, the researcher judged the interrater consistency to be overall acceptable. In cases where there was not a full agreement on a specific item among the raters, the point value assigned by two of the three raters was used, for instance, if 2, 2, 1 were assigned by different raters, 2 was used for the data analysis.

Problem-Solving Report Data Analysis

Justifications for using MANOVA. Multivariate Analysis of Variance (MANOVA) was considered for the data analysis of the experimental study. MANOVA is a procedure for analysis of variance and covariance for models containing two or more dependent variables (Stevens, 1986). MANOVA is performed for two reasons: (1) greater statistical power for detecting true differences; and (2) control of false positive results (Type I error). However, MANOVA presumes that interval data is used. Therefore, the use of MANOVA for this experimental study, in which ordinal data is used, becomes a concern. Yet, the work of Anderson (1964, 1976, 1977) showed that under certain conditions, numerically coded-category scales often approximated interval scales that justified an approximate equal-interval assumption. Thus, the rubric values used for this experimental study were also considered approximate interval/ratio data, which justified the use of MANOVA.

A moderate to strong correlation among the dependent variables is an additional justification for using two-way MANOVA. If subsequent overall MANOVA results are statistically significant, a one-way analysis (ANOVA) is conducted to further examine or identify where the differences reside. If there is no correlation, or if the correlation is weak among the dependent variables, MANOVA is not considered since a single outcome measure may be diluted in a joint test involving many variables that display no effect. In such a situation, individual univariate tests are directly conducted.

Pearson's correlation. The scores of the problem-solving reports were analyzed by examining the relationships among the multiple dependent variables by using Pearson's correlation technique. The purpose was to determine if there were statistical justifications to use Multivariate Analysis of Variance (MANOVA) (Stevens, 1986). The results of the Pearson's correlation (see Table 3.4) indicated an overall correlation among the four dependent variables (*problem representation, developing solutions, making justifications, and monitoring and evaluation*), significant at the .01 level. Although the correlation between *developing solutions* and *monitoring and evaluation* was only .26, significant at the $p < .05$ level, the overall correlation among the dependent variables was considered a moderate relationship. Therefore, multivariate analysis of variance was used.

Table 3.4
Pearson's correlation among the four dependent variables in ill-structured problem solving processes

Variable	1. Problem Representation	2. Generate Solutions	3. Construct Argument	4. Monitoring and Evaluation
		Participants (n=55)		
1. Problem Representation	—			
2. Generate Solutions	.544**	—		
3. Construct Argument	.625**	.491**	—	
4. Monitoring and Evaluation	.549**	.260	.494**	—

Note. ** suggests that correlation is significant at the 0.01 level (2-tailed).

Assumptions for MANOVA. MANOVA testing assumes that the residual errors follow a multivariate normal distribution in the population; this is a generalization of the normality assumption made in ANOVA. Since the sample size was small and it varied across different treatment groups in this study, it was especially important to investigate the homogeneity of variance assumption. A multivariate test of homogeneity of variance (the Box's M Test and the Levene's Test) was available to check this assumption. The Box's M Test tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups while the Levene Test tests the null hypothesis that the error variance of the dependent variable is statistically similar across groups. The results from the Box's M Test and the Levene's Test showed that the assumption of equal variance was met at the .05 alpha level.

After determining that the assumptions were met, the multivariate statistical output was examined. Then, providing the MANOVA result was statistically significant, the univariate results were examined for each dependent variable. For the significant univariate results, the post hoc comparisons were performed to identify where the differences resided. Since the assumption of equal variance was met and there were unequal subjects in the treatment levels, the Scheffe statistic was used for the post hoc results. The results of the multivariate tests, the univariate tests, the multiple comparison among the four dependent variables, as well as the descriptive statistics for the dependent variables are reported in Chapter 4.

Self-Report Questionnaire Data Analysis

Regarding the questionnaire, descriptive statistics were used to generate a profile of the participants' background information and their perceptions of their own problem-solving skills. The frequency count was used for Questions 1-10 to tabulate the results. For Questions 11-30, which were rated on a Likert scale of 1-5, mean scores were calculated for every treatment group and according to different question areas (i.e., Area 1: Questions 11-15; Area 2: Questions 16-20; Area 3: Questions 21-25; and Area 4: Questions 26-30). A one-way analysis (ANOVA) was conducted to determine the significance of the mean differences across different treatment groups. In addition, a reliability test was run for every question area to determine the Cronbach Alpha reliability values.

Qualitative Data Analysis

All the audiotaped and videotaped data from the think-aloud protocols, observation and interview sessions were transcribed (see Appendix G) before conducting the data analysis. Miles and Huberman's (1994) data analysis model, which involves three subprocesses of data reduction, data display and conclusion drawing and verification, was used to guide the qualitative data analysis of this study. The data analysis primarily consisted of following steps: reading and jotting marginal notes on the transcripts; identifying patterns and labeling concepts; organizing labeled concepts into a data display matrix, identifying themes and drawing conclusions. The focus of the analysis was on cross-case comparison viewed from different dimensions: the four ill-structured problem-solving processes and the effects of question prompts and peer interactions.

In the first step, the researcher read the transcripts several times and jotted notes wherever appropriate. After she had read through the transcripts of all the cases, she identified patterns and coded them with labels, such as "activating prior knowledge", "multiple perspectives", and "elaborating thoughts". The constructs and attributes for problem-solving processes were also used for labeling (e.g., "seek needed information", "explaining the system", "evaluate alternative solutions").

The next step was organizing the "reduced data" (Miles and Huberman, 1994), such as labeled coding, into a data display matrix. During this stage, the researcher reviewed the research questions, by which she presented the data in the data display matrixes or a data causal network (see Appendix H). The first data display matrix was a summary of cross-case comparisons of students' problem-solving process by conditions (IQ, IC, PQ, and PC). This matrix provided an overview of the students' problem-solving processes in different treatment conditions. Further, the data was organized by each of the problem-solving processes (e.g., problem representation), showing comparison of different cases in one particular problem-solving process. Organizing data by problem-solving processes helped the researcher to triangulate the comparative case study results with the experimental study results, which helped to interpret the experimental study results and answer questions such as "why IQ outperformed PC".

The third data display was a data causal network showing the effects of question prompts on students' problem solving and their cognitive thinking and metacognitive knowledge. The relationship between peer interactions and students' problem solving was presented through another data display matrix. These data displays were organized according to Research Questions 4 and 5, showing the cause-and-effect of question prompts and peer interactions. They helped the researcher to identify themes and draw conclusions to answer Questions 4 and 5. Based on the data display, conclusions were drawn on the influence of question prompts and peer interactions on students' cognitive thinking and metacognitive knowledge during their problem-solving processes.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the results of the study from the data analysis of the experimental study as well as the comparative case study. The results of the experimental study, in response to the three research questions (Questions1, 2 and 3), will be reported first. Following an overview of the statistical data analysis from the multivariate analysis of variance (MANOVA), the hypotheses presented in Chapter 1 will be examined, and the findings to the first three research questions will be discussed. Next, the findings from the comparative case study will be summarized and discussed. The comparative case study results are expected to serve two purposes: to provide insights into the findings of the experimental study and to explore and understand issues related to Research Questions 4 and 5. An overview of the eight cases will be presented, and the cross-case comparison will be summarized and discussed with specific focus on the four ill-structured problem-solving processes and the fourth and the fifth research questions. Last, the results of the self-evaluation questionnaire will be reported to provide a general profile of the participants' background information and their prior experience and knowledge in problem solving.

The Experimental Study Results

The purpose of the experimental study was to study the effects of (a) question prompts and (b) peer interactions on students' ill-structured problem solving performance, specifically in the processes of (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions. A multivariate analysis of variance (MANOVA) was employed to analyze the relationships between question prompts and the four problem-solving processes, as well as between peer interactions and the four problem-solving processes across the four different conditions (Peer-Question, Peer-Control, Individual-Question, and Individual-Control).

The statistical differences of the four treatment groups were compared and analyzed according to each of the four problem-solving outcomes. The research hypotheses were tested using the results from multivariate analysis of variance (MANOVA) and univariate analysis of variance (ANOVA) per procedures described by Tabachnick and Fidell (2001) and Stevens (1986). The results of the analysis were used to answer Research Questions 1-3.

Statistical Data Analysis

Table 4.1 presents the results of multivariate analysis of variance, showing overall differences for the treatment group effect and the four dependent variables of problem-solving processes. The Pillai's Trace was used to evaluate the multivariate (MANOVA) differences. The MANOVA results were statistically significant ($F = 4.025$, $p < .001$). This means that there were some statistical differences on at least one dependent variable. Further, the results of the univariate ANOVA tests, which are presented in Table 4.1, indicated that there were significant statistical differences in all the four dependent variables, with an F ratio of 20.433, 8.267, 11.263 and 7.213 respectively, significant at the $p < .001$ level.

Table 4.1
Summary of multivariate analysis of variance (MANOVA) results and follow-up one-way analysis of variance (ANOVA) results

MANOVA Effect and Dependent Variable	Multivariate F Ho:df = 12	Univariate F df = 3, 51
Treatment Group Effect	Pillai's Trace 4.025 (p <.001)	
Representing Problem		20. 433 (p < .001)
Developing Solutions		8.267 (p < .001)
Making Justifications		11.263 (p < .001)
Monitoring and Evaluation		7.213 (p < .001)

Therefore, the researcher further investigated the univariate statistics results (one-way analysis of variance) by performing a post hoc comparison for each dependent variable in order to identify significantly where the differences resided. Since the assumption of equal variance was met for the univariate statistics (the Levene's Test of equal variance p > .05), the Scheffe post hoc test was used. Table 4.2 is a summary of post hoc Scheffe mean comparison.

Table 4.2
Summary of Post Hoc Scheffe comparison

	Dependent Variable			
	Representing Problem	Developing Solutions	Making Justifications	Monitoring and Evaluation
Comparison Group	Mean Difference (%)	Mean Difference (%)	Mean Difference (%)	Mean Difference (%)
Peer Question (PQ) vs. Peer Control (PC)	**35.9441***	**20.2797***	**33.6663***	**35.5644***
Peer Question (PQ) vs. Individual Question (IQ)	**17.6410***	11.7949	7.6923	1.5385
Peer Question (PQ) vs. Individual Control (IC)	**39.8077***	**21.2740***	**27.3352***	**34.7527***
Peer Control (PC) vs. Individual Question (IQ)	**-18.3030***	-8.4848	**-25.9740***	**-34.0260***
Peer Control (PC) vs. Individual Control (IC)	3.8636	.9943	-6.3312	- .8117
Individual Question (IQ) vs. Individual Control (IC)	**22.1667***	9.4792	**19.6429***	**33.2143***

Note.

(a) The mean difference shown in this table is the subtraction of the second condition (on the lower line) from the first condition (on the upper line); for example, 35.9441 (Mean Difference for Problem Representation) = PQ - PC.
(b) (%). The mean difference is converted into percentage in order to create a common basis for mean comparison, as the subtotals for the four dependent variables are different.
(c) *. The mean difference is significant at the .05 level.
(d) Mean difference (%) is calculated using the values which appear in Table 4.3.

Table 4.3 summarizes the descriptive statistics for the dependent variables by treatment groups. As each dependent variable had a different subtotal of scaled points (10 points for Representing the Problem, 8 points for Developing Solutions, 7 points for Making Justifications, and 7 points for Monitoring and Evaluation), the percentage was used for the means to indicate the possible points earned out of the total. The use of the percentage helped to create a common basis for the mean comparison among the four dependent variables.

Table 4.3
Descriptive statistics for each dependent variable by treatment group

	Treatment Group							
	Peer Question (PQ) (N=13)		Peer Control (PC) (N=11)		Individual Question (IQ) (N=15)		Individual Control (IC) (N=16)	
Dependent Variables	Mean %	SD %	Mean %	SD %	Mean %	SD %	Mean %	SD %
Representing Problem	62.3077	17.3944	26.3636	15.6670	44.6667	15.5226	22.5000	11.2546
Developing Solutions	88.4615	11.9259	68.1818	17.1060	76.6667	10.4226	67.1875	11.0633
Making Justifications	79.1209	18.0846	45.4545	12.4838	71.4286	17.0747	51.7857	18.7174
Monitoring and Evaluation	61.5385	31.0719	25.9740	24.5932	60.0000	30.1599	26.7857	22.6629

Table 4.2 shows that there are many statistical mean differences among the four treatment conditions in the four dependent variables. Table 4.3 displays the means and the standard deviations of different treatment conditions by dependent variables. The mean differences are discussed below.

Problem representation. The Peer-Question (PQ) group (Mean = 62.3%, SD = 17.4%, p= < .001) significantly outperformed the other treatment groups (Peer-Control, Individual-Question, and Individual Control), with a mean difference of 35.9%, 17.6% and 39.8% respectively. Interestingly, the Individual-Question (IQ) group (Mean =

44.7%, SD = 15.5%) did significantly better not only than the Individual-Control (IC) group (Mean = 22.5%, SD = 11.3%), but also the Peer-Control (PC) group (Mean = 26.4%, SD = 15.7%). The mean difference between IQ and IC was 22.2% (p = .002), and that between IQ and PC was 18.3% (p = .032).

Developing Solutions. The PQ group (Mean = 88.5%, SD = 11.9%) significantly outperformed the PC group (Mean = 68.2%, SD = 17.1%), with a mean difference of 20.3% (p = .003). Additionally, the PQ group also performed significantly better than the IC group (Mean = 67.2%, SD = 11.1%), with a mean difference of 21.3% (p = .001). However, the result did not show any significant difference for "developing solutions" between the PQ group and the IQ group (Mean = 76.7%, SD = 10.4%), with p > .05.

Making Justifications. The PQ group (Mean = 79.1%, SD = 18.1%) again significantly outperformed the PC group (Mean = 45.5%, SD = 12.5%) and the IC group (Mean = 51.8%, SD = 18.7%). The mean difference between the PQ group and the PC group was 33.7% (p = .000), and the mean difference between the PQ group and the IC group was 27.3% (p = .001). The IQ group (Mean = 71.4%, SD = 17.1%) also did significantly better than the PC and the IC groups, with a mean difference of 25.9% (p = .004) and 19.6% (p = .024) respectively.

Monitoring and Evaluation. The PQ (Mean = 61.5%, SD = 31.1%) group performed significantly better than its counterparts, the PC group (Mean = 25.9%, SD = 24.6%) and the IC group (Mean = 26.8%, SD = 22.7%). The mean differences were 35.6% (p = .026) and 34.8% (p = .014) respectively. However, the PQ group did not outperform the IQ group (Mean = 60.0%, SD = 30.2%). At the same time, the IQ group also outperformed the PC and the IC groups, with a mean difference of 34.0% ($p = .028$) and 33.2% ($p = .015$) respectively.

Three noticeable patterns emerged from the statistical results. First, the PQ group outperformed the PC and the IC groups in all the four processes of problem solving. However, the PQ group outperformed the IQ group only in Representing the Problem. Second, the IQ group did significantly better than the PC and the IC groups in three of the problem-solving processes: Representing the Problem, Making Justifications, and Monitoring and Evaluation. Third, there were no significant differences between the PC group and the IC group in any of the problem-solving processes.

Summary of Hypotheses Tested

The research hypotheses were tested with the statistical data. Each hypothesis is presented, followed with a discussion of the results.

Hypothesis 1 (IQ > IC)

Students working individually and also receiving question prompts will demonstrate better problem-solving skills on an ill-structured task than their counterparts who did not receive the question prompts in (a) problem representation, (b) developing solutions, (c) making justifications and (d) monitoring and evaluating solutions.

The statistical results confirm the hypothesis, showing that students working individually and also receiving question prompts demonstrated higher problem-solving skills on an ill-structured task than the individuals who did not receive the question prompts in (a) problem representation, (c) making justifications, and (d) monitoring and evaluating solutions. However, they did not perform significantly better in (b) developing solutions.

Hypothesis 2 (PQ > IQ, IC; PC > IQ, IC)

Students working with peers, with or without question prompts, will demonstrate better problem-solving skills on an ill-structured task than students working individually, with or without question prompts, in (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions.

The statistical results partially support the hypothesis, that is, "PQ > IQ, IC" is confirmed while "PC > IQ, IC" is not. Students working with peers and also receiving question prompts outperformed the students working individually but without question prompts in all the four problem-solving processes. They also outperformed the students working individually but also receiving question prompts in (a) problem representation.

However, no significant differences were found in any of the four problem-solving processes between the students working with peers but without question prompts and those working individually without the question prompts. On the contrary, individuals who received question prompts did significantly better than the peers who received question prompts in three processes: (a) problem representation, (c) making justifications, and (d) monitoring and evaluating solutions.

Hypothesis 3 (PQ > IC, IQ, PC)

Students working with peers but also receiving question prompts will demonstrate better problem-solving skills on an ill-structured task than all the other treatment groups

(PC, IQ, and IC) in (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions.

In (a) problem representation, students working with peers but also receiving question prompts (PQ) demonstrated better problem-solving skills on an ill-structured task than the students in the other conditions (PC, IQ, and IC).

In (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions, the students in the PQ condition did significantly better than those in the PC and the IC condition. By comparison, in these three dependent variables, the students in the IQ condition performed statistically the same as those in the PQ condition.

Summary of Findings to Research Questions 1 - 3

The findings to the three research questions (Questions 1-3) are summarized below.

Question 1

Does the use of question prompts have an effect on students' problem solving on an ill-structured task in (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions?

Overall, question prompts have a significant effect on students' problem solving skills on an ill-structured task in (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions. This is evidenced by the statistical result that the PQ group significantly outperformed the PC and the IC groups in all the four problem-solving processes, and than the IQ group in (a) problem representation. In addition, except in (b) developing solutions, the IQ group significantly outperformed the PC and the IC groups. The result showed that the PQ group outperformed the IQ group only in (a) problem representation, which further indicated the effect of question prompts. It may be explained that the effect of the question prompts was so strong that the effect of peer interactions became less apparent.

Question 2

Does the use of peer interactions have an effect on students' problem solving on an ill-structured task in (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions?

Peer interactions had a partially positive effect on students' problem solving processes. The students in the PQ condition outperformed those in the IC condition in all the problem-solving processes and IQ condition in problem representation; however, the students in the PC condition did not perform significantly better than those in the IQ or the IC condition.

Question 3

Does the use of question prompts combined with peer interaction have an effect on students' problem solving on an ill-structured task in (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluating solutions?

Peer interactions have a significant effect on students' problem solving on an ill-structured task only when the strategy is combined with the strategy of question prompts. In fact, the PQ group outperformed the PC and the IC groups in (a) problem representation, (c) making justifications, and (d) monitoring and evaluating solutions, and the IQ group in (a) problem representation.

Summary of the Experimental Study Results

By comparing the two instructional strategies (question prompts and peer interactions), question prompts were found to be a dominant strategy over peer interactions, especially for the novice learners who have little experience in solving ill-structured problems. The experimental results revealed that students need procedural facilitation provided by some types of instructional intervention, such as question prompts, in order to be able to benefit from peer interactions in the group processing. In other words, peer interactions only work well for students when proper guidance for solving ill-structured problems, such as question prompts, are provided. Without proper guidance, the strategy of peer interactions may not show its advantages for students' ill-structured problem solving in comparison with students who work individually. On the other hand, students who worked individually but also had access to instructional guidance (e.g., question prompts), were found to perform significantly better during ill-structured problem solving than the students working with peers but without guidance.

The experimental study results will be triangulated with the qualitative data results from the comparative case study in the next section. The results from the comparative case study provided further information, which allowed the researcher to interpret the experimental study results and explore in-depth the relationships between question prompts and peer interactions and their impact on students' problem solving processes in an ill-structured task.

The Comparative, Multiple-Case Study Results

Eight cases were studied for cross-case comparison. The purposes of the multiple-case study are explained, and the case sampling and selection procedure are described in Chapter 3. After a brief introduction of the eight cases from different conditions, the multiple cases are compared according to the four ill-structured problem-solving processes. Following the cross-case comparison, the multiple-case analysis will be specifically focused on Research Questions 4 and 5.

Overview of the Cases

The eight cases were selected from the different four conditions (IQ, IC, PQ, and PC), with two cases from each condition. The following is an overall description of the cases, the treatment condition and a brief profile of the participants (e.g., major, the college year, and their experience with problem solving). The treatment condition is indicated in brackets. Pseudonyms are used to protect the identity of the participants.

Case 1 (IQ). Cathy, a participant in the Individual-Question condition, was a student majoring in Information Sciences and Technology (IST). She was selected by the researcher to do a think-aloud protocol in the question-prompts condition while solving the problem by herself. She also had an interview with the researcher following the think-aloud activity.

Case 2 (IQ). Joe, majoring in business and thinking of transferring to the IST major, was another participant in the Individual-Question condition. Like Cathy, he also did a think-aloud protocol with his problem-solving task and had a follow-up interview with the researcher.

Case 3 (IC). Shelly, was an IST major. She was a participant in the Individual-Control condition, in which she worked on the problem-solving task without the question prompts. She also performed a think-aloud protocol and interviewed with the researcher following the problem-solving task.

Case 4 (IC). Paul is an IST major and another participant in the Individual-Condition condition. Like Shelly, he worked on the problem-solving task without the question prompts, followed by an interview with the researcher.

Case 5 (PQ). This case consisted of a group of four participants working in the Peer-Question condition who received question prompts for the problem-solving task: Mark, Gerry, Al, and Sarah. Except Gerry, whose major was Computer Science, they were all IST majors. There was one female student and three male students. They had a follow-up interview with the researcher a couple of days after the problem-solving task.

Case 6 (PQ). This is another group of four participants in the Peer-Question condition, who received the question prompts during the problem-solving task and were interviewed afterwards. The members were Perry, Brandon, Matt, and Sheryl. They were all IST majors.

Case 7 (PC). There were four participants in this case, selected from the Peer-Control condition. They were Bryan (IST major), Gary (Electrical Engineering, sophomore), Joanne (Elementary Education) and Jim (no major yet). This group was heterogeneous in terms of their background (e.g., the major). Their problem-solving activity was videotaped and so was the follow-up interview, which was carried out several days later.

Case 8 (PC). This case consisted of three participants, Andy, Devin, and Victor. They were all males and IST majors. It was observed through the videotaping that this group was largely dominated by Andy, who delegated and divided up the group work. There were two data sources for this group: observation and the interview. However, it was noted that there were not many peer interactions among the group members during their problem-solving task.

The four participants in the individual conditions (IQ and IC), who were selected for the comparative case study, were considered good students by the instructor teaching this class. Whereas, the two groups in the PQ conditions were selected post hoc based on the quality and representativeness of the problem-solution reports. The other two groups in the PC conditions were selected for class observation based on the level of their interactions. The groups were pre-existing groups, in which the students had worked together for a problem-solving project. These students had some problem-solving experience from working on their IST 110 class project, some more than the other. Andy in Case 8 (PC) said that he had solved a similar problem in high school. In the IC condition, Shelly said that she had solved a similar type of the problem as well.

The data sources for the cross-data comparison were think-aloud protocols, interviews and observations. For the IQ and IC conditions (Case 1, 2, 3 and 4), think-aloud protocols and interviews were available while for the four groups, interview data were available. For Case 7, there was also observation data from the video transcripts, in addition to the interview.

Cross-Case Comparison on Students' Problem-Solving Processes

Representing the Problem

In this ill-structured problem-solving process, the cross-case comparison was focused on four attributes, which were in accordance with the scoring rubrics (see Appendix D): (a) defining the problem, (b) generating subgoals, (c) identifying available information (factors and constraints), and (d) seeking needed information. The cross-case analysis revealed two major themes: first, the students tried to relate the problem to their prior experience and knowledge, such as a customer of WalMart; second, the question prompts had an influence on students' intentional efforts in identifying and seeking needed information.

All the participants across the cases started the problem-solving task by relating the problem scenario to their prior experience, such as a WalMart customer. For Joe (IQ), since he had experience working in a retail store before, he had a better idea of what the problem entailed. Shelly (IC), since she had solved a similar problem for an IST group project, could relate the problem to her prior experience. Prior experience served to activate students' repertoire of knowledge, which helped them to understand the problem and develop the solutions. Based on previous research on problem-solving processes (Gick, 1986), this is a strategy typically employed by a learner during problem solving. When constructing a representation of the problem, the solver extracts the given and goal information and attempts to "understand" the problem (Greeno, 1978), so that an integrated representation can be formed (Gick, 1986). When schema activation occurs during this phase of problem solving, the problem-solving process is schema driven, with little search for solution procedures (Gick, 1986).

Second, depending on whether or not they had received the question prompts, the students varied in their intentional efforts to identify relevant information and seek needed information. For problem representation, the question prompts (see Appendix C) asked about parts of the problem and the user (user's need, expected information, and levels of prior knowledge). Prompted by the question prompts, the students who received the prompts were more deliberate in problem representation, such as listing and discussing the factors, constraints, and available information specifically. In addition, there were more factors and constraints identified. Cathy in Case 1 (IQ) was aware of the need to "answer some of the questions on the back of the page about the user". Subsequently, she proceeded to discuss specifically the questions asked in the Question Prompts (e.g., the user, level of prior knowledge). The problem-solution report by Case 6 (PQ) also indicated that they followed the question prompts in several places, for instance, identifying the information needed for developing the networked computer system (e.g., the products and their location in the store) and describing how the user will be interacting with the system. For Joe (Case 2, IQ), in response to some of the question prompts, he tried to seek needed information such as what and how many products the store carried and what needed to be done. As evidenced by the problem-solution report, Case 5 (PQ) was also deliberately seeking the needed information for the Shopper Computer Reference Terminal (SCRT) they were going to develop, such as inventory count, location of each item, and the cost.

By comparison, Case 3 (IC) and Case 4 (IC) in the control condition failed to discuss the available information and relevant factors explicitly, and they "came up with the solution pretty quickly". Although they addressed some of the relevant factors in their solution process (e.g., the user and usability) as they came to mind, the number of factors and constraints identified were very limited in comparison to the individuals or the groups receiving the question prompts. Case 7 (PC) simply skipped the problem representation and jumped right to the solution process, although the issues of user and usability came up, as they were developing the solutions. Case 8 (PC) did go through the process of problem representation, but they failed to include it in their solution reports.

The comparative case study results support the findings from the experimental study, which indicated that question prompts helped the participants to define the problem and identify relevant factors and available information, which in turn helped them to make connections between different parts of the problem. The reason why the participants in the Peer-Question condition performed better than the Individual-Question condition could possibly be explained by the multiple perspectives that the peers brought to the problem, which might result in an increased number of factors and constraints identified.

In summary, students in both conditions started the problem-solving process by relating to their prior experience as a WalMart customer. However, after defining the problem and generating subgoals, the students in the IQ and the PQ conditions were prompted to identify the factors and constraints while developing the solutions whereas those in the IC and the PC conditions jumped immediately to the solution process. In addition, the former paid special attention to the factors and constraints elicited by the experts' questions while the latter just discussed the factors and constraints that came to mind in the problem development process. In this situation, the students in the IC and PC conditions might have overlooked some important issues or aspects of the problem, which might have influenced their problem-solving processes. Intentional learning, as supported by prompting, helped to facilitate students' metacognitive knowledge and direct them to be more self-regulated (Brown & Palincsar, 1989; Salomon, 1985).

Developing Solution (s)

As suggested by the scoring rubrics, the solution process was evaluated by (a) the successful generation of the solution(s) with explicit explanations and (b) holistic assessment of the solution quality with specific considerations of factor and constraints identified. The question prompts corresponding to this process asked: "What should the system do?", "How should the different technical components of the proposed system interrelate?" and "what are the risks?" It was expected that the question prompts would also influence students' solution-generating process.

However, it was discovered that the question prompts did not seen to have as much effect as one's prior knowledge or experience in helping the students develop solutions, as the data showed that the students' problem solving approach was typically driven by their schema, a phenomenon noted by Gick (1986). The students either activated their knowledge about WalMart's physical setting (e.g., Case 1, Case 3, and Case 6) or some other stores which were successful in employing some kind of technology to solve a similar problem (e.g., Case 2 and Case 5). For example, Paul in Case 3 (IC) thought about his experience of shopping at WalMart, Joe in Case 2 (IQ) developed his solution based on his experience of working at a retail store, and Case 5 thought about similar situations in many big wholesale stores where the inventory and stock on databases were accessible to the customers.

Then depending on the levels of their prior knowledge and experience, their approaches for developing the solutions varied. There were three approaches observed by the researcher. The first approach was characterized by Case 1 (IQ), Case 5 (PQ) and Case 6 (PQ). Cathy in Case 1 pictured herself as a user and ran through a range of possible solutions, which were then narrowed down to one based on her reasoning of the factors and the constraints. The groups in Case 5 and 6 were similar in that the peers brainstormed a range of solutions, which were then compared and the best solution was selected based on their reasoning and justifications. Compared with Cathy, Case 5 and Case 6 spent some time "figuring out" what was the best solution while Cathy just ran through the possibilities and then "quickly" narrowed down to one solution. The assumption was that when peers worked together, they would spend more time reflecting on their solutions, identifying wider range of factors and constraints, and thus monitoring their problem solving process. This finding might possibly explain why the PQ group outperformed the other treatment groups in terms of problem solutions.

The second approach was characterized by Joe (Case 2, IQ), who knew immediately what the solution should be and proposed the solution straightforwardly based on his working experience at a retail store. Shelly (Case 4, IC) was also confident in suggesting her idea of placing stationary systems in the store based on her findings from Home Depot and Lowes.

The third approach was represented by Case 3 (IC) and Case 8 (PC), who had some vague but not fully developed ideas to start with, and they developed the ideas by testing and modifying them along the way. This approach might explain Paul's dilemma in Case 3 where he had trouble putting all his information together, because the solution was developed along the way and was not planned in advance.

Although the question prompts did not seem to help much in generating or selecting solutions, they seemed to help them to explain how their proposed system worked. The students who received and followed the question prompts were able to explain explicitly the parts, the components and the interrelationship of the system. Prompted by the questions, Cathy (Case 1, IQ) was able to elaborate the system she had proposed, including the visual components and database components. Joe (Case 2, IC) was also able to relate the factors and constraints he had identified in the problem representation stage, such as the interface, the database and the interaction between the two, to justify his solutions. It is possible that question prompts might have helped Paul (Case 3) to organize information and plan for the solution process.

Making Justifications

During this problem-solving process, the focus was on (a) constructing arguments and (b) providing evidence for the proposed solutions. The question prompts asked "How would I justify this specific system design?" and "Do I have evidence to support my chain of reasoning?" Three themes emerged during this stage. First, the question prompts helped the students to construct arguments intentionally. Second, question prompts for problem representation helped the students to construct an argument. Third, peer interactions could facilitate the justification process if the students were engaged in the process. Fourth, question prompts tended to guide peer interactions in the process of making justifications.

It was observed that by following the justification question prompts, the students were consistent and intentional in making justifications. They not only justified the reasons for every technological component they would include in the proposed system, but also argued for why a solution or combination of solutions was chosen over the others. For instance, based on her personal experience as a WalMart user, Cathy (Case 1, IQ) argued why she wanted to make her system straightforward by including the features of a database and the feature of a map, based on her consideration of the users of the store, the majority of which were students. She not only justified why an IT system was needed, but also why there should be a “visual component” and a “technological component” in her proposed system. It was noted that she used the word "components" which was used in the question prompts in explaining and justifying her solutions. Joe (Case 2, IQ) articulated his "chain of reasoning" for his proposed technological system based on his working experience at the retail store where he had worked previously, and which he used as a piece of evidence to support his reasoning. He argued for the viability of his suggested solution, which was a "console interactive with the database system". Joe not only made justifications for the consideration of different components, but also for the selected system as a whole.

It was also found that identifying relevant factors and constraints in the process of problem representation helped Cathy (Case 1, IQ) and Joe (Case 2, IQ) to construct argumentation. Their argument was based on each of the factors they had identified (user, levels of knowledge, needs, system's requirement, etc.), so that they were able to address each of the concerns specifically in their argumentation. Cathy related every factor she had thought about to support her design rationale, such as the user's level of prior knowledge, being easy to use, the time and so on. For Joe, every factor he discussed became his arguing point to anchor his reasoning for his solution. His consideration of the user's level of knowledge became a point to support his argument for a console system that would be "very simple and easy to understand" for "people who know nothing about the store."

It was noted that peer interactions could facilitate the process of making justifications, depending on the levels of interactivity of a group. The students working in groups either spent more time discussing the rationale for issues, concerns and factors related to the solution than individuals, or they did not make any argumentation at all in the group processing. From the interview, it was clear that the peers in Case 6 (PQ) spent considerable time brainstorming solutions. During this process, peers asked each other questions, such as whether a proposed solution worked or not, what were the pros and cons, and what were the risks and constraints. This group process enhanced the argumentation, as was shown by their solutions report. In Case 8 (PC), although they failed to address why they selected the proposed system (PDA), the peer interactions helped them to examine the feasibility of a solution.

By contrast, the students in Case 5 (PQ) did not seem to spend much time discussing the rationales for the solution. At the interview, Gerry said "someone came up with an idea, and then everybody agreed with it." This could explain why argumentation was weak in their solution reports. In Case 8 (PC), there were not many productive peer interactions either. It was observed that one group member (Andy) gave out instructions to his two group members, who tended to comply with Andy's directions. In this case, the evidence of argumentation for selecting their proposed system as shown in their solution report was not obvious. In such instances, the group processing style may determine the levels of interactions (Webb, 1989b), which in turn may affect their argumentation process.

The other finding related to the justification process was that question prompts provided guidance for students to make justifications during the peer interaction process. For students who did not use the question prompts, the students tended to construct an argument for why to include a technological feature or component in their proposed technology system; however, they did not seem to construct a strong argument for why that system was needed. Provided with question prompts, Brandon's group for Case 6 (PQ) were able to explicitly state their reasons for adopting the web-based design: "because it can be easily upgraded and there is no need for a hard drive". To justify their solutions, they considered all the "the pros and cons", options such as "internal or external systems", and the issues of use, such as "easy or hard to use". By comparison, Case 7 (PC) only argued how a palm pilot system could be better installed on a shopping cart, but they failed to look at a broader issue, which was why the Personal Digital Assistant (PDA) was chosen over the others and therefore make justifications for it as a solution.

Gerry's group (Case 5, PQ) failed to construct an argument in their problem-solution report, which was possibly because they only followed some of the question prompts and thus failed to be prompted to construct an argument. Gerry mentioned that he didn’t read the questions because he did not need them, while Sarah (Case 5, PQ) said that she only used the first part of the questions to brainstorm the ideas. A prompt seemed to be effective, then, only to the extent that students voluntarily engaged them.

Monitoring and Evaluation

For monitoring and evaluation, the researcher attempted to look for evidence of (a) evaluating the solution and (b) assessing alternative solutions (as described in the rubrics) in the problem-solution reports. The researcher also intended to look for evidence of monitoring understanding during the problem-solving process. The question prompts for this process asked the students to check if they were "on the right track" by reflecting on the technical components and the issues with use, (e.g., usability and effectiveness), thinking about the alternative solutions, and arguing for the most viable solutions. The cross-case comparison revealed that it was common for students to monitor and evaluate their problem-solving process while the solution was still being developed; however, without the question prompts, the students were less likely to make intentional efforts to evaluate the selected solutions, make comparisons with alternative solutions and make justifications for the viable solutions.

Monitoring and evaluation was critical for those students (e.g., Case 3 and Case 7) who developed a solution first and then gradually modified it along the way, which was described previously. Paul (Case 3, IC) tested the solution in his head and thought about what worked and what did not. Joanne's group (Case 7, PC) also discussed what was feasible and what was not while a solution was being developed and modified. However, in both cases, the participants failed to assess the constraints and think about alternative solutions, which was found to be a great distinction between the participants receiving the question prompts and those who did not.

Question prompts were found to direct students' attention to some important aspects of the problem, such as the constraints and limitations of solutions, alternative solutions, and justification for the viable solutions. Thus, question prompts helped the students to monitor and evaluate their thinking process intentionally. Prompted by the questions, Cathy (Case 1, IQ) and Joe (Case 2, IQ) seemed very intentional in making connections with the factors and constraints they had identified in the process of problem representation while evaluating their solutions. Matt in Case 6 (PQ) mentioned that they always went back to the main problem to make sure they were on the right track. The group kept using the phrase "on the right track", the language used in the question prompts. In addition, with question prompts, these participants seemed to be able to discuss constraints and limitations of the solutions and think about alternative solutions more than those who did not use the question prompts. Case 6 was not only able to discuss the risks, pros and cons of their proposed system, but also make justifications for the viability of their solutions after comparing the alternatives. In Case 1 (IQ) and Case 2 (IQ), both Cathy and Joe were able to recognize the constraints of their solutions and consider ways to overcome them. They were also able to compare alternative solutions and justify why their solutions were the most viable. By comparison, while Case 3 (IC) and Case 7 (PC) failed to address the constraints and think about alternative solutions, Shelly in Case 4 (IC) also failed to look at the alternative possibilities and argued for the viability of her solution. Interestingly, Case 5 (PQ), who were provided with question prompts but did not really use them, also failed to evaluate their solution and look at the other possibilities.

The data analysis showed that the individuals or groups who used the question prompts consistently made intentional efforts to assess their solutions while developing them, discussing the factors, constraints, and the alternative solutions. They all tried to articulate their rationale and viability of the proposed solutions. By contrast, those who were not provided with question prompts or did not use them, were less well planned and more intuitive in evaluation. They might not have even been aware of the need or the value of assessing the solutions. Evaluating and justifying a proposed solution in relation to a constraint, such as a possible problem that might occur if a solution was implemented, is a process that typically characterizes how experts think during ill-structured problem solving (Voss & Post, 1988). Therefore, it is argued that without expert modeling, it is difficult for novice problem solvers to reach the expert's level of monitoring and evaluation independently.

Findings to Research Questions 4 - 5

The cross-case comparison indicated that question prompts were useful in helping students to identify relevant factors and constraints, explain solutions, make justifications, and direct students' attention to their monitoring and evaluation process. It also indicated that, if the students were actively engaged in peer interactions, these interactions helped the students to develop ideas for solutions, get different points of view for comparing and selecting solutions, construct arguments, and reflect on their solution processes. The purpose of this section is to answer Questions 4 and 5 on how these two scaffolding strategies influenced students' cognitive thinking and metacognitive knowledge.

As is discussed in the literature review in Chapter Two, in ill-structured problem solving, cognition involves both domain-specific knowledge, i.e., content knowledge, (Voss et al., 1991) and structural knowledge, i.e., knowledge of how concepts are organized within a domain (Jonassen et al., 1993). Cognitive thinking can be interpreted as understanding the domain and representing information in schemata, which can be used to develop procedural knowledge for solving domain-specific problems (Jonassen et al., 1993). In association with the ill-structured problem solving in this study, cognition is operationalized by the ability to activate prior knowledge, define the problem, organize information to understand the problem, generate subgoals, accurately identify constraints or obstacles, and seek needed information.

Metacognitive skills, on the other hand, involves two aspects: (a) knowledge of cognition and (b) regulation of cognition (Brown, 1987). Knowledge of cognition refers to knowledge about and awareness of one's own thinking, as well as when and where to use acquired strategies (Pressley & McCormick, 1995). Regulation of cognition consists of planning, evaluation, and monitoring. In the ill-structured problem-solving processes, knowledge of cognition is mainly indicated by articulating one's own reasoning, constructing an argument, and providing evidence. Metacognitive skills are indicated by monitoring one's thinking or solution process, evaluating solutions, such as pros and cons, recognizing constraints, thinking about alternative solutions, and justifying the viability of the solution(s).

Question 4

How does the use of question prompts influence students' cognition and metacognition in the process of developing solutions to ill-structured problems? The cross-case analysis revealed that the question prompts supported students' cognition and metacognition through directing attention, articulating thoughts, and providing guidelines.

Directing attention. The comparative case study showed that question prompts served as a "reminder" to direct the students' attention to important information they might not have thought about. In Case 1 (IQ) and Case 2 (IQ), it was obvious that both Cathy and Joe were prompted by the questions several times to attend to factors such as the user, user's level of prior level of knowledge, and the risks. Cathy deliberately made an attempt to "answer some of the questions" in the question prompts while Joe followed the question prompts and answered the questions about the user and the level of prior knowledge. In addition, they were also reminded by the question prompts to state their reasons and construct arguments for their proposed solutions. Sarah in Case 5 (PQ) mentioned that the question prompts helped her and the other group members to clarify the reasons and justifications for their solutions.

The question prompts also directed the students' attention to the possible constraints in their solutions, such as discussing the "risks" (e.g., Case 2, and Case 6) and searching for ways to overcome them. Joe (Case 2, IQ) pointed out that a question helped him to think of all the problems and side effects that he would not have thought about. In addition, the question prompts also led the students to think about alternative solutions and the viability of their solutions (Case 1, Case 2 and Case 6), an aspect often overlooked by novice problem solvers.

Therefore, it is evident that question prompts were helpful in supporting students' cognition and metacognition through directing their attention to represent the problem, make justifications, and monitor and evaluate the ill-structured problem-solving process. The fact that Case 5 (PQ) failed to make justifications and evaluate their final solutions, partially due to their ignoring the question prompts, also supports the finding that question prompts were effective in supporting students' cognition and metacognition through directing attention.

Articulating thoughts. The question prompts not only helped to remind the students of the important aspects of the problem, but also helped them to articulate their thoughts. When the participants were directed to important issues like the user, level of prior knowledge, and the existing system, they were also prompted to articulate their thoughts by coming up with answers to the questions. Joe (Case 2, IQ) followed the question prompts and discussed each of the issues one by one. A question such as "what should the system do?" prompted him to articulate his reasons for the proposed solution. For Cathy (Case 1, IQ), the question "what are my reasons for the solutions?" prompted her to articulate her reasons for her proposed solution. Thus, question prompts guided students to make justifications for their actions, and decisions, and problem-solving processes. In Case 6 (PQ), Sarah said that the question prompts guided her group to write down their justifications, which would not have been made explicit without the question prompts. On this point, Case 6 was contrasted to Case 5 (PQ), in which the students said that they had thought about the constraints, but just did not write them down. It is argued that the failure to write down or articulate one's thoughts may limit one’s monitoring and evaluation, since ideas are not made explicit and thus are not amenable to reflection.

Articulating one's thoughts is important in helping one to become aware of his or her own thinking, which in turn helps a learner to become more aware of his or her own limitations, so that remedial actions can be taken (Pressley & McCormick, 1987). Therefore, question prompts may have played a role in making students' thinking explicit, which served to support students' metacognitive knowledge in making justifications, monitoring, and evaluating their solutions.

Providing guidelines. Case 5 (PQ) and Case 6 (PQ) recognized the importance of question prompts in helping them organize information to solve the problem. Joe (Case 2, IQ) said that the question prompts were useful for him to organize his thinking. Perry (Case 6, PQ) mentioned that the questions helped his group to break down the problem into small steps. It may be interpreted that question prompts provided a structure to help the students organize the information, and to analyze or represent the problem for developing solutions to the ill-structured problem. Perry (Case 6, PQ) observed that the problem seemed vague to him at first, but that the questions laid out "guidelines" to help the group through the problem. It could be inferred from Case 6 that the question prompts provided them with a cognitive tool to solve the ill-structured problem, so that they knew where to start, how to define the problem, what was needed to solve the problem, and how to plan for the solution. In contrast, without question prompts, the students might find it more difficult to represent and solve the problem. As Paul (Case 3, IC) said, he could not make connections between different parts of the problem, and he had trouble putting all his information together. As exemplified by Case 6 (PQ), question prompts also guided the group in their justification process. Therefore, the question prompts may have served as expert modeling to support students' cognitive and metacognitive thinking by guiding problem representation, metacognition, and the justification process.

Question 5

How does the use of peer interaction influence students' cognition and metacognition in the process of developing solutions to ill-structured problems?

The comparative case study indicated that the greatest advantages of peer interactions lie in building upon each other's ideas, questioning and providing feedback, providing multiple perspectives, and benefiting from distributed knowledge. Those attributes influence students' cognitive thinking and metacognitive knowledge.

Building upon each other's ideas. It was observed that when peers worked together, they typically started the problem-solving processes by brainstorming ideas, which were presented in the form of questions or suggestions. In Case 6 (PQ), a subject "went back and forth for a while" before solutions were developed and selected. Interactions like that created a "reflective toss" (van Zee & Minstrell, 1997), which was found to be a very effective instructional strategy by vanZee and Minstrell's case study. As a result, the students not only elaborated their thinking through each other's feedback but also improved the quality of the solution. In the process of asking questions, seeking explanations, providing feedback, and reflecting on others' inputs, the whole group elaborated a collective understanding, which in turn influenced individuals' cognitive and metacognitive thinking.

Questioning and providing feedback. When peer interactions occurred, as in Case 5 (PQ), Case 6 (PQ), and Case 7 (PC), students asked questions, offered suggestions, elaborated thinking and provided feedback. Mark (Case 5) noticed that "questioning and feedback" characterized their problem-solving process. For Case 7 (PC) and Case 8 (PC), questioning and feedback helped them to develop solutions. They asked questions, such as “Is this all right?" "Is this working?" and "Why do you think this is so?" and got feedback from other group members (e.g., Case 8). They discussed the needs, feasibility, pros and cons (e.g., Case 7). Thus, peer interactions created an opportunity to ask, clarify, explain, and elaborate if everyone was engaged and contributed equally. Such interactions seemed to promote cognitive and metacognitive thinking. In Case 8 (PC), however, the interaction was more of the tutor-tutee type, during which Andy, who was more experienced in contextually-similar problem solving, gave instructions to the other two members about what to do. Even in such a situation, both the student who asked questions or the one who gave explanations could learn from each other (Webb, 1989b).

Providing multiple perspectives. Peer interactions during problem solving helped to create a learning environment for students to provide and receive different perspectives, which subsequently promoted reflective thinking and metacognitive knowledge (Lin et al., 1999). Case 6 (PQ) spent considerable time brainstorming different ideas, weighing the pros and cons of each solution, asking questions, elaborating ideas, and providing feedback. Matt (Case 6, PQ) observed, "The group work made you see something you couldn’t see on your own.” If functioning properly, peer interactions could bring in different points of view, which would bring in a wider range of issues, factors, and constraints to the group. Consequently, a problem may be better represented and a solution could be improved. Multiple perspectives arising from peer interactions could influence students' cognition through better understanding of a problem and their metacognition through reflective thinking of their own problem solving processes.

Distributing cognition. Benefiting from each other's knowledge was one of the greatest advantages of working with peers during problem solving. For instance, in Case 7 (PC) Bryan taught his peers the concept of "PDA" (Personal Digital Assistance). The most noticeable peer interactions occurred when the students were trying to build the database prototype, during which they learned from each other about the server and user interface (e.g., Case 6, PQ). Perry (Case 6, PQ) thought that the group work helped to yield high-quality solutions, as four heads provided more inputs than one head. Working together might also help one to learn metacognitive skills. When asked about what he had learned from the group processing, Devin (Case 8, PC) said he had learned from Andy the problem-solving strategy. Hence, peer interactions may influence students' cognition and metacognition through taking advantage of each other's knowledge and competence. However, further investigation is needed to study the conditions for which peers will benefit from distributed cognition during ill-structured problem solving.

The Self-Report Questionnaire Results

The self-report questionnaire (Appendix E) consisted of two parts: students' background information (Questions 1-10) and their self-evaluation of their problem-solving skills (Questions 11-30). The purpose of the questionnaire was to obtain an overall profile of the participants as distributed across the four treatment conditions and their perceptions of problem-solving skills in general. The following is a summary of the questionnaire results, which is reported according to students' background information and their prior problem-solving skills. For background information, the descriptive statistics are reported by specific question items for all the participants and different treatment groups as well. For students' self-reported problem-solving skills, the results were compared by each of the four areas, each of which consisted of 5 questions. The results of one-way analysis of variance test (ANOVA) and post hoc mean comparison are reported.

Background Information: A Profile of the Participants

The results reported here are the highlighted information of a more detailed result summary (Appendix E - Summary of Self-Report Questionnaire Results). They are summarized by specific questions. As for the computer skills and knowledge, only those concerned with databases were reported. Only the dominant percentage of the responses to each question is reported.

Gender. Of a total of 115 participants, there were 89 male students and 35 female students. In the PQ condition, there were 35 males and 12 females, compared with the PC condition, in which there were 27 males and 10 females, so the ratio between males and females in these two conditions was similar. In IQ condition, there were 8 male students and 7 female students, compared to 11 males and 5 females in the IC condition. Overall, the distribution of the gender across the four treatment conditions appeared normal.

Major and year. The majority of the participants were IST students (77.4% IST majors vs. 22.2% non-IST majors). The percentage of IST majors in the PQ condition

(99.5%) was greater than that in the PC condition (70.3%), however, IST majors were dominant in both the groups. The percentage of IST majors in the IQ condition (60.0%) was similar to that in the IC condition (68.8%). All the IST majors were freshmen, who consisted of the majority of the participants, and the distribution pattern for the year in college was the same as that of the IST majors.

Reason(s) for taking IST 110. As the majority of the participants were IST majors, IST 110 was required for the major. Therefore, 70.4% of the participants took the class because it was required. Some participants also indicated that they were interested in the course content besides being required to take it. 76.6% of the participants in the PQ condition and 75.7% of the participants in the PC condition indicated that IST 110 was required for them. By comparison, 53.3% of the students in the IQ condition and 56.3% of the students in the IC condition said that IST 110 was a required course for them; however, the percentage was similar between the two conditions. In response to the question regarding why they signed up for a specific class section, the majority of the students indicated that it was based on their schedule.

Personal experience with problem solving. The majority of the participants (70.4%) indicated that they had solved a similar problem before. However, from informal conversations between the researcher and some students, it was learned that the type of the problem they had done before was substantially different from the one they did for this study. 78.7% in the PQ, 56.8% in the PC, 73.3% in the IQ and 75% in the IC conditions reported that they had solved similar problems a few times before. The percentage of the students who had some problem-solving experience before was slightly lower in the PC condition than that in the other conditions, but this fact is insufficient to explain why the PC group did not perform better than the other groups in the problem-solving task in the study, as the percentages in the IQ and IC conditions were similar but they did not have the same problem-solving outcomes.

Knowledge and skills on databases. In response to Question 10 (How well do you understand the database structure, such as a relational database model, hierarchical model?"), about 50% of the students rated themselves a "3" out of "5" (1=lowest; 5=highest), with 48.9% in the PQ, 45.9% in the PC, 46.7% in the IQ, and 62.5% in the IC conditions. As observed by the researcher, the students tended to rate themselves high on the questionnaire, so if they rated themselves a "3", it could be inferred that their level of knowledge on database was generally low.

In response to Question 7, which asked about the computer skills for the Microsoft Access computer program, 48.9% of the students in the PQ condition rated themselves Competent, whereas in the PC condition, only 37.8% of the students rated themselves as Competent while 56.87% of the students rated themselves Novice in using Access. On the other hand, the majority of the students in the IQ condition (46.7%) rated themselves Novice while the majority of the students in the IC condition (62.5%) rated themselves Competent. Yet, the IQ group did significantly better than the IC group in the problem-solving task. Therefore, students' computer skills in Access did not seem to be correlated with their problem-solving outcomes.

Results of Self-Reported Problem-Solving Skills

The second part of the self-report questionnaire investigated the students' perception of their problem-solving skills before participating in this study. There were

20 questions categorized into four areas. Area 1 (Question 11-15) was concerned with problem representation, Area 2 (Question 16-20) with problem solutions, Area 3(Question 21-25) with metacognitive skills such as monitoring and evaluation, whereas Area 4(Question 26-30) with students' general problem-solving strategies. Since every question is rated on a 1-5 likert scale, with 1 being Never and 5 Always, the maximum score for each question area was 25 points while the minimum score was 5 points.

Table 4.4 showed the results of post hoc tests, including means and standard deviation for each question area. One-Way ANOVA was used for this analysis. The post hoc tests did not show any significant differences in question area means between different treatment groups (IQ, IC, PQ, and PC) in any of the question areas, with F ratio = .39, .45, .33, and .50 for Question Area 1, 2, 3 and 4 respectively. The accuracy of students' self-rating of their own problem-solving skills remained in question, as the means of students' self-reported problem-solving skills were consistently high, which seemed to be inconsistent with their problem-solving outcomes as indicated by the experimental study results. Overall, it seemed that the students had higher level of confidence but lower level of competence in problem solving, regardless of the treatment condition they were assigned to. The students in the group conditions did not show higher perception of their problem-solving skills than those in the individual conditions, neither did the students in the question-prompt conditions show higher perception of their problem-solving skills than those in the other conditions.

Nevertheless, the results did provide some information about the distribution of the participants across the four treatment groups, indicating that the participants in different treatment conditions were considerably equal in terms of their perceived problem-solving skills. The results also revealed some interesting issues concerning students' perception, self-confidence and actual competence regarding problem-solving skills, which will be discussed in Chapter 5.

Table 4.4
Question area means and standard deviation

Area by Treatment Groups	N	Mean	S. D.	F	Sig.
Area 1 (Question 11-15)				.39	.76
PQ	46	19.33	3.26		
PC	35	18.60	3.22		
IQ	15	18.87	2.29		
IC	16	18.81	2.93		
Area 2 (Question 16-20)				.45	.72
PQ	46	18.39	3.09		
PC	35	18.03	3.03		
IQ	15	17.53	3.42		
IC	16	18.75	3.96		
Area 3 (Question 21-25)				.33	.81
PQ	46	18.39	3.07		
PC	35	17.86	3.73		
IQ	15	18.80	2.88		
IC	16	18.25	3.51		
Area 4 (Question 26-30)				.50	.68
PQ	46	17.52	2.86		
PC	35	16.83	3.29		
IQ	15	17.67	2.06		
IC	16	17.00	3.18		

Note. Cronbach Alpha reliability values: Area 1 = .66, Area 2 = .69, Area 3 = .72, and Area 4 = .58.

CHAPTER 5

GENERAL DISCUSSION

Overview of the Findings

The purpose of this study was to investigate the effects of two scaffolding strategies -- question prompts and peer interactions on supporting students' problem-solving performance on an ill-structured task. Problem solving performance was measured according to four processes: (a) problem representation, (b) developing solutions, (c) making justifications, and (d) monitoring and evaluation. The effects of question prompts and peer interactions were examined when they were used separately (as in the QI and the PC conditions) as well as when they were combined (as in the PQ condition). In addition, the study also investigated the influence of question prompts and peer interactions respectively on students' cognitive thinking and the use of metacognitive skills in their problem-solving processes. The findings related to the five research questions, from both quantitative and qualitative data sources, are summarized below, followed by a discussion of the implications for instructional design and future research.

1. *Question prompts had a significantly positive effect overall on students' problem-solving processes on an ill-structured task, specifically in* (*a) problem representation, (c) making justifications and (d) monitoring and evaluating solutions.*

First, the students in the PQ condition (working in groups and also receiving question prompts) significantly outperformed those in the other conditions (PC and IC) in all the four problem-solving processes: (a) problem representation, (b) developing solutions, (c) making justifications and (d) monitoring and evaluating solutions. Second, the students in the IQ condition (individuals receiving question prompts) performed significantly better not only than the students in the IC condition, but also than those in the PC condition, specifically in the following three processes: (a) problem representation, (c) making justifications, and (d) monitoring and evaluating solutions. Third, there were no significant mean differences between the IQ and the PQ condition in (b) developing solutions, (c) making justifications and (d) monitoring and evaluation. It is inferred that the strategy of question prompts was effective to the point that it might cancel out the effects of peer interactions.

The findings on question prompts support the hypothesis that question prompts not only support well-structured problem solving, as shown by the studies of Schoenfeld (1985) and King (1991a), but also ill-structured problem solving. The effectiveness of question prompts on problem representation support King and Rosenshine's (1993) study that structured guidance through questioning enhances knowledge representation. The positive effect of question prompts on making justifications is consistent with the findings by Lin and Lehman (1999) that reason justification prompts directed students' attention to understanding when, why, and how, which helped students to transfer their understanding to a novel problem. The effect of question prompts for monitoring and evaluation confirm the results of previous studies (e.g., Davis & Linn, 2000; King, 1991a; 1991b; Palincsar & Brown, 1984; 1989), which were all consistent in concluding that question prompts guided metacognitive knowledge and reflective thinking.

However, no differences were found between the IQ condition and the IC condition, and between the IQ condition and the PC condition in developing solutions. This could possibly be explained by the case findings that suggest that, given a familiar problem scenario like WalMart, students frequently searched their prior knowledge when generating possible solutions. Therefore, the question prompts may not have had as much influence as prior knowledge on students' developing a solution, though they were helpful with problem representation.

2. *The use of peer interactions had a partially positive effect on students' problem solving processes on an ill-structured task in that the students in the PQ condition significantly outperformed those in the IC condition in all the problem-solving processes and the IQ condition in problem representation; whereas the students in the PC condition did not perform significantly better than those in the IQ or the IC condition in any of the problem solving processes.*

The statistical results showed that the students in the PQ condition had significantly higher mean scores than those in the IC condition in all the four problem-solving processes and than those in the IQ condition in problem representation. However, the results of the PC condition did not show a positive effect on students' problem-solving performance on an ill-structured task. The statistical results showed that the students in the PC condition had significantly lower mean scores than those in the IQ condition in (a) problem representation, (c) making justifications, and (d) monitoring and evaluation. At the same time, there were no significant differences between the students in the PC condition and those in the IC condition in any of the four problem-solving processes.

While the findings confirmed previous research (Lin et al., 1999; Palincsar et al., 1987; Webb, 1982, 1989b) on the advantages of peer interactions in supporting students' cognitive and metacognitive development, they also suggested that there were certain conditions in which the use of peer interactions fully worked to facilitate learning. Greene and Land (2000) found that peer interactions were useful in influencing the development of ideas only when group members offered suggestions, when they were open to negotiation of ideas, and when they shared prior experiences. There may be times when group members do not know how to ask questions or how to elaborate thoughts, or there may be times when group members are not willing to ask questions or respond to others' questions, or there may be times when group members do not see the need for peer interaction. Webb's (1989b) model of peer interactions, derived from a combination of results and hypotheses, revealed that different conditions and patterns of peer interactions might lead to different learning outcomes. Webb (1989b) found that the students who learned most were those who provided explanations to others in their group. In this regard, question prompts can serve to facilitate the peer interaction process through eliciting responses from some students, and the responses may invoke further questions from other students who may require elaboration or explanation from their peers.

3. *In comparison with the separate use of question prompts and of peer interactions, the combination of question prompts with peer interactions showed the greatest positive effect overall on students' problem-solving processes on an ill-structured task.*

The statistical results showed that the students in the PQ condition did significantly better than the students in the other conditions in several problem-solving processes. For example, the students in the PQ condition outperformed those in the PC and IC conditions, with significantly higher mean scores in all the four problem-solving processes. In addition, the students in the PQ condition also outperformed those in the IQ condition in problem representation.

Again, the findings confirmed previous studies (e.g., Palincsar & Brown, 1984; Brown & Palincsar, 1989; Webb, 1989b) on the advantages of peer interactions in supporting learning and problem solving. At the same time, they also seemed to suggest that the use of question prompts helped the students in the PQ condition to fully benefit from peer interactions. The fact that the students in the PC condition did not do as well as those in the PQ condition showed that peer interaction alone may not be sufficient as a form of "scaffolding". From the perspective of social constructivism, the key to the strategy of peer interactions is social construction of knowledge (Bereiter & Scardamalia, 1989) mediated through interpretation, elaboration, explanation, negotiation, and argumentation. In other words, if students were not actively engaged in activities such as questioning, explaining, elaborating, negotiating meanings, and constructing arguments, they may not be able to benefit much from the peer interaction process. It follows that the peer interaction process needs to be scaffolded appropriately, and modeling through question prompts, as examined in this study, may facilitate this process.

4. *In the process of developing solutions to ill-structured problems, question prompts influenced students' cognition and metacognition by (a) directing attention, (b) articulating thoughts, and (c) providing guidelines for problem solving.*

The qualitative results of the study are consistent with previous research findings (e.g., King, 1991; 1992; King & Rosenshine, 1993) on the role of question prompts. Question prompts serve to improve cognition as well as metacognition, the two of which are often interrelated. The case study suggested that question prompts served as cues to direct students' attention to important and relevant information that the students might not have considered, a finding which is consistent with previous research (e.g., Osman & Hannafin, 1994; Wong, 1985). The major factors and constraints, identified by a content expert and translated into the form of question prompts, helped students to represent the problem, make connections between different factors and constraints and link to the solutions (e.g., Case 1, 2). Hence, question prompts seemed to enhance students' understanding of domain knowledge. From this aspect, the question prompts facilitated students' cognitive thinking. On the other hand, directing students' attention to relevant information made them aware of the important factors and issues to be considered, which in turn helped them to monitor their own understanding. Therefore, by directing attention, question prompts seemed to facilitate metacognitive thinking.

The justification prompts in this study, such as "what are the reasons for…?" helped the students to reflect upon and explain their own actions and decisions. Based on Chi et al.'s (1989) findings, self-explanation facilitated problem-solving processes. In addition, the results of the case study supported the findings by Lin and Lehman (1999) that questions can prompt students to make arguments for their solutions and decisions, and thus make thinking explicit. Questions also helped the students to monitor their status of understanding in their problem solving processes (Case 1, 2) by constantly referring back to the goals of the problem.

Finally, the qualitative data (Case 2, 5) also showed that question prompts served as *guidelines* to facilitate students' problem solving. Question prompts guided them through the problem-solving processes, such as helping them "break down a big problem into small steps" (Case 5).

5. *In the process of developing solutions to ill-structured problems, peer interactions influenced students' cognition and metacognition by (a) building upon each other's ideas, (b) questioning and providing feedback, (c) providing multiple perspectives and (d) distributing cognition.*

This study confirmed previous research findings that peer interactions, if functioning properly, can help to elicit responses and explanations, which promote comprehension of the one who received the explanation and the one who gave the explanation and feedback (Webb, 1989b). This case study (Case 6, 8) showed that through peer interactions, students developed solutions by building upon each other's ideas, questioning each other, providing feedback, and checking the solution process. The students (Case 7) also "checked" each other's ideas to test if the selected solution was feasible or not, which required justification for a solution or suggestion. Building upon each other's ideas naturally led to asking questions and providing feedback to each other's ideas, which facilitated the continuous monitoring of the problem-solving process.

One of the greatest potential advantages for peer interaction is the multiple perspectives students provide and receive, which was further confirmed by this study. All the groups interviewed recognized that advantage immediately. Multiple perspectives provide an opportunity for students to reflect upon and evaluate their solution process (Lin et al., 1999). They may direct students' attention to some important aspects of a problem that they might not have thought about, and as a result, students may re-examine their thinking process, elaborating or modifying their thoughts, recognizing limitations in their solutions, or making justifications for their solutions or decisions. In this regard, peer interactions facilitated students' metacognition in the problem-solving process through reflecting, monitoring and evaluation.

Another benefit of working with peers, as perceived by the students (Case 5, 6, 7, 8), was taking advantage of everyone's knowledge and competence to solve the problem and complete the task. By sharing and distributing cognition (Pea, 1993), students learned from each other through peer interactions. McNeese (2000) discussed three basic-level processes predicted to form the basis for acquiring, constructing, transferring, and remembering knowledge: collective induction, generative learning, and metacognition. In McNeese's (2000) definition, collective induction is a group cognitive process that reinforces synergistic interaction among group members such that ideas, knowledge and strategies are disseminated. Generative learning is a form of collective induction as members engage in active discussions and explanations, rather than just passively receive information. Metacognition, as has been discussed, allows learners to plan and assess their own cognitive behavior (elaborating ideas, monitoring errors and planning remedial actions). This study showed that peer interactions could embrace those three levels of group processes if guided appropriately, and thus support students' cognitive thinking and metacognitive knowledge in the process of solving an ill-structured problem.

Implications for Instructional Design

A number of implications are drawn from this study, which are discussed separately as implications for instructional design and for future research. In the section of implications for instructional design, issues and insights arising from this study are discussed on the use of question prompts and of peer interactions as strategies of instructional scaffolding.

Question Prompts as a Scaffolding Strategy

Facilitating Metacognitive Knowledge

From the discussion of the findings, it is evident in this study that question prompts can be used to scaffold students' problem-solving processes on ill-structured tasks. A close examination of the results revealed further what processes of problem solving seemed to be especially influenced by question prompts. The qualitative results highlighted the influence of question prompts on making the students aware of important aspects of the problem, reflecting on their actions, decisions and solutions and providing them with guidelines for their problem-solving processes. On the other hand, the quantitative data pointed to the effects of question prompts on all of the problem-solving processes except developing solutions. It may be inferred that the strategy of question prompts was particularly effective in supporting metacognitive knowledge. As evidenced by the qualitative data, question prompts helped students to make deliberate efforts to articulate their thoughts by responding to the question prompts (e.g., Case 1, 2), making justifications, reflecting and evaluating their solutions, and monitoring their understanding (e.g., Case 6). However, the quantitative results showed that question prompts did not facilitate substantially with generating problem solutions. This is evidenced by the experimental study results showing that there were no differences between IQ, PC, and IC treatment groups in developing solutions. The data sources from the students' problem-solution reports and interviews also indicated that, while question prompts supported problem representation, such as providing cues to important aspects of the problem, defining the problem and identifying relevant and important information, they did not seem to help with developing solutions. In developing solutions, students were found to be more dependent upon their prior knowledge, to which the students could relate to their personal experience.

However, the students' problem-solution reports also indicated that students lacked in-depth technical knowledge on databases, and so they failed to provide a specific explanation of the database, such as the interrelationship among the technological components. In the absence of domain knowledge, question prompts failed to provide cues or to activate students' schema on databases. As a result, the students either provided a superficial description of the database they were going to develop, or they did not explain the database at all, which suggested their limited knowledge on databases. This finding helps to explain why the effects of question prompt were not apparent in developing solutions. The better performance of the PQ condition in developing solutions may be explained by the effect of combined strategies of both question prompts and peer interactions, in which cognition or knowledge was distributed and guided by the question prompts.

The findings of this study on the effects of question prompts have two implications for instructional design:

First, question prompts are useful in supporting metacognitive knowledge in students' ill-structured problem-solving, such as reasoning, monitoring, reflection and evaluation, which makes learning activity "mindful" or "intentional" (Salomon, 1985). In fact, Davis and Linn's (2000) research indicated that reflection prompts, which were expected to facilitate metacognitive knowledge, were most successful in prompting autonomous knowledge integration than other types of prompts (e.g., activity prompts, which were designed to guide students to focus on their actions or activities). Therefore, question prompts can be integrated in instructional design, curriculum design, computer-based design, or web-based design to develop metacognition and facilitate self-regulated learning (Brown & Palincsar, 1989).

Second, domain knowledge seems important for students to take full advantage of the strategy of question prompts, which are designed to facilitate both cognitive and metacognitive knowledge. Land and Greene (2000) point to the paradox of prior knowledge and metacognitive knowledge for learning in complex environments, which can well be used to explain the paradox found in this study. According to Garner and Alexander (1989), although there is some evidence that metacognitive knowledge may be able to compensate for absence of relevant domain knowledge, there is also evidence that learning how to employ cognitive strategies may sometimes be dependent on having some relevant knowledge of the domain. The interplay between cognition and metacognition provides some insights into the conditions for using scaffolding strategies, such as question prompts, to support ill-structured problem-solving activities. Instruction of domain knowledge could be interwoven into a complex, ill-structured learning environment to help students acquire domain knowledge, while scaffolding strategies, such as question prompts, could be embedded in the instruction to support ill-structured problem-solving processes.

Individual Gains on Question Prompts

The experimental study results showed that the individual students (in the IQ condition) who received question prompts while working on an ill-structured problem task did significantly better not only than the students in the Individual-Control condition but also in Peer-Control condition in (a) problem representation, (c) making justification, and (d) monitoring and evaluation. In addition, the performance of the students in the IQ condition were not significantly different from those in the PQ condition in (c) making justification and (d) monitoring and evaluation. The case study revealed that the individual students who received question prompts (e.g., Case 1, 2) were prompted by the questions to attend to the important aspects of the problem (e.g., factors and constraints) and were able to map those factors and constraints to their problem solution.

The findings were worth noticing. They can be linked to a study by McNeese (2000), which examined the role and functions of cooperative learning groups in contrast to individual learning conditions, for both an acquisition and transfer task. Results indicated that for the transfer task, individuals did better overall than groups in the number of problem elements transferred from solving the previous problem. The study indicated that there were different pay-offs for the individuals and groups; that is, individuals increased their perceptual learning during the acquisition task whereas groups enhanced their metacognitive strategies. This paradox was explained by different amounts of time investment on different aspects of learning. For example, individuals spent more time using the computer to explore details of the perceptual macrocontext of the problem, whereas groups spent more time engaged with each other in metacognitive activities during the process of the acquisition task.

Similarly, the paradox found in this study may also be attributed to different investment of time, which brought about gains on different aspects of learning. The better performance of the students in the IQ condition than those in the PC condition could be explained by the possibility that, in the absence of peer help and other supporting resources, the individuals had to rely on the question prompts greatly to guide them through the process of solving a complex, ill-structured problem. Consequently, the individuals paid close attention to each of the question prompts and tried to think about and come up with answers to every question. On the other hand, groups in the PC condition might have spent a lot of time engaged in discussion and peer interaction. However, as those students in the PC condition were still novice problem solvers, they might have lacked the metacognitive knowledge needed to solve the ill-structured problem, for example, not knowing what kinds of questions to ask to their peers, how to interact, or what strategies to use to approach and solve the problem. In this case, the group in the PC condition did not show any superiority than the individuals in the IQ condition.

The findings on different advantages of working individually and with peers have implications for educators and instructional designers. A learning environment should be designed and created based on different characteristics of individuals and groups to scaffold students' problem-solving processes, so that students can fully benefit from both peer interactions and individual work. Individual and group work can be integrated to support students' learning process, with specific consideration of time, condition, task complexity and scaffolding strategies.

Peer Interactions as a Scaffolding Strategy

Scaffolding Peer Interactions

The qualitative findings showed that peer interactions had several advantages: developing ideas based upon each other's ideas, elaborating thinking, providing multiple perspectives, and distributing cognition. The findings seemed to be inconsistent with the quantitative results, which revealed that the students in the condition of peer interactions without receiving question prompts had significantly lower problem-solving performance than those in the condition of individuals who received question prompts. Additionally, the students in the condition of peer interactions without question prompts did not show any significant advantage over their individual counterparts in any of the problem-solving processes.

However, a review of sociocultural theory may shed light on the use of peer interactions for scaffolding and help to explain the inconsistent findings related to the advantages of peer interactions. According to Vygotsky's (1978) *zone of proximal development* scaffolding should be carried out "under adult guidance or in collaboration with more capable peers" (p. 86). In the setting of classroom instruction, cognitive support is provided by either the teacher or peers of higher levels of competence. Yet, in many cases of peer interactions, students working collaboratively begin at roughly the same levels of competence, a contrast to a peer tutoring situation in which one student is an expert while the other is a novice (Palincsar & Brown, 1984; Webb, 1989a). In this study, most of the students had very little experience with ill-structured problem solving, as indicated by the students' self-report questionnaire on their problem solving skills, and thus were considered novice problem solvers, with relatively equal levels of competence in terms of problem-solving skills. While the students could work together to solve a challenging problem-solving task and many advantages of peer interactions as described in the literature were apparent (e.g., Webb, 1989a), without other cognitive support, the results of the experimental study showed that there were significant differences between the groups who used question prompts and those who did not. The students working with peers but also receiving question prompts did significantly better in every problem-solving process than those who did not receive question prompts. Moreover, the students in the former condition did the best in comparison to the students in the rest of the conditions and in several problem-solving processes.

The results indicated that when peers with equal levels of competence work together, additional scaffolding to support peer interactions seemed critical. The positive effects of reciprocal teaching among the peers as demonstrated by the previous studies (e.g., Palincsar & Brown, 1984; Brown & Palincsar, 1989) is perhaps due to the fact that question asking was modeled and dialog between the teacher and the student was provided before the students were asked to provide peer tutoring each other. Similarly, when the students working in peers were provided with expert modeling presented in the form of question prompts, advantages of peer interactions were more fully displayed. The experimental study showed that the students in PQ condition had significantly better problem solving performance than students in the rest of the conditions, such as peers working together without guidance, and individuals working with or without the use of question prompts. Therefore, when support is provided to students for group collaboration, the benefits of peer interactions can be maximized. The guided peer interactions can help students to progress from what Vygotsky called their "actual developmental level" to their "level of potential development" (1978, p. 86) through the problem-solving task.

The better problem-solving performance of the students in the PC condition may be explained by the fact that the question prompts guided the novice problem solvers in the right direction through the thought-provoking question prompts generated by the expert. For example, for Case 6, question prompts on justification and evaluation guided them to construct sound arguments, evaluate solutions, and explain reasons for viable alternative solutions. This is indicated by their problem-solving report and the follow-up interviews. Interestingly, Case 5 only followed the first half of the questions, which explained why they missed the process of evaluating the solutions and alternative solutions in their solution reports. When asked if they had evaluated the alternative solutions, they said that the idea went through their minds, but they did not write them down.

Expert Modeling for Peer Interactions

The results of the study demonstrated that novice learners during problem solving need modeling and guidance in the problem-solving process. The students in Case 5 indicated that question prompts generated by the experts served as a guideline to help them start the problem-solving task. The qualitative data showed that the groups with the question prompts might ask each other questions provided by the question prompts, generate more questions among themselves, or elaborate thoughts in responding to those questions. The researcher observed that some groups were not as interactive as other groups. In this case, for groups in the Peer-Question condition, the question prompts provided a common ground for students to collaborate on the same problem. However, for the groups who did not receive the question prompts, they might have been at a loss as to how to start to solve the problem, as most of them had never worked on a similar ill-structured problem before, and they might not have known what questions to ask.

Graesser and Person (1994) noticed from previous research that student questions in the classroom were very "infrequent" and "unsophisticated" (p. 105), which appeared to be a universal phenomenon. Being "infrequent" means low frequency of questions asked by the students, and "unsophisticated" questions refer to shallow, short answer questions that address the content and interpretation of explicit materials. Graesser and Person argue that this phenomenon can be attributed to barriers at three different levels, one of them being the students' difficulty identifying their own knowledge deficits, unless students had high amounts of domain knowledge. Graesser and Person's argument is supported by Gavelek and Raphael (1985), who pointed out that students may lack the background knowledge necessary to ask their own questions or even answer the questions of others; and they may also lack the procedural knowledge for discriminating what it is that they do know from that which they do not know. It is assumed that if the frequency of questions are low or if the questions asked are superficial, there would not be many explanations elicited from other students or even themselves. As found by Chi et al. (1989), self-explanation was an important component to monitor one's learning process.

In this study, as suggested by the problem-solving reports and the accompanying database prototypes, most of the students did not have in-depth understanding of the domain knowledge on information systems, databases, and the underlying principles for designing and developing an information system. Metacognitively, as the students were novice problem solvers with low domain knowledge, it was predicted that they also had limited cognitive and metacognitive abilities. Thus, the students might not generate many questions to ask; or even if they did ask questions, the questions might not be focused or in-depth. It follows that providing question prompts to students working with peers served as an expert's modeling to ask important and relevant questions, which helped to elicit students' responses, elaborate their thinking and articulate their reasoning. Whether the response is verbally articulated or thoughtfully considered, answering one's own questions in the form of self-explanation can be an effective strategy for enhancing reflection and metacognition (Chi et al., 1989).

Technological Scaffolding Using Question Prompts and Peer Interactions

This study confirms the hypotheses about the effectiveness of question prompts and peer interactions in scaffolding students' ill-structured problem solving processes. The next important question would be how to implement the two scaffolding strategies and extend their use to different instructional contexts, including traditional classroom instruction, web-based instruction, and computer-based instruction.

Nosek and McNeese (1997) argue that process support (an essential component in collaborative problem solving in ill-defined situations) includes tools, techniques, and methods that can be used to support group knowledge elicitation and creation processes. Technology is a tool that can be used to integrate the two scaffolding strategies within one instructional context--a problem-solving learning environment with complex, ill-defined situations and tasks. Such a tool embodies two dimensions of scaffolds to support ill-structured problem solving: expert modeling and peer learning. Students can consult an expert's view or help through embedded question prompts during problem solving. They can also get multiple perspectives from peers through activities, such as peer feedback, in which they will be engaged in question asking, information seeking, providing explanations, elaborating thoughts, articulating reasons, and providing arguments and reflections.

Such types of tools have been in existence for a decade, such as Computer-Supported Intentional Learning Environments (CSILE) (Scardamalia, Bereiter, McLean, Swallow, & Woodruff,1989) and, more recently, Knowledge Integration Environment (KIE) (Davis & Linn, 2000). CSILE is a tool to support intentional learning by providing a means for a group of students to build a collective database (knowledge-base) of their thoughts. Procedural facilitation was provided in the form of notes labels, such as "Confusion" and "New Learning", to encourage peer interactions and facilitate the knowledge construction process. In KIE, scaffolding is provided in the form of reflection prompts, such as "Thinking ahead: To do a good job on this project, we need to…". Both

CSILE and KIE allow students to work both individually and collaboratively, and to reflect on their own as well as peers' actions, reasons and decisions.

The design rationale can be adapted to design a computer-supported learning environment to scaffold students' problem solving in ill-structured domains. It is expected that through the use of the tool, students will transfer the metacognitive knowledge acquired from the question prompts and gain a positive collaborative learning experience afforded by technology.

Real-World Task and "Anchored Instruction"

A common pattern emerging from the qualitative data showed that the students frequently related the problem to their personal experience as a WalMart user, which helped them to develop solutions for the problem. The WalMart situation helped the students to picture themselves as customers and allow them to form the representation of a given situation that was familiar to them. Students' knowledge about a given situation helped them to activate appropriate schemata. The schemata or prior knowledge is very important in helping students to represent problems and thus guided their retrieval of appropriate solution procedures (Chi & Glaser, 1985). In the absence of available schemata, novice learners are often forced to apply some general strategies in solving a problem, which are often inadequate to lead them to successful solution procedures (Gick, 1986). Therefore, Gick (1986) stressed the need to improve schema learning.

Using familiar cases or situations for learning and instruction has implications for instructional design and curriculum development. Bransford (2000) emphasized the importance of "conditionalized" knowledge (a specification of the contexts in which it is useful) as opposed to "inert" knowledge (knowledge that is not activated, even though it is relevant) for knowledge acquisition in learning. Conditionalized knowledge, such as a real-world problem, creates a situated learning environment for "anchored instruction", which not only becomes a scaffold itself to develop students' problem solving skills in an ill-defined domain, but also engage them to apply the acquired knowledge spontaneously and facilitate knowledge transfer (CTGV, 1990).

Implications for Future Research

Question Prompts, Modeling and Transfer

Further research is suggested to examine the transfer effect of question prompts on students' self-questioning if the students were provided with similar question prompts a number of times in solving a number of questions. This study showed that question prompts had positive effects in modeling expert's thinking and guiding peer interactions in solving ill-structured problems. Based on Vygotsky's (1978) sociocultural theory, scaffolding such as modeling can be gradually taken over and internalized by individual learners. The goal of the modeling is to develop self-regulation in students, who will possess three types of knowledge: knowledge of strategies for accomplishing tasks efficiently, metacognitive knowledge, and real-world knowledge (Brown & Palincsar, 1989). King's studies (e.g., 1991a; 1991b; 1993) showed that guiding students to generate their own questions had significant effects in their learning comprehension, knowledge construction, and problem solving. Thus, further study can be conducted to investigate the transfer effect of question prompts on groups' as well as on individuals' problem-solving skills on ill-structured tasks, after receiving an expert's modeling over a period of time. Special interest would be on how students model after the expert in self-generating questions, and how the question-generating skills influence their problem solving on an ill-structured task.

Task Complexity and Scaffolding

While the use of familiar cases or situations provide a base for anchored instruction, it also poses some important research issues on the relationship between the nature and the complexity of the task and students' needs for scaffolding during problem solving. If students were given unfamiliar cases, would they rely more on scaffolding strategies, such as expert modeling in the form of question prompts and peers' help in the process of solving ill-structured problems? If the answer to that question was affirmative, the next question would be: to what degree would students rely on those scaffolding strategies?

On the other hand, the problem-solving task in this study was limited in its level of complexity, with a general problem described and the type of solution specified (e.g., IT solution), which reduced the complexity of the problem and the task. Nosek and McNeese (1997) argue that task complexity is a key component of group process complexity. If the complexity of the task was increased, would the group process complexity increase, and would that increased group process complexity lead the students to rely more on the scaffolding strategies, such as question prompts and peer interactions in the process of solving ill-structured problems? If yes, to what degree would students rely on those scaffolding strategies? Webb (1989b) noted there were certain conditions for peers to receive help and benefit from peer interactions. One is whether the student receiving help needs it. Students who already understand the material are not likely to benefit from receiving help (Webb, 1989b). This finding suggests the need for further research on the relationship between levels of task complexity, between students' levels of domain knowledge, and the conditions for students to seek scaffolds.

Impact of Group Dynamics on Peer Interactions

Group dynamics is a critical issue to examine when investigating the behaviors of peer interactions. It involves many aspects, including peer learning approaches, peer interaction patterns, students' perception and motivation about peer learning. As it may have an impact on students' problem-solving performance, any of these aspects is worth further investigation within the context of scaffolding ill-structured problem solving.

There are three peer learning approaches: peer tutoring, group cooperation, and group collaboration (Webb & Palincsar, 1996). In the peer tutoring approach, one student instructs another student in the relationship of expert and novice, that is, more capable peer providing tutoring to the peer with less level of competence in a domain. In the group cooperation, the groups divide up the responsibility for mastering the task, while in peer collaboration, thinking is distributed among the group members, and every member contributes to the problem solving processes in every stage. In the case study, the researcher observed all three different peer interaction patterns across the groups. Case 8 represented peer-tutoring relationship; Case 5 was a combination of cooperation and collaboration; while Case 6 and Case 7 were examples of collaboration.

According to Webb (1989b), different patterns of peer interactions may lead to different learning outcomes. In the peer tutoring relationship, one person often dominates the group and peer interactions, which is characterized by more verbalization of the person who is in the role of leadership, and less communication from the other group members. In this case, fewer questions are elicited and less elaboration is provided. The cooperation approach is typically characterized by brainstorming the problem-solving task, then dividing up work and assigning individuals to work on different pieces of the task. The result is an output pieced together from different group members. With this approach, there are very few peer interactions and cognition is not shared or distributed among the group members. In the collaborative approach, group members are more engaged in peer interactions, and the levels of question asking and elaboration are high. From a combination of empirical results and hypotheses, Webb found that a high level of questioning can lead to a high level of elaboration, and this will lead to the greatest learning gains.

Students' perception of peer interaction also determines the number and the quality of questions, responses, elaborations, and explanations exchanged, and thus, the level and quality of the knowledge elicited and created. If students do not see the need for help, it is unlikely they will ask questions; if they are not interested in group work, they will not actively engage in the group activities. Students' motivation is also an interesting area for future research. In this study, it was observed that a group was not engaged in the problem-solving task; they were off task the entire time. Their motivation to work on the problem task directly influenced their peer interactions, and thus their problem-solving performance. Webb and Palincsar (1996) point out, "Groups are social systems. Students' interaction with others is not only guided by the learning task, it is also shaped by their emotions, perceptions, and attitudes. Some social-emotional processes are beneficial for learning, others are not." (p. 855) Therefore, the relationships between motivation, peer interactions, and ill-structured problem solving are worth further investigation.

Self-confidence and Competence in Problem Solving

An interesting phenomenon found in this study was that the students tended to overrate their own problem-solving skills, which seemed to contrast with their actual competence of problem solving. Students' belief or confidence about their own abilities to perform particularly academic tasks successfully is what Bandura (1995) referred to as self-efficacy. Self-efficacy has found to be important in self-regulated learning processes because it influences both the level at which the goals are set and one's own responses to failure to meet the present goals (Zimmerman, 2000). Efficacy beliefs may enhance motivation and self-regulation. However, high self-efficacy resulted from inaccurate rating may also influence students' self-regulation process. In this study, while the students' high self-efficacy about their problem-solving abilities may motivate them to set goals for problem-solving tasks, it may also limit their motivation to seek knowledge or strategies that may help them improve their problem-solving skills. The relationship between students' confidence and competence in ill-structured problem solving is worth investigating in future research.

Limitations of the Study

Due to the constraints faced by the researcher in conducting this study, some accommodation had to be made in order to fit the study into the IST 110 curriculum. While this accommodation allowed the researcher to conduct the study in the natural setting of the class, it also brought some constraints to the design and implementation of the study. The following were some noticeable limitations observed by the researcher, and remedies are suggested to overcome the problems.

First, there was a time constraint. The two-hour laboratory period seemed insufficient for most of the students to do a thorough job on the problem-solving task. This was evidenced by conversations between the researcher and some students after the problem-solving task. It also explained why some groups could not complete constructing the database prototype required by the task. This constraint limited the researcher's information source to investigate how the participants used their domain-specific knowledge to build a database prototype, even though students' domain knowledge used for developing the database prototype was not included in the rating. To overcome the limitation, sufficient time should be provided for students to work on a complex problem of an ill-structured task.

Second, the problem-solving task presented to the students was somewhat defined for the students, which may reduce the complexity of the task. For example, the problem was a general description, and the task requirement (e.g., asking for information technology solution) and criteria (e.g., need to provide argumentation and evaluate the solutions) were specifically explained. The decision to make the problem more defined was based on consideration of the time allowed in the laboratory hours and the feedback from the other instructors. Consequently, the scope of the problem seemed to be confined and the level of task complexity was reduced to some extent, which might affect students' problem-solving performance and strategies employed to complete the task. In the future, a more complex task should be provided in order to study how students' problem-solving performance varies according to the level of task complexity.

The third limitation was associated with the design of the experimental study. Given the posttest- only design, it would be ideal to assign the participants to different treatment conditions. In reality, however, it was difficult to randomly mix the students from different class sections and assign them to different working groups. Even if this were possible, the setting for the study would not be natural, as the students assigned to the same group might not know each other, which might lead to problems in the collaborative problem-solving activities. To overcome the threat to internal validity, nonequivalent control group design (that is, the design employing pre- and post- test or problem-solving tasks) could have been used instead of posttest-only control group design to ensure the comparability between the treatment groups and the controlled groups. However, the researcher argues that the qualitative study can provide additional information and insights into the quantitative study results, and thus may help to explain some potential problems caused by the non-random assignment. Moreover, the questionnaire results showing that the distribution of the participants were considerably equivalent also indicated that the randomization issue for the experimental study was not a major concern.

The other noticeable limitation was the limited observation of peer interactions caused by technical problems during the videotaping, which yielded some unusable data on the peer interaction process during the problem-solving task. Therefore, the researcher had to rely primarily on the interview data for the investigation of the peer interactions during the problem-solving task, which may have been insufficient.

Remedies can be done to overcome such problems in the future. For instance, more time can be spent on planning and preparing for the observation. The researcher can spend some time observing and identifying potential participants for the case study before implementation. The selected groups can be pulled out from the class for focus observation and better control of the environment.

BIBLIOGRAPHY

Anderson, N. H. (1964). Linear models for responses measured on a continuous scale. Journal of Mathematical Psychology, 1, 121-142.

Anderson, N. H. (1976). How functional measurement can yield validated interval scales of mental quantities. Journal of Applied Psychology, 61(6), 677-692.

Anderson, N. H. (1977). Note on functional measurement and data analysis. Perception and Psychophysics, 21(3), 201-215.

Bandura, A. (1995). Exercise of personal and collective self-efficacy in changing societies. In A. Bandura (Ed.), Self-efficacy in changing societies (pp. 1-45). New York: Cambridge University Press.

Barnes, W. G. W. (1994, April). Constructing knowledge from an ill-structured domain: Testing a multimedia hamlet. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. New Directions for Teaching and Learning, 68, 3-12.

Bereiter, C., & Scardamalia, M. (1989). Intentional learning as a goal of instruction. In L. B. Resnick (Ed.), Knowing, learning, and instruction: Essays in honor of Roger Glaser (pp. 361-392). Hillsdale, NJ: Lawrence Erlbaum Associates.

Blum, R. E., & Arter, J. A. (1996). Student performance assessment. Alexandria, VG: Associations for Supervision and Curriculum Development.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). How people learn: Brain, mind, experience, and school. Washington, DC: National Academy Press.

Bransford, J. D., Sherwood, R. D., & Sturdevant, T. (1987). Teaching thinking and problem solving. In J. B. Baron & R. J. Sternberg (Eds.), Teaching thinking skills: Theory and practice (pp. 162-181). New York: W. H. Freeman and Company.

Bransford, J. D., & Stein, B., S. (1993). The IDEAL problem solver: A guide for improving thinking, learning, and creativity (2nd ed.). New York: W. H. Freeman and Company.

Brown, A. L. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. E. Weinert & R. H. Kluwe (Eds.), Metacognition, motivation, and understanding (pp. 65-115). Hillsdale, NJ: Lawrence Erlbaum Associates.

Brown, A., L., & Palincsar, A. S., (1989). Guided, cooperative learning and individual knowledge acquisition. In L. B. Resnick (Ed.), Knowing, learning, and instruction: Essays in honor of Robert Glaser (pp. 393-451). Hillsdale, NJ: Lawrence Erlbaum Associates.

Bruning, R., H. (1994). The college classroom from the perspective of cognitive psychology. In K. W. Prichard & R. M. Sawyer (Eds.), Handbook of college teaching: Theory and applications (pp. 3-22). Westport, CT: Greenwood Press.

Champagne, A. B., & Klopfer, L. E. (1981). Problem solving as outcome and method in science teaching: Insights from 60 years of experience. School Science and Mathematics, 81, 3-8.

Chi, M., Bassok., M., Lewis, M., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. Cognitive Science, 13, 145-182.

Chi, M. T. H., & Glaser, R. (1985). Problem solving ability. In R. J. Sternberg (Ed.), Human abilities: An information processing approach (pp. 227-250). New York: W. H. Freeman and Company.

Cockrell, K. S., Caplow, J. A. H., & Donaldson, J. F. (2000). A context for learning: Collaborative groups in the problem-based learning environment. The Review of Higher Education, 23(3), 347-363.

Cognition and Technology Group at Vanderbilt. (1990). Anchored instruction and its relationship to situated cognition. Educational Researcher, 19, 2-10.

Coulson, R. L., Feltovich, P. J., & Spiro, R. J. (1989). Foundations of misunderstanding of the ultrastructural basis of myocardial failure: A reciprocation network of oversimplifications. Journal of Medicine and Philosophy, 14, 109-146.

Davis, E. A., Linn, M. (2000). Scaffolding students' knowledge integration: Prompts for reflection in KIE. International Journal of Science Education, 22(8), 819-837.

Ericsson, K. A., & Simon, H. A. (1996). Protocol analysis: Verbal reports as data revised edition. Cambridge, MA: Massachusetts Institute of Technology.

Feltovich, P. J., Coulson, R. L., Spiro, R. J., & Dawson-Saunders, B. K. (1992). Knowledge application and transfer for complex tasks in ill-structured domains: Implications for instruction and testing in biomedicine. In D. Evans & V. Patel (Eds.), Advanced models of cognition for medical training and practice (pp. 214-244). Berlin: Springer-Verlag.

Feltovich, P. J., Spiro, R. J., & Coulson, R. L. (1989). The nature of conceptual understanding in biomedicine: The deep structure of complex ideas and the development of misconceptions. In D. A. Evans & V. L. Patel (Eds.), Cognitive science in medicine: Biochemical modeling (pp. 111-172). Cambridge, MA: MIT Press.

Feltovich, P. J., Spiro, R. J., Coulson, R. L., & Feltovich, J. (1996). Collaboration within and among minds: Mastering complexity, individuality and in groups. In T. Koschmann (Ed.), CSCL: Theory and practice of an emerging paradigm (pp. 25-44). Mahwah, NJ: Lawrence Erlbaum Associates.

Fortunato, I., Hecht, D., Tittle, C. K. & Alvarez, L. (1991). Metacognition and problem solving. Arithmetic Teacher, 7, 38-40.

Gavelek, J. R., & Raphael, T. E. (1985). Metacognition, instruction, and the role of questioning activities. In D. L. Forrest-Pressley, G. E. MacKinnon, & T. G. Waller. (Eds.), Metacognition, cognition, and human performance (pp. 103-136). Orlando, FL: Academic Press.

Garner, R., & Alexander, P. A. (1989). Metacognition: Answered and unanswered questions. Educational Psychologist, 24, 143-158.

Gick, M. L. (1986). Problem solving strategies. Educational Psychologist, 21(1&2), 99-120.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. Cognitive Psychology, 12, 306-355.

Graesser, A. C., & Person, N. K. (1994). Question asking during tutoring. American Educational Research Journal, 31(1), 104-137.

Greene, B. A., & Land, S. M. (2000). A qualitative analysis of scaffolding use in a resource-based learning environment involving with the world wide web. Journal of Educational Computing Research, 23(2), 151-180.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs, Educational Evaluation and Policy Analysis 11, 255-274.

Greeno, J. (1978). Natures of problem-solving abilities. In W. Estes (Ed.), Handbook of learning and cognitive processes, Vol. 5 (pp. 239-270). Hillsdale, NJ: Lawrence Erlbaum Associates.

Hong, N. S. (1998). The relationship between well-structured and ill-structured problem solving in multimedia simulation. Unpublished doctoral dissertation, The Pennsylvania State University, University Park, PA.

Huck, S. W. (2000). Reading statistics and research. New York: Longman.

Jacobs, J. E., & Paris, S. G. (1987). Children's metacognition about reading: Issues in definition, measurement, and instruction. Educational Psychologist, 22, 255-278.

Jonassen, D. H. (1997). Instructional design models for well-structured and ill-structured problem-solving learning outcomes. Educational Technology: Research and Development, 45(1), 65-94.

Jonassen, D. H., Beissner, K., & Yacci, M. (1993). Structural knowledge. Hillsdale, NJ: Lawrence Erlbaum Associates.

King, A. (1991a). Effects of training in strategic questioning on children's problem-solving performance. Journal of Educational Psychology, 83(3), 307-317.

King, A. (1991b). Improving lecture comprehension: Effects of a metacognitive strategy. Applied Cognitive Psychology, 5, 331-346.

King, A. (1992). Facilitating elaborative learning through guided student-generated questioning. Educational Psychologist, 27(1), 111-126.

King, A. (1994). Guiding knowledge construction in the classroom: Effects of teaching children how to question and how to explain. American Educational Research Journal, 31(2), 338-368.

King, A., & Rosenshine, B. (1993). Effect of guided cooperative questioning on children's knowledge construction. Journal of Experimental Education, 61(2), 127-148.

Kitchner, K. S. (1983). Cognition, metacognition, and epistemistic cognition: A three-level model of cognitive processing. Human Development, 26, 222-232.

Kitchner, K. S., & King, P. M. (1981). Reflective judgment: Concepts of justification and their relationship to age and education. Journal of Applied Developmental Psychology, 2, 89-116.

Kluwe, R. H. (1987). Executive decisions and regulation of problem solving. In F. Weinert & R. Kluwe (Eds.), Metacognition, motivation, and understanding. Hillsdale, NJ: Lawrence Erlbaum Associates.

Kluwe, R. H., & Friedrichsen, G. (1985). Mechanism of control and regulation in problem solving. In J. Kuhl & J. Beckmann (Eds.), Action control: From cognition to behavior. New York: Springer-Verlag.

Land, S. M., & Greene, B. A. (2000). Project-based learning with the World Wide Web: A qualitative study of resource integration. Educational Technology: Research and Development, 48(1), 45-68.

Lin, X., Hmelo, C., Kinzer, C. K., & Secules, T. J. (1999). Designing technology to support reflection. Educational Technology: Research and Development, 47(3), 43-62.

Lin, X., & Lehman, J. D. (1999). Supporting learning of variable control in a computer-based biology environment: Effects of prompting college students to reflect on their own thinking. Journal of Research in Science Teaching, 3(7), 837-858.

Mayer, R. E. (1991). Thinking, problem solving, cognition. New York: W. H. Freeman and Company.

McNeese, M. D. (2000). Socio-cognitive factors in the acquisition and transfer of knowledge. Cognition, Technology & Work, 2, 164-177.

Miles, M. B., & Huberman, A. M. (Eds.). (1994). An expanded sourcebook: Qualitative data analysis (2nd ed.). Thousand Oaks, CA: Sage Publications.

National Science Education Standards. (1996). Washington, DC: National Research Council.

Newell, A., & Simon, H. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.

Noddings, N. (1985). Small groups as a setting for research on mathematical problem solving. In E. A. Silver (Ed.), Teaching and learning mathematical problem solving (pp. 345-359). Hillsdale, NJ: Lawrence Erlbaum Associates.

Nosek, J. T., & McNeese, M. D. (1997). Augmenting group sense making in ill-defined, emerging situations: Experiences, lessons learned and issues for future development. Information Technology & People, 10(3), 241-252.

Osman, M. E and Hannafin, M. J. (1994). Effects of advance questioning and prior knowledge on science learning. Journal of Educational Research, 88(1), 5-13.

Palincsar, A. S. (1986). The role of dialogue in providing scaffolded instruction. Educational Psychologist, 21(1 & 2), 73-98.

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. Cognition and Instruction, 2, 117-175.

Palincsar, A. S., & Brown, A. L. (1989). Instructions for self-regulated reading. In L. B. Resnick & L. E. Klopfer (Eds.), Toward the thinking curriculum: Current cognitive research (pp. 19-39). Washington, DC: Association for Supervision and Curriculum Development.

Palincsar, A. S., Brown, A. L., & Martin, S. M. (1987). Peer interaction in reading comprehension instruction. Educational Psychologist, 22(3-4), 231-253.

Pea, R. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), Distributed cognitions: Psychological and educational considerations (47-87). New York: Cambridge University Press.

Piaget, J. (1985). The equilibration of cognitive structures. Chicago: University of Chicago Press.

Pressley, M., & McCormick, C. B. (1987). Advanced educational psychology for educators, researchers, and policy makers. New York: HarperCollins.

Pressley, M., Wood, E., Woloshyn, V., Martin, V., King, A., & Menke, D. (1992). Encouraging mindful use of prior knowledge: Attempting to construct explanatory answers facilitates learning. Educational Psychologist, 27(1), 91-109.

Resnick, L. B., & Klopfer, L. E. (1989). Toward the thinking curriculum: Current cognitive research. Washington, DC: Association for Supervision and Curriculum Development.

Rockwell, S. K., & Kohn, H. (1989, Summer). Post-then-pre evaluation. Journal of Extension, 27, 19-21.

Rosenshine, B., & Meister, C. (1992). The use of scaffolds for teaching higher-level cognitive strategies. Educational Leadership, 4, 26-33.

Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. Review of Educational Research, 66(2), 181-221.

Salomon, G. (1985). Information technologies: What you see is not (always) what you get. Educational Psychologist, 20(4), 207-216.

Salomon, G., Globerson, T., & Guterman, E. (1989). The computer as a zone of proximal development: Internalizing reading-related metacognitions from a reading partner. Journal of Educational Psychology, 81(4), 620-627.

Scardamalia, M., Bereiter, C. (1985). Fostering the development of self-regulation in children's knowledge processing. In S. F. Chipman, J. W. Segal, & R. Glaser (Eds.), Thinking and learning skills: Vol.2. Research and open questions (pp. 563-577). Hillsdale, NJ: Lawrence Erlbaum Associates.

Scardamalia, M., Bereiter, C., McLean, R. S., Swallow, J., & Woodruff, E. (1989). Computer-supported intentional learning environments. Journal of Educational Computing Research, 5, 51-68.

Scardamalia, M., Bereiter, C., & Steinbach, R. (1984). Teachability of reflective processes in written composition. Cognitive Science, 8, 173-190.

Schmidt, H. G. (1989). The rationale behind problem-based learning. In H. G. Schmidt & M. W. de Vries & M. Lipkin, Jr. & J. M. Greep (Eds.), New directions for medical education: Problem-based learning and community-oriented medical education (pp. 105-111). New York: Springer-Verlag.

Schoenfeld, A. H. (1985). Mathematical problem-solving. San Diego, CA: Academic Press.

Schraw, G. (1998). On the development of adult metacognition. In M. C. Smith & T. Pourchot (Eds.), Adult learning and development: Perspectives from education psychology (pp. 89-106). Mahwah, NJ: Lawrence Erlbaum Associates.

Sinnott, J. D. (1989). A model for solution of ill-structured problems: Implications for everyday and abstract problem solving. In J. D. Sinott (Ed.), Everyday problem solving: Theory and application (pp. 72-99). New York: Praeger.

Spiro, R. J., Vispoel, W. L., Schmitz, J., Samarapungavan, A., & Boerger, A. (1987). Knowledge acquisition for application: Cognitive flexibility and transfer in complex content domains. In B. C. Britton & S. Glynn (Eds.), Executive control processes (pp. 177-200). Hillsdale, NJ: Lawrence Erlbaum Associates.

Stake, R. E. (2000), Case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), Handbook of qualitative research (2nd ed.), (pp. 435-454). Thousand Oaks, CA: Sage Publications.

Stevens, J. (1986). Multivariate statistics for the social science. Hillsdale, NJ: Lawrence Erlbaum Associates.

Stinson, J. E., & Milter, R. G. (1996). Problem-based learning in business education: Curriculum design and implementation issues. New Directions for Teaching and Learning, 68, 33-42.

Strauss, A., & Corbin, J. (Eds.). (1998). Basics of qualitative research: Techniques and procedures for developing grounded theory. Thousand Oaks, CA: Sage Publications.

Tabachnick, B. G., & Fidell, L. S. (Eds). (2001). Using multivariate statistics. Boston: Allyn and Bacon.

Tashakkori, A., & Teddlie, C. (1998). Mixed methodology: Combining qualitative and quantitative approaches. Thousand Oaks, CA: Sage Publications.

van Zee, E., & Minstrell, J. (1997). Using Questioning to Guide Student Thinking. The Journal of the Learning Sciences, 6(2), 227-269.

Voss, J. F. (1988). Problem solving and reasoning in ill-structured domains. In C. Antaki (Ed.), Analyzing everyday explanation: A casebook of methods (pp. 74-93). London: Sage Publications.

Voss, J. F., & Post, T. A. (1988). On the solving of ill-structured problems. In M. H. Chi, R. Glaser & M. J. Farr (Eds.), The nature of expertise (pp. 261-285). Hillsdale, NJ: Lawrence Erlbaum Associates.

Voss, J. F., Wolfe, C. R., Lawrence, J. A., & Engle, R. A. (1991). From representation to decision: An analysis of problem solving in international relations. In R. J. Sternberg & P. A. Frensh (Eds.), Complex problem solving. Hillsdale, NJ: Lawrence Erlbaum Associates.

Vygotsky, L. S. (1978). Mind in society. Cambridge, MA: Harvard University Press.

Wager, W., & Mory, E. H. (1993). The role of questions in learning. In J. V. Dempsey & G. C. Sales (Eds.), Interactive instruction and feedback (pp. 55-67). Englewood Cliffs, NJ: Educational Technology Publications.

Webb, N. M. (1982). Group composition, group interaction and achievement in cooperative small groups. Journal of Educational Psychology, 74, 475-484.

Webb, N. M. (1989a). Critical distinctions among three approaches to peer education. International Journal of Educational Research, 13, 9-19.

Webb, N. M. (1989b). Peer interaction and learning in small groups. International Journal of Educational Research, 13, 21-39.

Webb, N. M. (1991). Task-related verbal interaction and mathematics learning in small groups. Journal for Research in Mathematics Education, 22, 366-389.

Webb, N. M., & Palincsar, A. S. (1996). Group processes in the classroom. In D. C. Berliner & R. C. Calfee (Eds.), Handbook of educational psychology (pp. 841-873). New York: Simon & Schuster Macmillan.

Webb, N. M., Troper, J. D., & Fall, R. (1995). Constructive activity and learning in small groups. Journal of Educational Psychology, 87(3), 406-423.

Weiner, C. J. (1978, April). The effect of training in questioning and student question generation on reading achievement. Paper presented at the annual meeting of the American Educational Research Association, Toronto, Ontario, Canada.

Wineburg, S. S. (1998). Reading Abraham Lincoln: An expert-expert study in the interpretation of historical texts. Cognitive Science, 22, 319-346.

Wittrock, M. C. (1990). Generating processes of comprehension. Educational Psychologist, 24(4), 345-376.

Wong, B. Y. L. (1985). Self-questioning instructional research: A review. Review of Educational Research, 55, 227-268.

Wood, D. J., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. Journal of Child Psychology and Psychiatry, 17, 89-100.

Yin, R. K. (1989). Case study research: Design and methods (2nd ed.). Thousand Oaks, CA: Sage Publications.

Zimmerman, B. J. (2000). Self-efficacy: An essential motive to learn. Contemporary Educational Psychology, 25, 82-91.

APPENDIX A

RESEARCH RECRUITMENT AND CONSENT FORMS:

Informed Consent Form for Research

Request for Permission for Audiotaping

Request for Permission for Videotaping

INFORMED CONSENT FORM FOR RESEARCH

The Pennsylvania State University

Title of project:

The effects of question prompts and peer interactions in scaffolding ill-structured problem solving processes

Principal Investigator: Ms. Xun Ge
Ph.D. Candidate, Instructional Systems
The Pennsylvania State University
315 Keller Building
Phone: 814-865-8950
E-mail: xxg4@psu.edu

Investigator: Dr. Susan Land
Instructional Systems
The Pennsylvania State University

Dear IST 110 Students,

We are inviting you to participate in a study on problem-solving skills. The purpose of the study is to explore effective instructional strategies used to support students' real-life problem-solving processes. The findings of this research will be used to help students develop effective learning strategies and problem-solving skills. It is hoped that this study will contribute to the process of integrating problem-based learning approach into the curriculum.

The major part of this study will take place either during or outside the class/lab sessions. If this study takes place during one of the lab sessions, your attendance in the lab is a requirement, although your participation in this study is voluntary, Your participation in this lab counts toward your lab grade. Your task during this lab is to solve a problem related to Information Science and Technology and propose a solution report of 1-2 pages. You may be asked to work on the task either in groups or individually. At the end of the problem-solving task, those of you who have agreed to participate in this study will be asked to complete a questionnaire, which takes no more than 10 minutes. If you agree to participate in this study by signing this consent form, you allow the investigators to use all the data collected for the study.

In addition, a few volunteer participants may be randomly selected for observation and a follow-up interview through videotaping or think-aloud activity and a follow-up interview through audio-taping.

In return for your kindness of offering to participate in this study, the principal investigator will provide a tutorial to those of you who are interested, showing you some useful learning strategies and tools for problem-solving processes. You will also be awarded 2 credits for participating in this study.

There are no known discomfort or risks associated with this study.

If you have any questions regarding this study, please feel free to contact Xun Ge at xxg4@psu.edu or (814) 865-8950.

Your participation in the research is confidential, though your confidentiality can only be assured to the extent available to online media. Only the investigators of this study have access to the data. In the event of publication of this research, no personally identifying information will be disclosed. To make sure your participation is confidential, only a code number will appear on the problem solution report you have written.

Your participation is voluntary. You are free to withdraw from the study at any time or to decline to answer any specific questions without penalty.

Participant

I agree to participate in the investigation of "The effects of question prompts and peer interactions in scaffolding ill-structured problem solving processes" as an authorized part of the education and research program of the Pennsylvania State University.

I understand the information given to me. I have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described.

I understand that my participation in this study is voluntary, and that I may ask the investigator to withdraw my data at any time by notifying the investigator.

I am 18 years of age or older.

I understand that I will receive a signed copy of this consent form.

____
Print Name

__________________________________ ______________________
Signature **Date**

Principal Investigator:

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

__________________________________ ______________________
Signature **Date**

REQUEST FOR PERMISSION FOR AUDIOTAPING

Title of project: The effects of question prompts and peer interactions in scaffolding ill-structured problem solving processes

Principal Investigator: Ms. Xun Ge, E-mail: xxg4@psu.edu, Phone: 862-5169, Address: 315 Keller

Advising Investigator: Dr. Susan Land

Dear ______________________________ (Student's Name):

This is to acknowledge that you have signed a consent form agreeing to participate in the study "The effects of question prompts and peer interactions in scaffolding ill-structured problem solving processes". We would like to thank you sincerely for your voluntary participation and offer of help.

In the meantime, we would like to inform you that you have been selected for think-aloud audiotaping during the problem-solving task in the lab session designated for this study, which is indicated in the Informed Consent Form. Think-aloud means talking aloud to yourself what comes to your mind while you are engaged in the problem-solving activity. The principal investigator will provide an approximately 10-minute training session for the think-aloud activity before the participant begins to work on the problem-solving task. The think-aloud protocols articulated by the participant during the problem-solving process will be audiotaped. An interview will be conducted a few days later, following the think-aloud activity. The whole conversation process between the investigator and the participant will be audiotaped as well.

Only the investigators of this study have access to all the data recorded on audiotapes. The tapes will be stored in a secure location in the advising investigator's office in Keller Building. All the tapes will be destroyed after 5 years.

If you agree to be audiotaped for think-aloud protocol activity and participate in a follow-up interview as part of the study, please give us your permission by signing this form.

Should you have any questions or concerns regarding the techniques or procedures, please contact the principal investigator at the email, phone number or the address above. Thank you!

Participant

I, ______________________ **(Print Name)**, understand the information given to me. I have received answers to any questions I may have had about the techniques and procedures indicated in this permission request form.

__________________________________ __________________________

Signature **Date**

Principal Investigator:

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

__________________________________ __________________________

Signature **Date**

REQUEST FOR PERMISSION FOR OBSERVATION AND INTERVIEW

Title of project:
The effects of question prompts and peer interactions in scaffolding ill-structured problem solving processes
Principal Investigator: Ms. Xun Ge, E-mail: xxg4@psu.edu, Phone: 862-5169, Address: 315 Keller
Advising Investigator: Dr. Susan Land

Dear ________________________________ (Student's Name):

This is to acknowledge that you have signed a consent form agreeing to participate in the study "The effects of question prompts and peer interactions in scaffolding ill-structured problem solving processes". We would like to thank you sincerely for your voluntary participation and offer of help.

In the meantime, we would like to inform you that you have been selected for observation during the problem-solving task in the lab session designated for this study, which is indicated in the Informed Consent Form. Students' interactions in the process of problem-solving tasks will be videotaped by using a stationary camera. The observation will also be followed by a focus-group interview, which will be conducted several days later. The conversations exchanged between the principal investigator and the students, as well as among the students during the group-interview session, will also be videotaped by using a stationary camera.

Only the investigators of this study have access to all the data recorded on videotapes. The tapes will be stored in a secure location in the advising investigator's office in Keller Building. All the tapes will be destroyed after 5 years.

If you agree to be observed and interviewed as part of the study, please give us your permission by signing this form.

Should you have any questions or concerns regarding the techniques or procedures, please contact the principal investigator at the email, phone number or the address above. Thank you!

Participant

I, ______________________ **(Print Name)**, understand the information given to me. I have received answers to any questions I may have had about the techniques and procedures indicated in this permission request form.

_________________________________ _____________________

Signature **Date**

Principal Investigator:

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

_________________________________ _____________________

Signature **Date**

APPENDIX B

PROBLEM-SOLVING TASK MATERIALS:

Validation Tool for the Problem-Solving Task Material

The Problem-Solving Task Material

Validation Tool for the Problem-Solving Task Material

Features	Responses			Comments
1. Is the problem relevant to the class (IST110)?	Yes	Somewhat	No	
2. Does the problem require the use of IT concepts and principles?	Yes	Somewhat	No	
3. Is the problem complex?	Yes	Somewhat	No	
4. Will the problem have multiple perspectives?	Yes	Somewhat	No	
5. Will the problem have multiple solutions	Yes	Somewhat	No	
6. Does the problem solution call for justifications/ argumentation	Yes	Somewhat	No	
7. Can the problem-solving task be completed within a period of 2 hours?	Yes	Somewhat	No	
8. Does the case need to be modified? If yes, how? Please write the comment in the space provided.	Yes	Somewhat	No	

Problem Solving Task Material

Many customers complain that they have difficulty finding items in a large store. This problem especially affects college students, who often have very little time for shopping. Since students are major customers in this small university town, the manager of the local Wal-Mart has hired your team as a consultant to propose IT-based solutions to the problem. Your task is to make suggestions about the features to be included in a new information system. As part of this, you are to develop a prototype (i.e., a simple model) illustrating your proposed system. Based on the findings of a survey, the proposed information system should be able to help customers to find items quickly, to present an overall view of all the items on a shelf and an aisle, and to map out the shortest route for getting all the items a customer needs to purchase. There may be some other important factors you may want to consider.

Your Tasks:

1. In a word document of 2-3 pages, draft a proposal to be submitted to the manager of Wal-Mart, analyzing the problem or situations, and making suggestions about the technological solutions, that is, the type of IT system you are going to develop. Support your solutions or decisions with argument and evidence, and evaluate your solutions or decisions.
2. Illustrate the proposed IT-system with a diagram.
3. Create a prototype or mockup (i.e., a simple model) of your proposed system (a mini system) by using MS Office 2000 applications (e.g., Access) or other computer applications, such as web. The purpose is to demonstrate how the system works, It does not mean that you have to use Access or Web to create the prototype.
4. (a) Submit a hard copy of #1 (the proposal) and #2 (the diagram), specifying group #, names, and email addresses.

   (b) Save #3 (as well as #1 and #2) to a floppy disk distributed to you and turn it in, specifying class section #, group # and names on the disk.

APPENDIX C

TREATMENT MATERIAL:

Question Prompts -- "Something to Think About… "

Something to Think About…

As you work through the problem, please read and think about the following questions.

How do I define the problem?

1. What are the parts of the problem?
2. What are the technical components?
3. What information do you need for this system? How will the system be used, by whom, and for what?
    - Who would be the users?
    - What information do you expect the users need?
    - What level of prior knowledge do you expect the users to have?
    - How would a user ideally interact with the proposed system?

What solutions do I need to generate?

4. What should the system do?
5. How should the different technical components of the proposed system interrelate?
6. What are the risks?

What are my reasons/argument for my proposed solution?

7. How would I justify this specific system design? For example, if I develop a web-based solution, can I explain why I took that approach?
8. Do I have evidence to support my solution (that is, the specific IT system I have proposed)? What is my chain of reasoning to support my solution?

Am I on the right track?

9. Have I discussed both the technical components and the issues with use, for example, usability and effectiveness?
10. Are there alternative solutions?
    - What are they?
    - How are they compared with my proposed system?
    - What argument can I make or what evidence do I have to convince the Wal-Mart manager that my solution is the most viable?

APPENDIX D

SCORING RUBRICS:

Scoring Rubrics for Measuring Ill-Structured Problem-Solving Processes

Summary of Measure Agreement among the Three Raters

Scoring Rubrics for Measuring Ill-Structured Problem-Solving Processes

1. Representing the problem (Subtotal Points: 10)

1.1. Define the problem

Score	Description	Examples
2	Problem clearly and completely stated.	"…their store is so large in size and holds a wide variety of items that customers who are in a hurry cannot find the products when they have little time to shop."
1	Problem vaguely or incompletely stated.	"…there is a large problem with finding items in your store…"
0	Problem not stated	

1.2. Generate subgoals

Score	Description	Examples
2	At least one specific goal for problem solution is clearly stated.	"…to help customers cut down the time in finding items in the store."
1	At least one goal for problem solution is clearly stated, but it is vague or general.	"…to help you increase sales and productivity"
0	Subgoal(s) not stated.	

1.3. Identify relevant information (known factors and constraints)

Score	Description	Criteria
3	8-10 of the known factors and constraints (stated in the criteria) are identified	Known factors and constraints: e.g. • Time • Location • Navigation • Complexity of the system • Cost • Use • Users • Implementation • buy vs. build • risks
2	5-7 of the known factors and/or constraints (stated in the criteria) are identified.	
1	3-4 of the known factors and constraints (stated in the criteria) are identified.	
0	0-3 Known factors and constraints (stated in the criteria) are not identified at all	

1.4. Seek needed information

Score	Description	Criteria
3	5-6 pieces of the needed information (stated in the criteria) discussed.	Needed information such as: • Who will be the users • Prior knowledge of the users • Existing system • Previous efforts • Cost • Time
2	3-4 pieces of the needed information (stated in the criteria) discussed.	
1	1-2 pieces of the needed information (stated in the criteria) discussed.	
0	Needed information (stated in the criteria) is not discussed at all.	

2. Developing solution(s) (Subtotal Points: 8)

2.1. Selecting or developing solutions, with explicit explanation.

Score	Description	Criteria
3	A solution is selected or developed, with explicit explanation on how the solution works.	The explanation should include the interrelationship between different critical technical components, such as the system, the interface, technical features, etc.
2	A solution is selected or developed, with minimal explanation on how the solution works.	
1	A solution is selected or developed, but without any explanation how it works.	
0	No solution is selected or developed.	

2.2. Quality of the solution(s) (Holistic Assessment)

Score	Description	Criteria
5	Exceptional	The holistic assessment is based on the following: (a) arriving solutions required by the problem-solving task: • Finding the items quickly • Give an overall information of the items on the shelf • Mapping the route (b) The number of factors addressed, e.g., existing systems, previous efforts, time, cost, implementation, risk, user; usability
4	Excellent	
3	Good	
2	Weak	
1	Poor	
0	No solution	

3. Making justifications for the proposed solution(s) (Subtotal Points: 7)

3.1. Constructing argument

Score	Description	Criteria
4	Argument is well constructed.	Coherent and persuasive premises are provided to support the proposed solution, and factors or constraints are discussed.
2	Argument is poorly constructed.	Irrelevant or incoherent premises are provided to support the proposed solution, and factors or constraints are partially discussed.
0	No argument is constructed.	Premises are missing, and no factors or constraints are discussed.

3.2. Providing evidence

Score	Description	Criteria
3	Evidence to support the argument is strong and relevant.	The evidence has been tested, or based on previous experience or real examples.
2	Evidence to support the argument is relevant.	The evidence is plausible or based on imagery examples.
1	Evidence to support the argument is weak or irrelevant.	The evidence is not plausible or relevant at all.
0	No any evidence is provided.	

4. Monitoring and evaluating problem space and solutions (Subtotal Points: 7)

4.1. Evaluating solution(s)

Score	Description	Criteria
3	The proposed solution is evaluated, and constraints are discussed, supported with reasoning.	A statement is made about the effectiveness or benefits of the solution. The pros and cons of the solution(s) (e.g. cost, risks, etc.) are discussed, supported with relevant evidence (e.g. from the past experience), as well as how the constraints can be overcome.
2	The proposed solution is evaluated, and constraints are mentioned, but no reasons are provided.	A statement is made about the effectiveness or benefits of the solution, and the constraints of the solution (e.g., risks, cost, etc.) are mentioned but not discussed in relation to pros and cons (e.g., cost, risks, etc.), nor supported with relevant evidence.
1	Evaluation of the solution is stated, but no reasoning is provided, and no constraints are mentioned.	A statement is made about the effectiveness or benefits of the solution, but the constraints of the solution (e.g., risks, cost, etc.) are not mentioned.
0	The solution is not evaluated.	No statement is made about the effectiveness or benefits of the solution.

4.2. Assessing alternative solutions

Score	Description	Criteria
4	Alternative solution is stated, and the viability of the solution(s) is discussed.	At least one optional solution is discussed. Reasons are given on why an option is selected over the other(s), with constraints discussed.
2	Alternative solution is stated, but the viability of the solution is not discussed.	At least one optional solution is described, but no reasons are given on why it is selected.
0	Alternative solution is not mentioned at all.	

Summary of Measure Agreement among the Three Raters

Item/ Value Range	Point Value Assigned	Measure Agreement
1.1. Define problem (0, 1, 2)	0, 1, 2	• There was a full agreement on point value 2 assigned. • There were some variations with point values 0 and 1 assigned (with k value = 1.0 and 0.615 respectively, $p < 0.05$).
1.2. Generate subgoals (0, 1, 2)	0, 1, 2	• There was a significant agreement on point values 0 and 1 assigned. • There was a slight variation with point value 2 assigned (k value = 0.635, $p < 0.05$)
1.3. Identify information (0, 1, 2, 3)	0, 1, 2, 3	• There was a significant agreement on all the point values assigned (0, 1, 2, 3), with full agreement on 0 and 2, and significant agreement on 1 (k value = -0.085, $p > .05$).
1.4. Seek needed information (0, 1, 2, 3)	0, 1, 2, 3	• There was a full agreement on the point value assignment for 1, 2, 3. • There was a slight variation with point value 0 assigned (k value = 0.512, $p < 0.05$).
2.1. Select and explain solutions (0, 1, 2, 3)	2, 3	• There were some variations with point values 2 and 3 assigned (with k value = 0.634 and .529 respectively, $p < .05$).*
2.2. Quality of solution (0, 1, 2, 3, 4, 5)	2, 3, 4, 5	• There was a significant agreement on all the point values assigned (2, 3, 4, 5) (with k value = 0.418 for 3 and 1.0 for 5, $p > 0.05$).
3.1. Constructing argument (0, 2, 4)	0, 2, 4	• There were some variations with point values 2 and 4 assigned (with k value = 0.732 and 0.561 respectively, $p < 0.05$).*
3.2. Providing evidence (0, 1, 2, 3)	0, 1, 2, 3	• There was a significant agreement on point values 0, 1,and 2 assigned. • There was a slight variation with point value 3 assigned (k value = 0.05, $p < 0.05$).
4.1. Evaluate solutions (0, 1, 2, 3)	0, 1, 2, 3	• There was a significant agreement on point values 0, 2, 3 assigned. • There was a slight variation with point value 1 assigned (k value = .406, $p < 0.05$).
4.2. Assess alternative solutions (0, 2, 4)	0, 2, 4	There was a full agreement on point values 0 and 4 assigned. There was a slight variation with point value 2 assigned (k value = 0.688, $p < 0.05$).

Note.

- K value is the kappa value for calculating measure agreement between raters. It takes into account base rates, which is the relative frequency of the behavior being rated in the study.
- * suggests that there is no significant agreement among the three raters on the values assigned to that item.
- For items which had no full measure agreement among the raters, the point value assigned by the majority of the raters were used

APPENDIX E

STUDENTS' SELF-REPORT ON PROBLEM-SOLVING SKILLS:

Self-Report Questionnaire

Summary of the Questionnaire Results

Questionnaire

Name ________________ **Date ___________________**

Course and Section # _________________ **Gender: F M**

1. I am in the
   A) IST major
   B) Other ________ (Specify).

2. I am a
   A) freshman
   B) sophomore
   C) Other (Specify) ________________

3. Why do you take this class?
   a) It is required for my major b) I am interested in it
   c) I am thinking of taking major in IST d) Other _______ (specify)

4. Why are you enrolled in this class section?
   a) because it fits into my schedule b) because someone recommended this professor to me
   c) No particular reason d) Other _________ (specify)

5. How often have you solved a problem like the case study you have completed for this study?
   A) Often
   B) A few times
   C) Never

6. Please rate your computer skills in using Excel or other spreadsheet applications:
   a) Expert
   b) Competent
   c) Novice
   d) Clueless

7. Please rate your computer skills in using Access 2000 or other database applications:
   a) Expert
   b) Competent
   c) Novice
   d) Clueless

8. Please rate your web page development skills:
   a) Expert
   b) Competent
   c) Novice
   d) Clueless

9. How well do you understand the functions of a spreadsheet? Please rate yourself on a 1-5 scale, with 5 being the highest and 1 the lowest:
   5 4 3 2 1

10. How well do you understand the database structure, such as relational database model, hierarchical model? Please rate yourself on a 1-5 scale, with 5 being the highest and 1 the lowest:
    5 4 3 2 1

Direction. The following questions inquire how you solve a problem.[1] Please read the following statements and circle the answer that best describes the way you are when you are trying to solve a problem. Think about a problem that you might see in a math or science class. There are no right answers, please describe yourself as you are, ***not how you want to be or think what you ought to be***:

1 = Never (N)
2 = Seldom / Rarely (SLD)
3 = Sometime (STM)
4 = Often / Frequently (OFT)
5 = Always (AL)

Before you begin to solve a hard problem, what do you do?	N	SLD	STM	OFT	AL
11. I think to myself, do I understand what the problem is asking me?	1	2	3	4	5
12. I try to remember if I have worked a problem like this before.	1	2	3	4	5
13. I think about what information I need to solve this problem.	1	2	3	4	5
14. I ask myself, is there information in this problem that I don't need?	1	2	3	4	5
15. I try to think about the constraints of the problem.	1	2	3	4	5
What do you do as you work the problem?					
16. I list all the information available and the constraints.	1	2	3	4	5
17. I try to identify the critical relationships from the information given.	1	2	3	4	5
18. I create a picture in my head or on a piece of paper to help me understand the problem.	1	2	3	4	5
19. I plan all the steps as I work on the problem	1	2	3	4	5
20. I keep looking back at the problem after I do a step.	1	2	3	4	5
What do you do after you finish working on the problem?					
21. I look back at my problem-solving process to see if it makes sense.	1	2	3	4	5
22. I try to find evidence to justify and support my solutions.	1	2	3	4	5
23. I think about the solutions and see if there are alternatives.	1	2	3	4	5
24. I try to look at the problem solutions from different perspectives.	1	2	3	4	5
25. I test my solution or hypothesis by asking myself "if…what…".	1	2	3	4	5

[1] Questions 11-30 are adapted from
(a) Fortunator, I., Hecht, D., Tittle, C. K., & Alvarz, L. (1991). Metacognition and problem solving. Arithmetic Teacher, 38(4), 38-40.
(b) Hong, N. S. (1998). The relationship between well-structured and ill-structured problem solving in multimedia simulation, The Pennsylvania State University, University Park, PA.

<u>In what way do you work on problems?</u>

26. I draw a picture to help me understand the problem.	1	2	3	4	5
27. I develop a hypothesis first and then test it.	1	2	3	4	5
28. I pick out the steps I need to do for this problem.	1	2	3	4	5
29. I prioritize the problems or goals and focus on the most critical one.	1	2	3	4	5
30. I follow a problem-solving model.	1	2	3	4	5

Summary of the Self-Report Questionnaire Results

I. Background Information (Questions 1-5)

	QUESTIONS					
	Gender (N)	1. Major (%)	2. Year of college (%)	3. Why take the class? (%)	4. Why in this class section? (%)	5. How often solve the problem? (%)
Overall Profile N=115	M: 80 F: 35	IST: 77.4 Other: 22.6	Freshman: 77.4 Sophomore: 21.7 Other: 0.9	Required: 70.4 Possibly IST: 14.8 Interested: 6.1 Other: 0.9	Schedule: 68.7 By chance: 27 Other: 2.6 Recommended: 0.9	A few times: 70.4 Never: 18.3 Often: 11.3
Condition						
Peer-Question (PQ) N = 47	M: 35 F: 12	IST: 91.5 Other: 8.5	Freshman: 91.5 Sophomore: 6.4 Other: 2.1	Required: 76.6 Interested: 8.5 Possibly IST: 6.4	Schedule: 59.6 By chance: 34 Other: 4.3	A few times: 78.7 Never: 12.8 Other: 8.5
Peer-Control (PC) N = 37	M: 27 F: 10	IST: 70.3 Other: 29.7	Freshman: 70.3 Other: 29.7	Required: 75.7 Possibly IST: 10.8 Interested: 8.1	Schedule: 78.4 By chance: 18.9 Recommended: 2.7	A few times: 56.8 Never: 270 Often: 16.2
Individual-Question (IQ) N = 15	M: 7 F: 8	IST: 60.0 Other: 40.0	Freshman: 60.0 Other: 40.0	Required: 53.3 Possibly IST: 40	Schedule: 66.7 By chance: 26.7 Other: 6.7	A few times: 73.3 Never: 20.0 Often: 6.7
Individual-Control (IC) N = 16	M: 11 F: 5	IST: 68.8 Other: 31.3	Freshman: 68.8 Other: 31.3	Required: 56.3 Possibly IST: 25.0 Other: 6.3	Schedule: 75.0 By chance: 25.0	A few times: 75.0 Never: 12.5 Other: 12.5

II. Computer Knowledge and Skills (Questions 6-10)

	QUESTIONS				
	6. Excel (%)	7. Access (%)	8. Web (%)	9. Spreadsheet functions (%)	10. Database structure (%)
Overall Profile N=115	Competent: 72.2 Expert: 16.5 Novice: 11.3	Competent: 46.1 Novice: 44.3 Expert: 5.2 Clueless: 4.3	Competent: 51.3 Novice: 34.8 Expert: 11.3 Clueless: 2.6	(5=highest; 1=lowest) (4): 55.7 (5): 21.7 (3): 20.9 (2): 1.7	(5=highest; 1=lowest) (3): 49.6 (4): 22.6 (2): 13.0 (5): 11.3 (1): 3.5
Condition					
Peer-Question (PQ) N = 47	Competent: 63.8 Expert: 21.3 Novice: 14.9	Competent: 48.9 Novice: 36.2 Expert: 12.8 Clueless: 2.1	Competent: 42.6 Novice: 38.3 Expert: 19.1	(5=highest; 1=lowest) (4): 57.4 (5): 25.5 (3): 17.0	(5=highest; 1=lowest) (3): 48.9 (4): 27.7 (5): 14.9 (2): 8.5
Peer-Control (PC) N = 37	Competent: 70.3 Expert: 16.2 Novice: 13.5	Novice: 56.8 Competent: 37.8 Clueless: 5.4	Competent: 51.4 Novice: 43.2 Clueless: 5.4	(5=highest; 1=lowest) (4): 48.6 (3): 29.7 (5): 16.2 (2): 5.4	(5=highest; 1=lowest) (3): 45.9 (2): 18.9 (4): 18.9 (5): 10.8 (1): 5.4
Individual-Question (IQ) N = 15	Competent: 86.7 Expert: 6.7 Novice: 6.7	Novice: 46.7 Competent: 40.0 Clueless: 13.3	Competent: 60.0 Expert: 20.0 Novice: 13.3 Clueless: 6.7	(5=highest; 1=lowest) (4): 86.7 (3): 6.7 (5): 6.7	(5=highest; 1=lowest) (3): 46.7 (4): 20.0 (1): 13.3 (2): 13.3 (5): 6.7
Individual-Control (IC) N = 16	Competent: 87.5 Expert: 12.5	Competent: 62.5 Novice: 37.5	Competent: 68.8 Novice: 25.0 Expert: 6.3	(5=highest; 1=lowest) (4): 37.5 (5): 37.5 (3): 25.0	(5=highest; 1=lowest) (3): 62.5 (4): 18.8 (2): 12.5 (5): 6.3

APPENDIX F

SAMPLE INTERVIEW QUESTIONS:

Interview Questions for Cases 1-2 (IQ)

Interview Questions for Cases 3-4 (IC)

Interview Questions for Cases 5-6 (PQ)

Interview Questions for Cases 7-8 (PC)

Sample Interview Questions for Cases 1-2 (the IQ Condition)

Background Information Questions

- Are you IST or other major?
- Are you freshmen, sophomore, junior or senior?
- Have you ever done a problem-solving task like this before? How often?

On Problem Solving

- Would you please tell me how you solved the problem in detail, for example, how you approached the problem at first, and how you came up with solutions?
- Did you consider various factors when you defined the problem? What were those factors that came to your mind?
- What were your reasons for selecting those solutions?
- Were you trying to compare different ideas and alternatives? What were those options?
- Did you think about different perspectives, alternatives, or constraints?
- Did you go back to your problem solution and test it? Could you give me an example?

On Question Prompts

- Did you use those question prompts? If yes, did you find them helpful in solving the problem? In what ways? Could you give me some examples?

On Peer Interactions

- Do you think it would be easier or more difficult to work with group members? Please explain why.

Sample Interview Questions for Cases 3-4 (the IC Condition)

Background Information Questions

- Are you IST or other major?
- Are you freshmen, sophomore, junior or senior?
- Have you ever done a problem-solving task like this before? How often?

On Problem Solving

- Would you please tell me how you solved the problem in detail, for example, how you approached the problem at first, and how you came up with solutions?
- Did you consider various factors when you defined the problem? What were those factors that came to your mind?
- What were your reasons for selecting those solutions?
- Were you trying to compare different ideas and alternatives? What were those options?
- Did you think about different perspectives, alternatives, or constraints?
- Did you go back to your problem solution and test it? Could you give me an example?

On Peer Interactions

- Do you think it would be easier or more difficult to work with group members? Please explain why.

Sample Interview Questions for Cases 5-6 (the PQ Condition)

Background Information Questions

- Are you IST or other major?
- Are you freshmen, sophomore, junior or senior?
- Have you done a problem-solving task like this before? How often?

On Problem Solving

- Would you please explain to me in detail how your group collaborated to solve this problem? Please give me examples.
- Prompting Questions:
  How did you start the problem solving process?
  How did you come up with the solutions?
  What did you think of your solutions? How did you justify your solutions?
  Did you try to compare with some other alternative solutions?
  Did you go back to your problem and evaluate the solutions?

On Groups Collaboration

- Did the group help you to solve this problem? How? Please give examples.
- Would you please explain specifically how the group members collaborated in this problem solving process?
- Were there a lot of conversations exchanged among the members? Did you ask each other questions?

On Question Prompts

- Did you use the questions provided? Why or Why not?
- Did you find the questions helpful? In what ways? Please give examples.

Sample Interview Questions for Cases 7-8 (the PC Condition)

<u>Background Information Questions</u>

- Are you IST or other major?
- Are you freshmen, sophomore, junior or senior?
- Have you done a problem-solving task like this before? How often?

<u>On Problem Solving</u>

- Would you please explain to me in detail how your group collaborated to solve this problem? Please give me examples.
- Prompting Questions:
  How did you start the problem solving process?
  How did you come up with the solutions?
  What did you think of your solutions? How did you justify your solutions?
  Did you try to compare with some other alternative solutions?
  Did you go back to your problem and evaluate the solutions?

<u>On Groups Collaboration</u>

- Did the group help you to solve this problem? How? Please give examples.
- Would you please explain specifically how the group members collaborated in this problem solving process?
- Were there a lot of conversations exchanged among the members? Did you ask each other questions?

APPENDIX G

SAMPLE TRANSCRIPTS:

Sample Think-Aloud Protocols (Case 1)

Sample Observation Transcripts (Case 7)

Sample Interview Transcripts (Case 3)

Sample Interview Transcripts (Case 6)

Sample Think-Aloud Protocols (Case 1)

Participant: Cathy

Condition: Individual-Question

Transcripts	**Notes**
I'm going to develop an IT system for, to make products at WalMart easier to access. So the first thing I'll probably think about would be categorizing the type of products, cause you walk into a store, oftentimes I don't walk in with a specific purpose, but for those people that want to find something right away, it would be nice for them to get an overall picture right away of where a product would be in the store in general. So I'm going to start writing about the analysis of the problem. OK, the problem is that having a store so big that has so many different types of products, ranging from clothing to shoes to kitchen ware to, I mean, electronics, some sort of organizational system should be implemented to categorize and, and organize the information. Probably the first thing that I would suggest would be to get a large overall picture of the layout of the actual store so that when customers walked into the store they could have a pretty good feel for the areas and what direction they would be heading in. That wouldn't involve any sort of technological, like appliance, but probably, I mean that could help people once they started searching for specific things but at the beginning they should have just a big picture of generally how the store's going to be laid out. And I know that WalMart already does have a sort of system where they have hangs hanging up from the ceiling of the different areas, but it would probably be helpful also to have maps throughout the store. I find also that when I'm in a store like WalMart it's not set up, like, even the sections are kind of confusing, like you don't really understand where the aisles start and stop and like, like it's just not a series of straight blocks like some of them seem like they go into others or are like, or surround others, you know what I mean, so like I would probably suggest laying out the products in a very block, …	

Sample Observation Transcripts (Case 7)

Participants: Bryan, Gary, Joanne, Jim

Condition: Peer-Control Condition

Events	Verbalization	Notes
8:20-8:22 Brainstorming	Bryan: Hum, all I am going to do is that we could do something like, make it possible to get a debit card. You can…you can pay for your purchase on your cart or other locations other than the cashier, cause sometimes it gets very crowded, and that if they were looking for one thing, in an aisle or something, not even like pay face-to-face but automatically. Gary: There have been Walmarts around. Bryan: Lots of them…If you walk through the door with some people… Joanne: Maybe with a little camera or something… Jim (murmuring): Maybe the easiest way is to let a Walmart person take something… Bryan: Yeah, right (laughing) (Bryan writes something on the paper) Jim: (inaudible) Yeah, seriously…I would start six dollars an hour… Joanne: Hum, do you know at Giant, they have a little checkout thing? Bryan: Yeah, do they? Joanne: Yeah, the system is like…and they don't charge it. When you scan it, and you have to put it in the bag, and underneath the bag is like a scale and it weighs it, like you don't do it, if you don't put it in the bag, you just put the bag in the cart, like customer service of Walmart, because you don't…like if you have a…it is too easy to…(inaudible). So…not only will there be less complaints, but they will have no more rushing emergencies. Bryan: Why not do something like that?	

Sample Interview Transcripts (Case 3)

Interviewee: Paul

Condition: Individual-Control

Interview	**Notes**
Researcher: Did you analyze the problem? How did you analyze the problem Paul: I analyzed it in my head. Well, I just, I read through it, I thought what the customers needs would be. For example, I actually, actually I just came up with that idea, so maybe I didn't think through it, but I thought, I guess I really didn't think, analyze it at first, but I just I jumped into the solution and kind of just went as, went as it developed. Figured out what the needs would be of the customer as I went through it, so yes, I guess I really didn't think in the beginning. Researcher: How did you approach the problem? Did you have a plan in your mind? Paul: I had a general plan and then I went by that and modified, Researcher: What was your plan? Paul: And then I recognized the problem, I guess I came up with a solution pretty quickly, and then analyzed how I could make my solution better. Researcher: How did you do that (TAPE CHANGE) Paul: Well, as I was just talking out loud I realized I was missing, as I was talking out loud I realized stuff I was missing and, when I write papers it takes me a while. Researcher: So what was your general plan? Paul: My general plan. Well I would, kind of a plan, just, well recognize the solution, or come up with a solution, recognize the problem, come up with a solution. Researcher: What's the problem you recognized? Paul: That when you go in, when a person goes into WalMart, it's so big,	

Sample Interview Transcripts (Case 6)

Interviewees: Shryle, Brandon, Perry, Matt

Condition: Peer-Question

Interview	Notes
Perry: probably based on our own experience, what would our customers like? Perry: Like us walking in the Walmart, don't know where I am going (laugh). Researcher: So, based on your prior experience. Brandon: Yeah, prior experience. Researcher: Would you please tell me how your group collaborate to solve this problem? And what did you do? Brandon: I think the biggest thing is to come up with ideas what is the best system, and what is the best solution. Hm, Researcher: That's where you started, brainstorming. Perry: Yeah, brainstorming. Researcher: What types of things did you brainstorm? Perry: You know the type of the system we want, and everybody has his own ideas. Brandon: Where are we going to place them, and what type of stuff will be in that system? Shryle: There was a point where we kind of had set ideas and we said, "Alright, what other things could we do?" and then trying to figure out why this was better doing than the other. Perry: Right. Matt: One subject like came back and forth for a while, and actually it came up very well. Matt: like the server, external, Brandon: external and internal. Matt: Right, external and then internal. Brandon: You actually had the internal server in the store, where you can retrieve the information from the computer, and then if the store has the server, you update the server without …	

APPENDIX H

QUALITATIVE DATA DISPLAY (SAMPLE):

Summary of Cross-Case Comparison of

Students' Problem-Solving Processes on an Ill-Structured Task (Sample)

Cross-Case Comparison in Problem Representation (Sample)

Network Display: Effects of Question Prompts

on Students' Problem-Solving Process (Sample)

Data Display Matrix: Effects of Peer Interactions

on Problem-Solving Processes (Sample)

Summary of Cross-Case Comparison of Students' Problem-Solving Processes on an Ill-Structured Task (Sample)

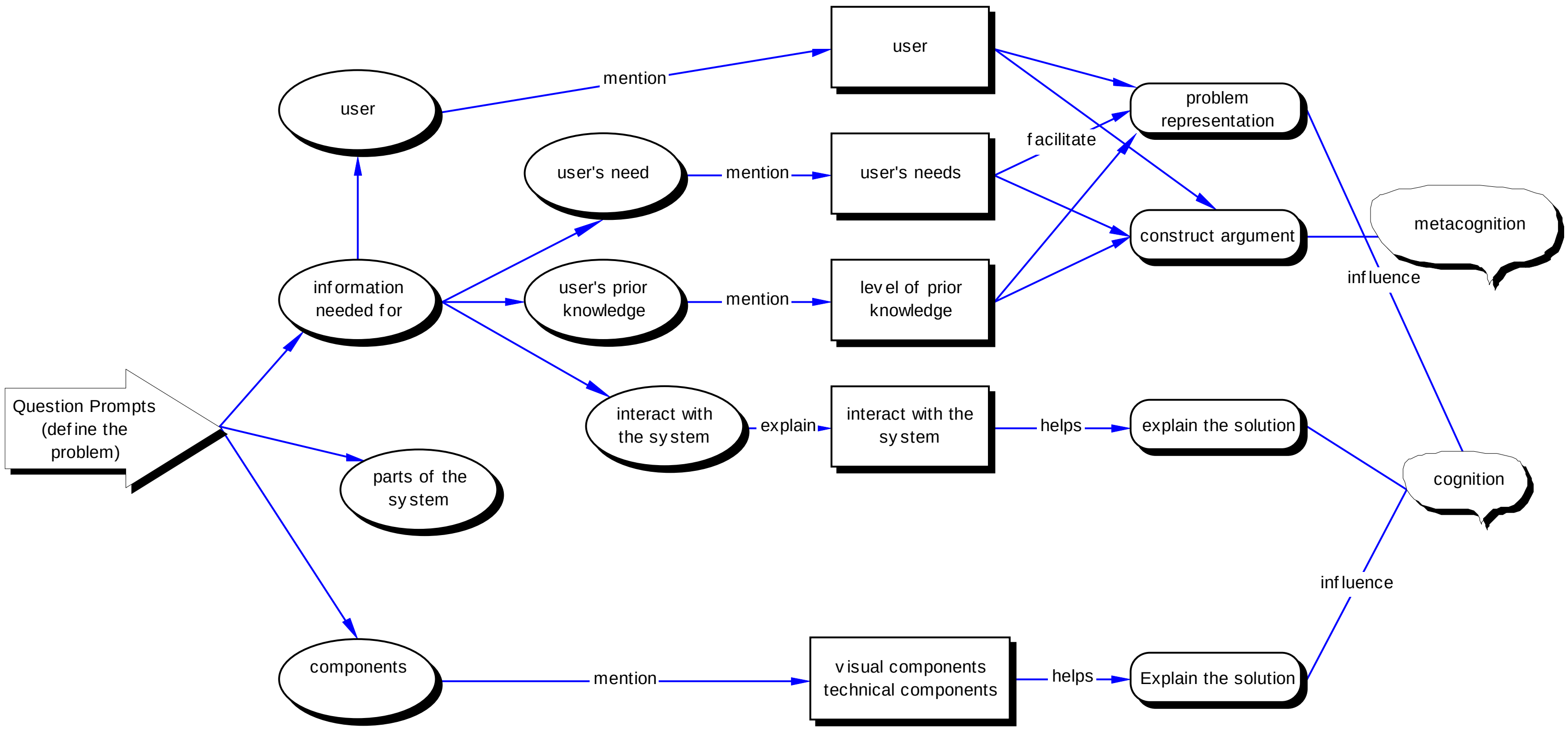
CASE #: 1 CONDITION: IQ

ILL-STRUCTURED PROBLEM-SOLVING PROCESSES				
	Representing Problems	2. Developing Solutions	3. Making Justifications	4. Monitoring and Evaluation
RUBRICS	1.1. Define the problem 1.2. Generate subgoals 1.3. Identify available information (known factors and constraints) 1.4. Seek needed information and constraints	2.1. Selecting or developing solutions, with explicit explanation. 2.2. Quality of the solutions (holistic assessment, as well as in relation to the criteria identified)	3.1. Constructing argument 3.2. Providing evidence	4.1. Evaluating solutions 4.2. Assessing alternative solutions
PERFORMANCE	1.1. Define the problem: -Organize information based on personal experience -state the problem clearly 1.2. Generate subgoals --Generate subgoals (articulate reasons for this goals) 1.3. Identify available information and constraints --Walmart has the existing system --Possible factors or constraints: user, level of prior knowledge, parts of the system, etc. 1.4. Seek needed information: (not pursued)	2.1. Explain the system, how different components interact with each other: --Activate schema for the problem solution, based on her own experience as a user. --Explain the system, e.g., the organization of the database system: (a) visual component, and (b) database 2.2. Consider different factors when developing solutions; trying to map the factors with the solutions (user, use, level of prior knowledge, parts of the system, implementation/testing of the system) Trial testing solutions. Started with a range of possibilities available, then narrowed it down to some kind of device	3.1 constructing argumentation --rationale for the design "easy to use" --argue for alternative solutions 3.2. Provide evidence --personal experiene based on her experience as a WalMart user.	4.1. evaluate the solutions --recognize the constraints of the solution --when selecting solutions, also considering ways to overcome constraints --reflect on the solution after the proposal was drafted 4.2. think about alternative solutions --argue for alternative solutions Other evidence of monitoring and evaluation: --Planning (I am going to start writing about the analysis of the problem) --Monitoring thinking process: e.g., articulating reasoning for the subgoals.

Cross-Case Comparison in Problem Representation (Sample)

CASE #	CONDITION	Representing the Problem 1. Define the problem	2. Generate subgoals	3. Identify needed information (factors, constraints, etc.)	4. Seek needed information
1	IQ	• Relate to her experience as a WalMart user • organize information to understand the problem • state the problem clearly	• generate subgoals, and articulate reasoning for this goal	• e.g., Walmart has the existing system • possible factors or constraints: user, level of prior knowledge, parts of the system, risks; cost; etc.	(Not pursued)
2	IQ	• Relate to his prior experience of working at a store (CompUSA). • Organize relevant information based on his knowledge, e.g., think about what the situation might be.	• Generate subgoals: a database and articulate reasons for this goal.	• Identify constraints: (interweaving with the solution process): user, use, level of prior knowledge, risks, implementation, usability, effectiveness	• what products the store carried • how many…carried • what needs to be done • etc.
3	IC	• Activating schema to understand a problem based on prior experience • organize information	(Note clear)	**(while developing the solutions):** user, use	
4	IC	• Activating schema to understand a problem based on prior experience • organize information to understand the goal of the problem	• make a little CD display	**(while developing the solutions):** (a) user (b) use (efficiency; effectiveness) (c) implementation	• Only cost was mentioned.

Network Display: Effects of Question Prompts on Students' Problem-Solving Process (Sample)



Case 1 (IQ); Participant: Kathy

Relationship of the question prompts (questions 1-3) on Kathy's problem-solving processes

Data Display Matrix: Effects of Peer Interactions on Problem-Solving Processes (Sample)

Form of Peer Interactions	Reactions	Processes/Thinking Influenced
Brainstorm	• Comes up with different ideas to solve the problem (e.g., Case 5, 6, 7)	• Problem representation (cognitive thinking)
Ask questions	• Explain (Case 8): explain what PDA is (Case 5): what server is • Examine thinking process, solutions, etc. : (Case 7): cause one to examine the feasibility of a solution (Case 8): evaluate the solutions, modify the solution accordingly (Case 8): explain what PDA is	• Develop solutions (cognitive thinking) • Make justifications (metacognitive skills) • Monitor and evaluate solution process (metacognitive skills)
Provide feedback	• Monitor thinking process, e.g.; (Case 6): examine pros and cons, decide what systems to use (e.g., external vs. internal) (Case 5): testing the system • Reflect on one's thinking (Case 5) see things that could not have thought about	• Monitor and evaluate solution process (metacognitive skills)
Elaborate ideas	• Build upon each other's ideas (Case 7, 8, 6)	• Developing solutions (cognitive thinking) • Problem representation (cognitive thinking)
Make suggestions	• Build upon each other's ideas for developing solutions (Case 7, 8, 6) • See things from other perspectives (Case 5) think about things that could not have thought about	• Developing solutions (cognitive thinking) • Monitor and evaluate solution process (metacognitive skills)
Share ideas	• Get multiple perspectives (Case 5, 6, 8) • Share expertise (Case 6): my ideas combined with other people's ideas (Case 7, 8): take expertise from each other	• Monitor and evaluate solution process (metacognitive skills) • Developing solutions (cognitive thinking)

VITA

Xun Ge was born and grew up in Fuzhou, a coastal city in southeast China. She had dreamt of becoming a Chinese-English interpreter and translator during her high school days, but started her career as an English instructor. She was on her way to become a sociolinguist in bilingual education while she found her interest shifted to instructional technology. Now she is weaving her dream of bringing *language*, *education* and *technology* to a coherent place.

Ms. Ge holds a B.A. and an M.A. degree in English language and literature, as well as an M.Ed. degree in bilingual/multicultural education. Before she came to the United States in 1994, she had been a faculty member in Foreign Language Department, Fijian Teachers University, P. R. China. In 1997, after her graduate studies in bilingual education at Northern Arizona State University, she became a doctoral student in the program of Instructional Systems, The Pennsylvania State University.

During her four years at The Pennsylvania State University, she has been a graduate assistant, computer laboratory administrator in Instructional Systems; a teaching assistant in School of Information Sciences and Technology; an intern instructional designer at the Center for Academic Computing and at the World Campus, an institute for online distance education. She also had an opportunity to intern at the PricewaterhouseCoopers as an instructional consultant in 1999.

Ms. Ge's current research interest is in scaffolding strategies for problem solving and collaborative learning, in both online and classroom environments, which she hopes to continue in her new faculty position at the University of Oklahoma.