SELF-APPRAISAL AND SELF-MANAGEMENT OF COGNITION AND PROBLEM DIFFICULTY: RELATIONSHIP AND METACOGNITIVE CHANGES DURING AN ENGINEERING DESIGN PROJECT

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DISSERTATION

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ABSTRACT

From numerous studies, researchers found that metacognition, which is often referred to as the ability to think about thinking, plays an important role in learning (Chambres, Bonin, Izaute, & Marescaux, 2002; Chan & Moore, 2006; Chi, 1981; Graves, 1983; Jonassen, Strobel, & Lee, 2006; Ross, Green, Salisbury-Glennon, & Tollefson, 2006). Metacognition is higher-level thinking that involves active control over the thinking processes involved in learning. Among the many definitions of metacognition, Paris and Winograd (1990) offered a more comprehensive view in which metacognition is observed through two essential features: (a) cognitive self-appraisal (CSA) and (b) cognitive self-management (CSM). While self-appraisal in learning refers to a learner's personal judgment about his or her ability to meet a cognitive goal, self-management refers to maintaining executive control that will indicate, "how metacognition helps to orchestrate cognitive aspects of problem solving" (p. 18). The ability to plan, regulate, and evaluate learning are the skills commonly used to indicate the presence of students' self-management.

This study investigated the relationship between cognitive self-appraisal and cognitive self-management, and their relationship with the level of difficulty of the problem of three different groups of engineering students (i.e., computer science, electrical and computer engineering, and mechanical engineering) working on their senior design projects. Moreover, this study also evaluated students' metacognitive changes while engaged in their project. Four research questions were constructed to guide this study: (a) Was there any significant relationship between cognitive self-appraisal and cognitive self-management of the three groups of engineering students (i.e., electrical-

computer engineering, mechanical engineering, and computer science) while engaged in the design project?, (b) Was there any significant relationship between a student's metacognition (i.e., cognitive self-appraisal and cognitive self-management) and the level of difficulty of the design problem of the three groups of engineering students?, (c) Did electrical-computer engineering, mechanical engineering, and computer science students exhibit significant differences in cognitive self-appraisal and self-management while engaged in the design project?, and (d) Was there any significant change in students' metacognition during their engagement in the design project?

The quantitative study involved 168 engineering students working on 60 different design projects, and 3 engineering professors advising the students and evaluating the level of difficulty of the projects. The study used 2 survey instruments: A 34 Likert-scale of items of Engineering Design Project Inventory (EDPI) for assessing students' cognitive self-appraisal and self-management, and a 6 Likert-scale of items of Rubric for Rating Students' Design Project (RRSDP) for evaluating the level of difficulty of students' design projects. Statistical tests such as Bivariate Correlation, one-way Analysis of Variance (ANOVA), and Paired-Samples *t* tests were conducted to analyze the data and answer the four research questions.

The students participants were asked to complete the EDPI survey instrument twice, once at the early and once at the final stage of the project. During the second round of completing the EDPI survey, the student participants were also requested to answer two open-ended questions regarding to the possibility of experiencing self-appraisal and self-management change while engaged in the project. Approaching the end of the semester, the advising professors were requested to rate the level of project difficulty by completing an RRSDP.

The statistical tests results revealed (a) the existence of a significant relationship between students' cognitive self-appraisal and self-management, (b) the absence of a significant relationship between students' metacognition and level of project difficulty, (c) the absence of a significant metacognitive difference among the three groups of engineering students, and (d) the existence of a significant metacognitive change in mechanical engineering students' overall metacognition between the early and final stages of the design project. Eighteen distinct themes that described the influencing factors for students' CSA change and 23 distinct themes that described the influencing factors for their CSM change were also presented. Based on the findings of this study, a number of recommendations were made to engineering educators and researchers who wish to pursue further research in this area.

To my mother, mother-in-law, wife Nanik, son Kevin, and daughter Stephanie

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CHAPTER 1

THE PROBLEM

When electrical-computer engineering students are asked to design an 8-bit digital counter, they may begin by asking questions such as, "What do I know about a digital counter?", "What kind of knowledge is needed to do the design?", and "Do I possess that knowledge so that I can complete the task successfully?" Such questions assess the descriptive, procedural, and conditional knowledge and skills needed to design the digital counter. The questions evaluate metacognition, which is often referred to as strategic thinking or, more simply as *thinking about thinking*. Metacognition is a higher-level cognitive process that involves active control over the thinking processes involved in learning.

In addition to assessing the descriptive, procedural, and conditional knowledge, one also must be in charge of setting goals and performing actions to achieve those goals. When engaged in a situation that involves specific levels of task ambiguity and complexity, one must make plans, such as the type of digital counter to be designed and what approach and components are to be considered in building the counter. With the awareness of one's thinking processes, understanding of the task, and an accurate determination of the abilities required to solve the design task, one may establish the strategies needed to resolve problems encountered enroute to the successful design of a digital counter.

In addition to cognitive issues, metacognition also involves emotional and motivational aspects. When electrical-computer engineering students believe that they have the ability to manage their own thinking and have a positive attitude toward the design task, they are more likely to explore ways to cope with various challenges that may have occurred during the design process. The influence of emotional and motivational aspects on learning performance was found in a study conducted by Chan and Moore (2006). Two interesting findings about grade 5 to 9 students' developmental attribution of beliefs (i.e., the individual's beliefs about the self that may contribute to performance) and strategic knowledge in learning were highlighted in the study. First, it was found that maladaptive attributional beliefs tend to negatively impact academic achievement, and in some instances, strategic knowledge and use. Second, combining the teaching of cognitive/metacognitive strategies for learning with attempts to convince students to attribute success can break the vicious cycle of helplessness that negatively impacts strategic learning and academic achievement.

Besides the Chan and Moore study (2006), there are many other cognitive studies that investigated the impact of metacognition on learning in contexts such as writing (Graves, 1983), speaking English as a foreign language (Chambres, Bonin, Izaute, & Marescaux, 2002), study strategies as a function of testing (Ross, Green, Salisbury-Glennon, & Tollefson, 2006), engineering design (Lawanto, 2007), and problem solving in mathematics (Jonassen, Strobel, & Lee, 2006). One study conducted by Efklides (2002) found that feelings of familiarity, difficulties, confidence, and satisfaction are interrelated and inferential in nature; what Flavell (1979) called *metacognitive experience*. From these studies, researchers found a positive relationship between the use of metacognition and performance; and they reported that metacognition is a fundamental tool that enables learners to take control of their own cognition, emotion, and motivation.

As a result, they tend to learn better (Bransford, Brown, & Cocking, 1999; Chambres, Bonin, Izaute, & Marescaux, 2002).

Despite the growing interest in metacognitive research, few studies have investigated how students' cognition, emotion, and motivation are interrelated while solving ill-structured design problems in academic environments. In engineering education curricula, for example, much emphasis is placed on building a student's proficiency, not only in solving problems that are defined completely and have clear operations to yield solutions, but also in coping with real-world engineering problems. Engineering students are expected to demonstrate the ability to apply their knowledge of mathematics, science, and engineering through problem solving, design, and experimental activities during their study (Baillie & Moore, 2004). As they enter the professional world, students are expected to not only apply technology and science in design toward meeting human needs, but also to bridge the gaps between science and art. These workplace engineering problems often involve problem elements that are unknown (Wood, 1983), or have multiple solutions, or solution paths (Kitchner, 1983). Multiple criteria for evaluating solutions often require engineers to make judgments about the problem (Meacham & Emont, 1989). In such situations, metacognition plays an essential role to aid students and professionals in monitoring, and when necessary, to revise their thinking to complete the problem solving activities.

Engaging in ill-structured problems is a challenging experience for students, as they normally receive little guidance and instruction from their instructors. Students are expected to become self-regulated learners (Knowles, 1975), and solving ill-structured problems will require them to develop more decision-making responsibility. Self-regulated learners engage in motivational, cognitive, and metacognitive strategies (Zimmerman, 1986; Zimmerman & Martinez-Pons, 1988), and therefore, a student's metacognitive skill plays an essential role in solving ill-structured problems.

Statement of the Problem

Researchers have uncovered a close relationship between attributional beliefs, strategic learning, and achievement (Chan & Moore, 2006; Graves, 1983; Ross, Green, Salisbury-Glennon, & Tollefson, 2006). Although the findings contribute positively to educational practices, knowledge of how those attributional beliefs, strategic learning, and achievement are related in ill-structured, problem solving activities is still limited. Furthermore, many of the studies involve working on hypothetical problems that do not reflect the authentic learning contexts that students may encounter in their classroom activities. Hypothetical problems are generally simple, and clear instructions lead to the solutions.

Because metacognition involves a cognitive dimension of evaluating one's knowledge and abilities (Paris & Winograd, 1990), the context of the problem that students are to solve may influence the manner in which they use metacognitive abilities. Students' capability and confidence to solve a particular problem, and their subjective perception of the task-value may correlate with the actual planning, monitoring, and regulating during problem solving activity. Because metacognitive ability is believed to play an important role in a problem solving situation, especially when dealing with an ill-structured problem (Hong, Jonassen, & McGee, 2003), any study focused on school-related problems will significantly benefit the educational practices.

Jonassen (2000) argued that design problems are usually among the most ill-structured kinds of problems that are encountered in practice. Design is the core of engineering practice (Dieter, 1983). The design problems may involve activities that produce an artifact, problem structuring, or articulation. Software design problems are somewhat better structured than hardware design problems (Guindon, 1990; Jeffries, Turner, Polson, & Atwood, 1981). Each design activity may have unique goals, task characteristics, and expected outcomes. For instance, design tasks that are more hardware-oriented, such as mechanical or electrical-computer engineering-related designs may involve evaluation of a manufacturing process, development of a new product or production process, schematic drawing, component selections, testing of product characteristics, analysis of material behavior, simulation of in-field product performance, or optimization of system performance. Such tasks require designers to come up with various assumptions and working strategies. Computer software design, on the other hand, is distinct from hardware design. However, because computer software design is constrained by language and systems, there is no single, generalizable top-down model that will work for all task decomposition processes (Guindon & Curtis, 1988; Jeffries, Turner, Polson, & Atwood, 1981).

Because of the uniqueness of design features among engineering disciplines, the focus of this study was to investigate students' metacognition used to solve ill-structured problems in three engineering disciplines (i.e., computer science, electrical-computer, and mechanical engineering). Three unique engineering contexts were purposely selected for this study to determine if a relationship existed between students' cognitive self-appraisal and self-management applied across the three engineering design contexts.

Existing studies found that metacognitive skill is teachable (Chan & Moore, 2006; Paris 1986) and enhance students' ability to solve problems (Bransford, Brown, & Cocking, 1999; Chambres, Bonin, Izaute, & Marescaux, 2002; Paris, 1986); therefore, having a better understanding about students' metacognition while solving ill-structured problems is beneficial to educators. This study investigated metacognitive abilities that were used in solving real-world engineering problems in school settings.

Purpose of the Study

This study investigated the connection between cognitive self-appraisal and self-management, and their relationship with the level of difficulty of the design problem of three different groups of engineering students working on their senior design projects. In addition, this study also investigated students' metacognitive changes during the design project time. The three groups were comprised of senior engineering students majoring in computer science, electrical-computer, or mechanical engineering. Investigations included finding: (a) the relationships between students' cognitive self-appraisal and self-management across the three engineering disciplines, (b) the relationship between students' metacognition (i.e., cognitive self-appraisal and self-management) and level of difficulty of the design problem, (c) the difference between students' metacognition (i.e., students' cognitive self-appraisal and self-management) across the three engineering disciplines, and (d) the difference between students' metacognition at the beginning and the final stages of the design project time.

The Research Questions

Four research questions guided this study:

1. Was there any significant relationship between cognitive self-appraisal and self-management of the three groups of engineering students (i.e., electrical-computer engineering, mechanical engineering, and computer science) while they were engaged in the design project?

2. Was there any significant relationship between a student's metacognition (i.e., cognitive self-appraisal and self-management) and the level of difficulty of the design problem of the three groups of engineering students?

3. Did electrical-computer engineering, mechanical engineering, and computer science students exhibit significant differences in cognitive self-appraisal and self-management while engaged in the design project?

4. Was there any significant change in students' metacognition during their engagement in the design project?

Conceptual Framework Guiding the Study

The application of metacognitive skills may be observed through what a person does for a particular given task. Brown (1978) identified metacognition through activities such as planning, monitoring, and revising. Paris and Winograd (1990) offered a more comprehensive view in which metacognition may be observed through two essential features; (a) cognitive self-appraisal (CSA) and (b) cognitive self-management (CSM). The two metacognitive features involved cognitive and motivational issues such as skill and will, which are interwoven (Corno & Mandinach, 1983), shareable among people (Paris, Winograd, 1990), and influenced greatly by the social aspects of the situation (Dunbar, 2000). These aspects included affective and motivational characteristics of thinking that often lead to situations where students are less likely to invoke complex cognitive and metacognitive routines to improve learning.

Self-appraisal in learning refers to a learner's personal judgment about his ability to meet a cognitive goal. Furthermore, Paris and Winograd (1990) argued that self-appraisal concerns "judgments about one's personal cognitive abilities, task factors that influence cognitive difficulty, or cognitive strategies that may facilitate or impede performance" (p. 17). In contrast, self-management refers to maintaining executive control that will indicate "how metacognition helps to orchestrate cognitive aspects of problem solving" (p. 18). The self-management issue relates to processes that involve evaluation, planning, and regulation. Self-management skill refers to students' abilities to plan before they handle a task and make necessary adjustments and revisions during their work, which consequently has direct implications for their performance. The ability to plan, regulate, and evaluate learning are the skills commonly used to indicate the presence of students' self-management. Planning involves activities such as setting goals, analyzing tasks, and selecting strategies to achieve specific goals. Regulating refers to the fine-tuning and continuous adjustment of learners' cognitive activities. Evaluation refers to assessing learners' current knowledge state. Evaluation occurs continuously: before, during, and after a task.

According to Jonassen (2000) and Simon (1973), any task may be classified into a continuum set of problems, from a well-structured problem to an ill-structured one. While a well-structured problem is easily identified by the clarity of specific goals and solution path, the process of obtaining the solution in an ill-structured problem may be quite cumbersome. Unlike well-structured problems, ill-structured problems are usually complex in nature, and they may yield several solutions. Solving an ill-structured problem requires strategies gained from one's experience and often involves integrating multiple knowledge domains (Simon, 1973).

Significance of the Study

Working with an ill-structured, open-ended, and project-based assignment is a learning activity that mimics the working environment experienced by most engineers in their professional engineering careers. To answer that challenge, therefore, engineering students are trained to engage in engineering design problems that replicate real industrial projects. Such projects are often poorly defined, less-structured, and surrounded by vast amounts of information that is often irrelevant. In higher education, especially for higher-level engineering design courses, the challenge increases as students receive minimal guidance from their professors before and during the project.

As numerous studies on human cognition suggest that the quality of students' problem solving performance may be improved if students exercise appropriate thinking skills while engaging in thinking processes, there has been no research performed that quantitatively examines the relationship of self-appraisal and management, and the relationship of metacognitive abilities and performance of students working on engineering design tasks. Focusing on ill-structured problems, such as design problems, may be the most important type of problem to investigate because so many professionals are paid for designing things (i.e., products, systems, etc.). Although thinking is a normal activity that naturally occurs, students' ability to perform the various processes may be augmented by increasing awareness of the component skills and increasing their skill proficiency through conscious practice.

It was the intent of this study to provide engineering educators (i.e., professors, curriculum developers) with an understanding of the relationship between students' cognitive self-appraisal and self-management while working on actual school-based engineering design activities across three unique engineering domains. An understanding of these relationships demands reliable evaluative procedures. It was also the objective of this study to reconstruct instruments that were able to assess the metacognitive features of students working on one particular design problem. The lack of psychometrically sound instruments available to assess the metacognitive features of students working on one particular problem makes evaluation a difficult task.

The practical implication of this study may relate to the creation of an instructional environment developed to help both engineering educators and students improve their metacognitive abilities. The results of this study enables curricula to be designed to favorably promote positive changes in building students' self-appraisal that may later influence self-management when solving engineering design tasks. It was also expected that the findings of this study would aid engineering students in understanding and controlling their own abilities, self-efficacy, and confidence.

Limitations

This study had four limitations. First, data were drawn from a top-ranked engineering school with a relatively homogeneous population. Therefore, generalizability of the results beyond this sample should be made with caution. Second, as there are many other kinds of ill-structured problems beyond those investigated in this study, the results of this study may not be relevant to all ill-structured problems in all sciences or all engineering disciplines. Third, although there were 168 engineering students who participated in the study, the number of study participants in each group of engineering students was relatively small. Fourth, due to the nature of the course management of the three senior design classes, only one instructor was able to evaluate the level of each student's project difficulty. No crossed-evaluation process was done to triangulate or validate any evaluation made for each student's design project.

The Senior Design professors evaluated the difficulty level of the design projects. Because there was only one professor responsible for evaluating students' design projects for each design course in each field of engineering, no crossed-evaluation process was done to triangulate or validate any evaluation made for each student's design project. Therefore, it may be predicted that the electrical-computer engineering professor might have used a different standard of grading than his counterparts from mechanical engineering and computer science for evaluating each of the six items of Rubric for Rating Students' Design Project (RRSDP). For that reason, therefore, we focus our discussion on exploring the relationship between metacognition and the difficulty level of the project for each group.

Definition of Terms

In order to facilitate understanding and provide a basis for reference, the following terms were defined:

Cognition

At this stage in the research, cognition is generally defined as thinking skills and thinking processes used in solving engineering design tasks (Marzano et al., 1988).

Metacognition

Metacognition is an awareness of one's thinking while performing a specific task, and then using this awareness to control what one is doing. (Marzano et al., 1988)

Cognitive of Self-Appraisal

This first feature of metacognition includes personal reflection about one's knowledge state and abilities (Paris & Winograd, 1990).

Cognitive of Self-Management

This second feature of metacognition reflects the ability of students to plan, monitor, and revise ongoing performance (Paris & Winograd, 1990).

Design Project Problem

Design project problem is a task that is to produce artifact, problem structuring, and articulation (Jonassen, 2000)

Well-Structured Problems

Well-structured problems involve providing the solver with four different sorts of information: the initial state of the problem, the goal state, legal operators to solve the problem, and operator restrictions (Kahney, 1993).

Ill-Structured Problems

Any problem is considered ill-structured when little or no information is provided on the initial state, the goal state, the operators, or some combination of these (Kahney, 1993).

Organization of the Dissertation Proposal

Discussion in the following chapters was organized as follows: In Chapter 2, the researcher discussed the theoretical framework that helps in the understanding of metacognitive skills through literature review in the area of metacognition as applied in numerous contexts. In Chapter 3, the researcher provided the context of this study by examining the methods used for data collecting, the participants of the study, and data analysis. While the findings and analyses of data were presented in Chapter 4, the researcher presented some discussion, conclusions, and recommendations in Chapter 5.

CHAPTER 2

REVIEW OF THE LITERATURE

A major objective of education and educators is to achieve a better understanding of how to improve human learning. Cognitive science, which is a study of the human mind, has aided educators in providing considerable insight about how people think and learn. Many studies have been conducted to investigate and construct new theories on important issues, such as how learners acquire, retain, and actively use their knowledge and skills. Studies on cognition and learning have been the central concepts of many studies conducted by researchers from various disciplines, including educational psychology, physical sciences (i.e., physics, biology, etc.), engineering, and technology.

Although they come from different fields of expertise, all of the researchers have one common objective for conducting their educational research. The intent of their studies is primarily to understand important issues, such as how people learn, what kind of cognitive processes are required to solve problems, how cognitive processes relate to the various types of problem solving tasks, and what learning paradigms and environments are suitable for instructional practices. All of these issues are not interrelated. They seek to understand how these issues would behave in their particular teaching of expertise. Their studies help enhance classroom instruction as they provide more articulate and valid principles that serve as assumptions of practice (Greeno, Collins, & Resnick, 1996). *Design experiments* (Brown, 1992; Collins, 1992), for example, are cognitive studies that have provided important and useful insights for educational researchers and have offered positive and constructive feedback to the education communities (e.g., teachers, students, parents, school administrators, education policy makers, etc.) for the betterment of instructional practices. These studies led to the development of principles of a practical theory that can serve as instructive models about conditions leading to successful processes of cognition and learning.

In this study, the researcher investigated the metacognitive abilities students used in solving engineering design tasks. This study also evaluated how those metacognitive abilities correlated with the level of difficulty of students' design problems across three engineering disciplines. Furthermore, this study investigated if there was any significant change in students' metacognition during their engagement in the design project. Because this study focused on the issue of metacognition, certain keywords such as *cognition*, *metacognitive skills*, *cognitive self-appraisal,* and *cognitive self-management* will be used extensively. These keywords are psychological constructs that are frequently used in numerous social science databases, such as the Education Resources Information Center (ERIC) and the Elton B. Stephens Company (EBSCO). This chapter is organized into four subsections: (a) Introduction, (b) Metacognition as Processes and Skills, (c) Metacognition in Problem Solving Activities, and (d) Engineering Design.

Metacognition as Processes and Skills

Metacognition is often referred to as skills that enable us to think about our own thinking. In simple terms, metacognition is the ability to think about thinking. Despite numerous classifications and definitions for humans' thinking, Marzano et al. (1988) clearly distinguished between thinking processes and thinking skills. Thinking processes are complex cognitive processes that involve the use of multiple thinking skills. While thinking skills are defined as cognitive operations, such as observing, comparing, analyzing, integrating, evaluating or inferring, thinking processes are broader in scope and take a longer time to complete. A skill is an ability that is learned and often acquired through training. Marzano et al. (1988) did not include metacognition as part of what was referred to as *core thinking skills,* which are basic skills used in metacognitive reflection and thinking processes. In other words, one who metacognitively reflects may use one or more basic thinking skills to complete whatever task he/she is engaged in.

Thinking processes may be classified into two major groups of processes: *knowledge acquisition* and *knowledge production* or *application.* Students who face new subject matter will first engage in knowledge acquisition consisting of three processes: concept formation, principle formation, and comprehension. The three processes help students build a foundation for learning any discipline. Several definitions for concepts are available (e.g., Bruner, Goodnow, & Austin, 1977; Taba, 1967). Klausmeier (1985) offered a useful definition for instructional purposes. He defined *concept* as a mental construct commonly symbolized by a word in a society. He wrote that a "concept consists of a person's organized information about one or more entities – objects, events, ideas, or processes – that enable the individual to discriminate the particular entity or class of entities and also to relate it to other entities and classes of entities" (p. 276). Principle formation, on the other hand, refers to a proposition that expresses the relationship of concepts. Because principles describe relationships, therefore, they help to organize information in a discipline. Katz (1976) and Klausmeier (1985) classified principles as cause and effect, correlational, probability, and axiomatic. Lastly, comprehension is the process of generating meaning from varied sources. Regardless of the source, the process of comprehending involves extracting new information and integrating it with what we already know in order to generate new meaning.

Knowledge production or application, which may involve activities such as problem solving, decision-making, research, and composition, often builds on the knowledge acquisition processes because it involves the production or application of knowledge. Problem solving and decision-making are closely related to one another. The distinction between the two is sometimes difficult to discern, especially in a situation where one must solve problems that contain incomplete information and may lead to several workable solutions. Each of these possible solutions has its strengths and weaknesses, and a decision must be made to choose one.

As metacognition involves awareness of one's thinking processes, knowledge acquisition and production may occur in a continuous loop. Therefore, it may be reasonable to include both as essential components in a metacognitive domain. As an illustration, in daily life we are challenged constantly to solve numerous problems, and in some of those events we may experience unsuccessful processes (i.e., knowledge production), which in turn may lead us to apply alternative strategies or rules (i.e., knowledge acquisition) to seek better solutions. The production and acquisition processes flow back and forth dynamically during cognitive endeavors. Metacognition enables us to control these dynamic processes and, therefore, plays an essential role in any cognitive enterprise, especially in problem solving situations. Many researchers believe that metacognition contributes to the successful accomplishment of a cognitive action (Paris, 1986).

Metacognition in Problem Solving Activities

It is a commonly held belief that the central focus of education is to teach people how to improve their learning and actively use knowledge and skills to solve real-life problems. In their professional life, people are rewarded for the ability to solve problems not only within their area of expertise, but also in areas outside the boundary of their expertise. Unfortunately, in school environments, we often find that problem solving skills are developed primarily through extensive practice with solving problems (Dufresne, Gerace, Hardiman, & Mestre, 1992). Many educators believe that presenting students with great numbers of problems to solve will make them become good problem-solvers.

Frederiksen (1984) argued that instruction in problem solving generally emphasizes well-structured problems, which means that all of the information and appropriate algorithms needed are available to the problem-solver. Students' academic successes are often measured through their ability to memorize facts, formulas, or strategies that they have learned throughout their school years. This extensive practice with solving problems is insufficient to develop mental structures and processes necessary for skilled problem solving performance (Dufresne, Gerace, Hardiman, & Mestre, 1992).

Although problem solving is considered as the center of practice according to contemporary learning theories, few data are available in the literature to help understand the breadth of problem solving activities (Jonassen, 2000). Extensive literature exists on the issues faced by experts and novices in solving problems (Ahmed, Wallace, & Blessing, 2003; Atman, 1999; Cross, Christians, & Dorst, 1994; Guindon, 1990; Ho, 2001; Johnson, 1988; Kavakli & Gero, 2001; Kumsaikaew, Jackman, & Dark, 2006). From these studies, many positive implications for improving teaching may be gained. Furthermore, problem-solver profiling that distinguishes experts and novices has been suggested from these studies. Another interesting finding demonstrated that assigning many problems to students will not help them develop a deep understanding of concepts and principles, even among students who are generally proficient problem solvers (Leonard, Dufresne, & Mestre, 1996). Much discussion in the literature involves issues on general strategies that are widely used to solve problems. Unfortunately, few provide in-depth information on the mental interaction between problem-solvers' personal reflections about their knowledge states and abilities and the actual action that may take place during the problem solving activities.

Among the four dimensions of thinking (i.e., critical and creative thinking, thinking processes, core thinking skills, and relationship of content-area knowledge to thinking), metacognition is a dimension of thinking that describes the interactions between *knowledge and control of self* and *knowledge and control of process* (Marzano et al., 1988; Paris & Winograd, 1990). Knowledge and control of self is comprised of factors such as commitment, attitudes, and attention. Many people believe strong commitment, positive attitude, and appropriate level of attention toward academic tasks will lead to great accomplishment. Control of process is comprised of knowledge that is important in metacognition and executive control of behavior. Declarative, procedural, and conditional knowledge are essential aspects of metacognition, and therefore, they should be taught and reinforced to students. Executive control of behavior refers to process activities such as planning, evaluating, and regulating, in which students may also monitor and control commitments, attitudes, and attention.

Although researchers offer many different definitions and models, metacognition remains a "fuzzy" concept because researchers classify any cognition that might have relevance to knowledge and thinking as a *metacognition* (Paris & Winograd, 1990). Researchers in cognition pose varying definitions of metacognition, many of which overlap. While Marzano et al. (1988) simplified the definition of metacognition by explaining it as a state of awareness of our thinking, Cuasay (1992) defined metacognition as a process by which the brain organizes and monitors its cognitive resources. As specific tasks are performed, individuals use this awareness to control what they are doing.

Looking at previous definitions, it is clear that metacognition is a fundamental tool that enables learners to take control of their own cognition. As a result, they tend to learn better (Bransford, Brown, & Cocking, 1999; Chambres, Bonin, Izaute, & Marescaux, 2002). Researchers also classify the features or components of metacognition differently. However, there is some overlap. Flavell (1979) stressed the phenomena of metacognitive knowledge that consist primarily of factors of person, task, and strategies.

The factor of person encompasses everything that learners might believe about the nature of themselves and other people as cognitive processors. The factors of task and strategies refer to the information available that leads to learners' understanding of the task demands (i.e., goals), and of strategies to achieve those goals. In his definition, Flavell successfully identified those three factors that influence the awareness and control of one's cognitive endeavor while engaging in a particular task.

From a different view, Pintrich (2002) divided metacognition into two aspects: *metacognitive knowledge* and *metacognitive control.* Metacognitive knowledge refers to knowledge of strategies that might be used for a particular task and knowledge of the conditions under which these strategies might be used. Metacognitive control is a cognitive process that learners use to monitor, control, and regulate their cognition and learning. Despite various ways to define metacognition, Paris and Winograd (1990) argued that the important issue in metacognition is to understand the relationship between metacognition and action; what matters is the agreement between what people say, how they act upon their thoughts, and their feelings about their thinking.

Metacognition and Its Manifestations

The application of one's metacognitive skills may be observed through what a particular person does for a given task. Brown (1978) identified metacognition through activities such as planning, monitoring, and revising. Paris and Winograd (1990) offered a more comprehensive view in which metacognition is observed through two essential features of metacognition: *cognitive self-appraisal* and *cognitive self-management.* Furthermore, the knowledge about cognitive states and abilities is shareable among people (Paris & Winograd, 1990) and influenced greatly by the social aspects of the situation (Chambres, Bonin, Izaute, & Marescaux, 2002). These aspects include the affective and motivational characteristics of thinking. Like other knowledge, metacognitive understanding develops with age and experience (Garner & Alexander, 1989) and is an ongoing process of progressing through deeper insights or realizations that, in turn, lead to awareness or conscious understanding of self as agent (McCombs & Marzano, 1990). All of these theories have led us to a belief that metacognition plays an important role in human learning at any level (e.g., K-12, post-secondary, organizations) and for any knowledge domain (e.g., language, mathematics, technology, and engineering) to do all kinds of cognitive enterprises (e.g., reading, troubleshooting, case-study, design).

Paris and Winograd's View of Metacognition

This study used Paris and Winograd's (1990) view of two essential features of metacognition: cognitive self-appraisal and cognitive self-management. The reason for using this particular framework was twofold. First, compared to Pintrich's (2002) idea of metacognitive knowledge and control, Marzano's et al. (1988) knowledge and control of self and process, and Flavell's (1979) classification of person, task, and strategy, Paris and Winograd's (1990) is simpler and has a distinct boundary between self-appraisal and self-management. All of the essential components of metacognition offered by Pintrich (2002), Flavell (1979), and others are included in Paris and Winograd's (1990) cognitive self-appraisal and self-cognition. Second, this model places the learner as the central part of the metacognition issue. While Flavell (1979) defined the factor of person to be any cognitive processors, learners or other individuals, Paris and Winograd (1990) placed more focus on the learners themselves. As this study will evaluate a student's metacognition individually, it would be appropriate to adopt such a framework.

Despite different ways of classification, this model covers all elements of metacognition discussed by many other metacognitive researchers. Two metacognitive features involve cognitive and motivational issues such as skill and will, and are interwoven with one another (Corno & Mandinach, 1983). Low self-confidence and low self-efficacy often lead to situations where students are less likely to invoke complex cognitive and metacognitive routines to improve learning.

Cognitive self-appraisal. Self-appraisal in learning refers to learners' personal judgment about their ability to meet a cognitive goal. When students are asked to calculate the volume of a triangular-shaped birthday cake, they may immediately wonder if they have enough knowledge (i.e., declarative, procedural, and conditional knowledge) to answer the question. Self-appraisal is about "judgments about one's personal cognitive abilities, task factors that influence cognitive difficulty or cognitive strategies that may facilitate or impede performance" (Paris & Winograd, 1990, p. 17).

Paris and Winograd further argued that self-appraisal often relates to static judgments, as students are asked to assess knowledge or gauge ability in a hypothetical situation. This self-appraisal is often called knowledge of self (Flavell, 1979), in which students activate their relevant knowledge about their own strengths and weaknesses pertaining to the task, as well as their motivation for completing the task (Pintrich, 2002).

Self-appraisal has a motivational aspect. Students' motivational components, such as intrinsic goal orientation, self-efficacy, task value, and learning beliefs play an important role in self-directed learning. According to Pintrich, Smith, Garcia, and McKeachie (1991), intrinsic goal orientation concerns the degree to which the student perceives himself to be participating in a task for reasons such as challenge, curiosity, and mastery. Furthermore, Pintrich et al. (1991) argued that unlike goal orientation that refers to the reason why a student participates in a task, task value refers to the student's evaluation of how interesting, important, and useful the task is. Self-efficacy is a strong belief about the student's ability and confidence to perform the task. Bandura (1977) argued that self-efficacy refers to one's convictions to successfully execute a course of action required to obtain a desired outcome. This expectancy of achieving a desired outcome may lead to a positive influence on the individual's willingness to initiate difficult tasks (Corno & Mandinach, 1983). Unlike self-efficacy, learning belief refers to a student's belief that the outcomes are contingent on his own effort (Corno & Mandinach, 1983; Pintrich, et al., 1991).

In this study, the self-appraisal aspect was identified by students' self-confidence and self-efficacy to solve one particular problem, and how students valued the problem to be solved. Students' self-confidence refers to performance expectation, and relates specifically to task performance. Self-efficacy includes judgments about students' ability to accomplish a task as well as their confidence in their skills to perform that task. Task value refers to students' perceptions of the design project in terms of interest, importance, and utility. These three motivational factors indicate personal reflections about students' knowledge states and abilities, and these self-judgments are deemed to be the forerunners of their actions (Paris & Winograd, 1990). If students judge themselves as having little knowledge and expectation for success in solving a problem, and place minimal value on the problems they are about to solve, they will likely expend little effort to work on the problem.

Cognitive self-management. Self-management skill, which is often called executive control of behavior (Paris, Lipson, & Wixson, 1983), refers to students' abilities to plan before they handle a task and make necessary adjustments and revisions during their work. Three skills are commonly used to indicate the presence of students' self-management: their ability to plan, regulate, and evaluate their learning. Planning involves activities such as setting goals, analyzing tasks, and selecting strategies to achieve specific goals. Regulating refers to the fine-tuning and continuous adjustment of learners' cognitive activities. Evaluating or monitoring refers to assessing learners' current knowledge state. Evaluating activities include tracking of learners' attention as they learn, and self-testing and questioning. Evaluating occurs continuously: before, during, and after a task. This cognitive self-management has direct implications for students' performance and subsequent instruction (Paris & Winograd, 1990). This study examined how students executed those three metacognitive self-regulatory tasks in engineering design activities.

To complete engineering design tasks successfully, students are challenged to exercise their knowledge on self-appraisal and self-management. Proficiency in exercising metacognitive abilities is one of the factors that distinguishes novices from experts (Bransford, Brown, & Cocking, 1999), and is pedagogically valuable for students (Leonard, Dufresne, & Mestre, 1996). Experts monitor their own problem solving activities as they observe their solution process and the outcomes of their performance (Glaser, 1992). Furthermore, Glaser argued that novices, on the other hand, rely more on the surface features of the problems rather than monitoring their own thinking while solving problems. It was the intent of this study to evaluate students' self-appraisal, self-management, and performance while engaging in a design task (Figure 1). The investigation was focused on how the components of self-appraisal, self-management, and the level of difficulty of the design problem were statistically correlated.

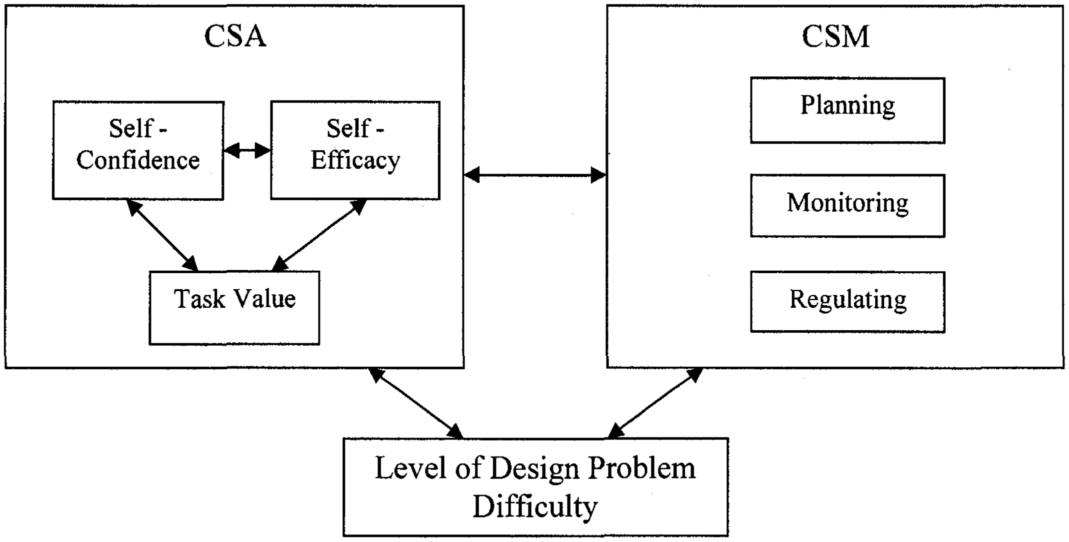

Figure 1. Self-appraisal, self-management, and level of design difficulty.

Engineering Design

The way engineers solve an engineering task is influenced by the structure of the problem. According to Jonassen (2000) and Simon (1973), any problem may be classified into a continuum of problem types, ranging from a well-structured to an ill-structured problem. While a well-structured problem is easily identified by the clearness of specific goals and solution paths, the process of obtaining a solution for an ill-structured problem may be quite cumbersome. Ill-structured problems are typically complex in nature, and may yield several solutions. Solving an ill-structured problem requires strategies that are gained from one's experience and often requires integrating multiple knowledge domains (Simon, 1973).

In a school environment, engineering students often engage in well-structured problems, such as problems that are commonly found in many engineering textbooks. A well-structured problem may be found in numerous forms, such as a mathematical problem that requires a few steps to get to the solution, or a story problem that has a predictable procedural path that will eventually lead to the final answer. Extensive discussion about problem solving activities have been conducted and well documented in many research papers (Guindon, 1990; Ho, 2000; Jonassen, 2000; Kumsaikaew, Jackman, & Dark, 2006; Sobek & Jain, 2004). In those technology-related educational studies, an ill-structured problem is often referred to as a design problem.

Design problems are among the most complex and ill-structured kinds of problems that are encountered in practice. For many years, researchers (Reitman, 1965; Simon, 1973) characterized design problems as ill-structured because they have ambiguous specification of goals, no determined solution path, and the need to integrate multiple knowledge domains. Goel and Pirolli (1989) articulated the characteristics of design problems, including many degrees of freedom in the problem statement, which consist only of goals and intentions, limited or delayed feedback from the world, artifacts as outputs that must function independently of the designer, and "answers that tend to be neither right nor wrong, only better or worse" (Jonassen, 2000, p. 80).

Besides the complexity of the context, the importance of an artifact as evidence of problem solving and the lack of clear standards for evaluating solutions are what make design problems so ill-structured. It may be difficult to judge the solution by simply giving a right or wrong answer because the success criteria can be multiple and undefined. Because of the ill-structured nature and the complexity of design problems, problem solvers (i.e., novices or experts) are required to engage in extensive problem structuring, often using artificial symbol systems (Goel & Pirolli, 1989). Furthermore, solving this type of problem also requires greater commitment and self-regulation by the problem solver (Jonassen, 2000). Persons who, because of their professional careers, are involved in design activities may be required to develop thinking processes from their experience.

Although engineers are not the only people who design things, it is true that the professional practice of engineering is largely concerned with design. The Accreditation Board for Engineering and Technology (ABET) defines engineering design as "the process of devising a system, component, or process to meet desired needs. It is a decision making process (often iterative), in which the basic science is applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation" (Diaz-Herrera, 2001, p. T2D-2). While Dieter defined engineering design as efforts "to pull together something new or arrange existing things in a new way to satisfy a recognized need of society" (1983, p.27), the MIT Committee on Engineering Design views engineering design from the skills required and outcomes of the design activities. It defines engineering design as "the process of applying the various technique and scientific principles for the purpose of defining a device, a process or a system in sufficient detail to permit its physical realization" (Diaz-Herrera, 2001, p. T2D-3). Engineering design is the product of planning and work, and that particular product has not existed, instead, it is created expressly to satisfy a need (Dieter, 1983). In general, engineering design is about designing a system that may consist of the entire combination of hardware, information, and people necessary to accomplish some specific mission.

Besides the contexts and skills essential to design, there is a distinct characteristic between hardware- and software-oriented designs. Software design problems are somewhat better structured than hardware design problems (Guindon, 1990; Jeffries, Turner, Polson, & Atwood, 1981). Hardware-oriented design may involve evaluation of a manufacturing process, development of a new product or production process, schematic drawing, component selections, testing of product characteristics, analysis of material behavior, simulation of in-field product performance, or optimization of system performance. Those tasks require designers to come up with various assumptions and working strategies, and generally follow a prescribed staging (Akin, 2001). Computer software design, on the other hand, is distinct from hardware design and considered more well-structured than most design problems. Wroblewski (1991) argued that software construction is sometimes practiced as a craft. Although there is an attempt to drive the craft out of software development, Wroblewski stated that "the categorical boundary between tools and materials completely disappears during the practice of software construction" (1991, p. 10). Unlike hardware design, computer software design is constrained by language and systems, and, therefore, there is no single generalizable top-down model that will work for all task decomposition processes (Guindon & Curtis, 1988; Jeffries, Turner, Polson, & Atwood, 1981).

Design has been recognized as a highly complex activity that requires a considerable amount of knowledge beyond what is stated in the design problem. Strickfaden, Heylighen, Rodgers, and Neuckermans (2005) argued that learning or doing is more than a cognitive activity. Because design is also considered as one of the most ill-structured problems (Jonassen, 2000), therefore, whenever engaging in such task, designers generally rely heavily on their previous design experience.

When working on a design project, students generally not only bring their past design experiences to the table, but moreover, they also bring with them their cultural medium, that is, behavior that is gained through interactions in various social situations. This cultural medium may occur within and outside the design domain. While the internal factor of this behavior closely relates to design and the instruction provided by the instructor, the external factor includes aspects that are a mixture of personal experiences and common cultural values. An anthropologist, Pierre Bourdieu (1984), speculated that the culture medium affects their design process. Bourdieu held that individual-personal everyday activities influence the way someone approaches a design task. Therefore, "learning and doing is more than a cognitive activity. Ways of knowing and doing are unique to each group, and can be called its specific culture" (Strickfaden, Heylighen, Rodgers, & Neuckermans, 2005, p. 60).

An ethnographical study, conducted by Strickfaden, Heylighen, Rodgers, and Neuckermans (2005) supported Bourdieu's speculation. In the study, Bourdieu investigated the *references* that are considered to be the inroad to understanding the culture medium of a group of industrial design students. References are shared communication in the design environment that includes speech and visual representations (e.g., sketches and images from magazines or books). The study found that approximately 50% of all references come from the inside of the design; the other half comes from outside. References from outside either have a tangible relationship to the artifact being created or are more intangible, more distant from the task at hand. Tangible references were more frequently discussed than intangible ones.

It was also the intent of this study to investigate if the cognitive self-appraisal and self-management differ across different engineering disciplines. Due to the nature of the design process that is different between hardware- and software-oriented designs, it might be appropriate to speculate that students have different cognitive self-appraisal and self-management across those two kinds of design activities.

CHAPTER 3

METHOD

As described in previous chapters, this study investigated the relationship between cognitive self-appraisal (CSA) and cognitive self-management (CSM), and the relationship between metacognitive abilities and the level of difficulty of design problem of three different groups of engineering students working on their senior design projects. In addition, this study also investigated if there was any significant change in students' metacognition during their engagement in the design project. The students were majoring in electrical-computer engineering (ECE), mechanical engineering (ME), or computer science (CS) at one large public university in the Midwest, which will hereafter be referred to as Large Public University (LPU). The quantitative study involved the use of two metacognitive instruments to assess students' CSA and CSM, and one evaluation rubric to assess the level of difficulty of students' design projects. Each of the students engaged in a design project as part of their curriculum requirements. They were invited to voluntarily participate in the study and were asked to complete the two survey instruments, one at the early stage of the project and the other at the final stage. As referenced in Chapter 1, four research questions were constructed to guide the study.

Research Design

This quantitative study involved three groups of engineering students who participated in the Senior Design classes across three different engineering disciplines in the fall semester, 2007. In the Senior Design classes, students were required to work in teams, and each team solved one design problem of their choice. The course coordinator, who was often called an advising professor, evaluated the proposed design projects to ensure that they met the requirements stated in the course syllabus, were worth doing and were doable within a semester.

One survey instrument to assess students' CSA and CSM was used in the study. Students from the three groups were invited to participate in the study and based upon their approval, were asked to complete the metacognitive instrument. An evaluation rubric was used to assess the level of difficulty of students' design projects. The advising professors evaluated these students' design projects.

Overview of the Research Setting

This study investigated the relationship between self-appraisal and self-management of cognition, and their relationships with working performance on engineering design projects among ECE, ME, and CS students at the Large Public University (LPU). LPU is one of the most well-respected universities in the U.S. According to *The Princeton Review* (2005), LPU was named as one of the best Midwestern colleges, and *U.S. News and World Report* (2006), reported that both the undergraduate and graduate programs in engineering were tied for fourth in the country. Being such a well-respected university, the admission is competitive, and the quality standard to complete any level of academic degrees from any of the engineering programs at LPU is high.

The Large Public University is the largest public university among the many public universities in the Midwest; it educates more than 40,000 undergraduate and graduate students. The university employs a wide range of distinguished scholars who teach and conduct research in numerous colleges and departments. The university's reputation of excellence is supported with numerous internationally recognized individuals. Among them are academicians and professionals who have received high recognitions in their fields (e.g., Nobel Prize winners).

Within its 12 academic departments, the College of Engineering at LPU plays an important role in teaching and cutting-edge research activities. Among those engineering departments, the ECE, ME, and CS departments were ranked in the top 10 in the nation (*U.S. News and World Report*, 2006). In 2007, the ECE, ME, and CS departments had 1,836, 1158, and 1340 students, respectively, working toward a bachelor, master, or doctoral degree.

Study Participants

This study involved engineering students and teaching professors as the study participants. The criteria used to select engineering students to participate in the study dictated the selection of the study participants of teaching professors. Only professors who involved in teaching the selected student-participants were invited to participate in the study.

There were two criteria used in the selection of the study participants (i.e., students). First, the study participants were to be working on an engineering design problem. Second, the study participants were to be from various engineering disciplines and working on a design problem within their area of expertise. These two criteria were established to fulfill the objectives of the study, and consequently they would dictate the selection process of the study participants.

Because the context of the study involved students working on an engineering design project, it was logical to select the study participants from students enrolled in any of several engineering design courses. Students who participated in the Senior Design course were the potential participants for this study. The decision to select this particular course was threefold. First, engineering students in general considered Senior Design to be the most design-intensive course. Second, the learning objectives of the Senior Design course across these three disciplines were very similar. Senior Design was a project-based course that must be completed in one to two semesters. Students involved in intensive design activities received little, if any, direct guidance from their professors. Third, all students participating in Senior Design were to be in senior standing in their academic pursuit. By inviting the Senior Design students to participate in this study, all of the participants had the same level of academic experience in problem solving. All students who enrolled in the Senior Design course were qualified and invited to participate in the study.

The second criterion required the researcher to select the engineering disciplines from which the prospective study participants were selected. This study involved three groups of undergraduate students from three different engineering disciplines: electrical-computer engineering (ECE 445), mechanical engineering (ME 470), and computer science (CS 492). The expected outcomes and design processes of these three types of engineering design contexts were quite distinct. The expected outcomes from the ECE and ME Senior Design projects were expected to be more associated with building physical objects, while CS students were expected to develop computer programs. As far as the design process is concerned, ECE and ME design projects normally begin with some research and development (R&D) before developing or building the design products, while in computer software design, R&D and product development are the mingling of each other.

There were 60 teams or projects comprised of 168 students (Table 1). Their participation was voluntary and upon approval of their participation they were asked to sign a consent letter. Not all members of the 60 teams participated in the study, some of them refused to participate in the study from the beginning, and some agreed to participate in the study but did not complete both surveys instruments. Among the 168 study participants, 48 were electrical-computer engineering students working on 22 projects, 66 were mechanical engineering students working on 23 projects, and 54 were computer science students working on 15 projects. Three professors participated in the study: one professor for each Senior Design class (i.e., ECE 445, ME 470, or CS 492).

Table 1

Study Participants

Department	Groups/projects	Students	Professors
ECE	22	48	1
ME	23	66	1
CS	15	54	1
Total	60	168	3

Context of the Design Activities

The objective of the three Senior Design courses was to help engineering senior students transition into industry through self-chosen team projects. The courses required students to emulate the day-to-day life of a real engineering design environment. Students were expected to gain a variety of benefits from their ill-structured problem solving experience that required them to synthesize and apply the knowledge they had gained through their engineering courses, to work within certain constrains (e.g., time, budget), and to present their progress and results through oral and written communication with clients (i.e., external third party or LPU faculty) and their advising professors.

All of the study participants engaged in intensive engineering design activities throughout the semester. Although it was required for students to work in a team format, three ECE students received permission from their professor to work alone for their projects. There were no Senior Design projects completed by a single student in CS and ME. All advising professors of the three Senior Design courses agreed that all tasks that the students engaged in were ill-structured problems with various levels of task difficulty. The advising professors evaluated the level of difficulty of design problems based upon ill-structuredness, complexity, and dynamicity proposed by Jonassen (2004).

There was one common learning objective across the three Senior Design courses. Students were expected to be able to solve typical commercial or industrial problems by implementing design stages that they had learned from their experience and other past courses. The general information containing characteristics of the design projects is available in Table 2.

The students worked on a wide variety of design projects, ranging from designing products that might satisfy individuals as their end-users to designing manufacturing systems/machineries used in industry; from designing and building various instruments using a conventional micro controller chip to developing an electric circuit using silicon nitride membranes; and from database migration to building security and emergency response of a building using a 3-D virtual reality tool.

Table 2

Common Characteristics of 3 Engineering Senior Design Projects (ECE 445, ME 470, CS 492)

Course components	Specifications
Learning objective(s)	To solve typical commercial or industrial problems
Length of project	1 semester
Credit hours	2 or 3
Evaluated tasks	Project proposal, design techniques, status reports, final presentation, technical presentation skills
Team size	2-4 students[a]

[a] Three ECE students elected to work alone.

Instrumentations

General Description

This study used two survey instruments: *Engineering Design Project Inventory* (EDPI) and *Rubric for Rating Students' Design Project* (RRSDP). EDPI is a self-reporting instrument designed to assess a student's self-appraisal and self-management of cognition while solving relatively large ill-structured problems. The instrument is based on two metacognitive features introduced by Paris and Winograd (1990). Another article by Brown (1978) discussed the theoretical framework. EDPI was designed in two versions: EDPI-Phase 1 and EDPI-Phase 2. While all items in EDPI-Phase 1 were written in the future tense, all items in EDPI-Phase 2 were written in the past tense. Students were invited to complete EDPI-Phase 1 at the early stage of their project, during the time when they were preparing for the project proposals. They were invited to complete EDPI-Phase 2 at the final phase of their projects, typically during final product presentations. The Rubric for Rating Students' Design Project was used to evaluate the level of difficulty of students' design projects. The advising professors were requested to complete this rubric.

The EDPI consisted of 19 items that assess a student's self-appraisal of cognition and 15 items that assessed students' self-management of cognition. In addition to the 34 items of self-appraisal and self-management, one demographic question regarding students' cumulative grade point average (GPA) was included in EDPI-Phase 1. Two open-ended questions were added to inquire about further information about student's CSA and CSM change at the end of the EDPI-Phase 2 instrument. The two open-ended questions were used to shed some light on the possibility of students' metacognitive changes (see the discussion section in Chapter 5). There were essentially three components of students' CSA: self-confidence, self-efficacy, and task value. The self-confidence scale consisted of 5 items (i.e., items 19, 21, 27, 29, and 32) and assessed a student's self-confidence to accomplish a project. The self-confidence scale was defined as self-assurance while engaged in problem solving activities (Heppner, 1988). Another synonym for this scale was expectancy for success (Pintrich et al., 1991). The self-efficacy scale consisted of 9 items (i.e., items 1, 3, 5, 9, 11, 13, 17, 25, and 34) regarding students' ability to perform. Pintrich et al. (1991) included judgments about students' ability to accomplish a task and their confidence in performing that task in self-efficacy. The task value scale consisted of 5 items (i.e., items 7, 15, 23, 31, and 33) concerning students' evaluation of how they think of the task. Task value refers to students' perceptions of the course material in terms of interest, importance, and utility.

This instrument had three metacognitive components for evaluating the *metacognition in action* (Paris and Winograd, 1990), and three parts of activities while solving the design problem. The first part reflected the planning process (i.e., items 2, 4, 12, 22, and 24), and included activities such as goal setting and task analysis. The second part assessed students' monitoring process (i.e., items 6, 8, 14, 16, 18, 26, and 28), and included activities such as tracking a students' attention as they work on the problem, self-testing, and questioning. The third part concerned students' regulating process (i.e., items 10, 20, and 30), which refers to the fine-tuning and continuous adjustment of students' cognitive activities. Both versions of the instrument were distributed in classrooms and students were able to complete each instrument within 15 minutes' time.

A Rubric for Rating Students' Design Project (RRSDP) was developed and used to evaluate the level of difficulty of students' design projects (LDDP). The rubric consisted of six indicators involving three variable attributes of problems (Jonassen, 2004): ill-structuredness, complexity, and dynamicity. Ill-structured problems often possess aspects that are unknown (Wood, 1983) and they possess multiple solutions or solution methods (Kitchner, 1983). Problem complexity is determined by the number of issues, functions, or variables involved in the problem, the degree of connectivity among those variables, and the stability among the properties of the problem over time (Funke, 1991). While the problem environment and its factors change over time, students are expected to continuously adapt their understanding of the problem and search for new solutions. The advising professors rated their students' LDDP on a 4-point Likert scale from *few* or *low* or *unlikely* (a score of 1) to *many* or *high* or *likely* (a score of 4).

The contents of both version of the EDPI instruments and the LDDP instrument were analyzed for their content and face validities. Three doctoral students who were knowledgeable in cognitive self-appraisal and cognitive self-management constructs read and made suggestions for the purpose of improving the EDPI instruments. Two engineering professors also read and made suggestions to improve the LDDP instrument.

Development of EDPI

Eighteen items of EDPI were taken from the Problem Solving Inventory (PSI) developed by Heppner (1988) and the Motivated Strategies for Learning Questionnaire (MSLQ) developed by Pintrich, Smith, Garcia, and McKeachie (1991). The adopted items were modified by rewording them in such a way that they enabled students as the respondents to focus on a particular problem. The rewording became an essential factor in modifying the instruments because a student may distinguish between his/her capabilities for dealing with two or more characteristically different topics or problems within the same measurement specificity (Bong, 1999).

Heppner's PSI is a 32-item instrument used to assess an individual's perceptions of his/her own problem solving behaviors and attitudes. For each item, respondents use a 6-point Likert scale to rate the extent to which they agree or disagree with the statement (1 = strongly agree; 6 = strongly disagree). Low scores represent positive appraisals of problem solving ability, which includes three scales: Problem Solving Confidence (defined as self-assurance while engaged in problem solving activities), Approach-Avoidance Style (a general tendency to approach or avoid problem solving activities), and Personal Control (being in control of one's emotions and behaviors while solving problems). Test-retest reliability measured for those three scales and the total PSI score ranged from .83 to 0.89 across 2 weeks, from .77 to .81 for a new sample tested over 3 weeks, and from .44 to .65 for a third sample tested after a 2-year period. Cronbach's alpha coefficients for the three scales and the total score range from .72 to .91 across three independent samples.

Pintrich's et al. (1991) MSLQ, is an 81-item instrument designed to assess college students' motivational orientations and their use of different learning strategies for a college course. Students rate themselves on a 7-point Likert scale from *not at all true of me* (a score of 7) to *very true of me* (a score of 1). Motivational scales include Value Components (i.e., Intrinsic Goal Orientation, Extrinsic Goal Orientation, and Task Value), Expectancy Components (i.e., Control Beliefs and Self-Efficacy for Learning and Performance), and Affective Components (i.e., Test anxiety). Learning Strategies scales include Cognitive and Metacognitive Strategies (i.e., Rehearsal, Elaboration, Organization, Critical Thinking, and Metacognitive Self-Regulation), and Resource Management Strategies (i.e., Time and Study Environment, Effort Regulation, Peer Learning, and Help Seeking). The Cronbach's alpha coefficients are robust, ranging from .52 to .93. Lambda-ksi estimates of the MSLQ, which are analogous to factor loadings in an exploratory factor analysis, indicated well-defined latent constructs.

There were 8 items (1, 3, 9, 11, 17, 19, 25, and 27) of the EDPI that were modified from the Problem Solving Confidence scale of Heppner's PSI. As far as the students' task-value and self-management of cognition were concerned, 10 items (4, 6, 7, 12, 15, 20, 22, 26, 30, and 33) were adopted from Task-Value and Metacognitive Self-

Regulation scales of Pintrich's et al. MSLQ. The others 16 items of the instrument were developed by the researcher and together with the 18 adopted items, they made up all of the available scales in EDPI.

Scoring the EDPI and RRSDP

As EDPI was a self-report instrument, students rated themselves on a 7-point Likert scale from *not at all true of me* to *very true of me*. Scales were constructed by taking the mean of the items that made up that scale. For example, summing the 19 items of the instrument and taking the average would compute a student's overall self-appraisal of cognition. A similar process was needed to calculate a student's overall self-management of cognition score. Besides finding the correlation between a student's overall self-appraisal of cognition and his/her overall self-management of cognition, the researcher also found how components of self-appraisal, self-management, and level of difficulty of the design projects were statistically correlated. Students' CSA and CSM were individually computed for each group of students (i.e., electrical-computer engineering, mechanical engineering, and computer science) at both the early and final stages of the projects.

Item #6 was marked as α which was a reverse-coded item and was reflected prior to scale construction. This negatively worded item and the rating was reversed before an individual's score was computed. If an item was reversed, a student who had circled 1 for that item received a score of 7, and so on. Accordingly, a 1 became a 7, a 2 became a 6, a 3 became a 5, a 4 remained a 4, a 5 became a 3, a 6 became a 2, and a 7 became a 1. The simplest way to reflect a reverse-coded item was to subtract the original score from 8.

While students were invited to complete EDPI survey instruments (i.e., EDPI-Phase 1 and EDPI-Phase 2), the three advising professors were invited to rate the level of difficulty of their students' design projects using RRSDP. RRSDP was a 4-point Likert scale rubric where a score of 1 was used to represent a response of *few* or *low* or *unlikely*, and a score of 4 was used to represent a response of *many* or *high* or *likely.* The overall level of difficulty of project was computed by summing the scores of all RRSDP items.

Data Collection Procedures

Students who enrolled in Senior Design classes from the three engineering disciplines (i.e., ECE 445, ME 470, CS 492) were invited to participate in the study. The researcher contacted the advising professors of the three Senior Design courses to discuss the nature of the projects involved in this course and also the possibility of inviting their students to participate in the study.

No data were collected until an approval from the Office of Human Subjects Research of the College of Education at Large Public University was granted. The participation for the study was voluntary. Due to the sensitive nature of the data collected, no other identification was included in both survey instruments except for the last four digits of a student's university identification number (UIN). Data were held in strict confidence and maintained in a password-coded computer. As soon as all data were entered into SPSS for data analysis, all of those students' identifications were deleted and replaced with 3-digit numbers; *1xx* was for ECE students, *2xx* was for ME students, and *3xx* was for CS students. Only the researcher had access to the data.

Because the survey instruments assess students' perception, which reflects their metacognitive experience, they must be completed as soon as any experiences with self-appraising and self-managing occur. As soon as the fall semester began, the researcher introduced himself to the students and briefed them about the study. Because CSA is a cognitive dimension that evaluates students' knowledge states and abilities (Paris & Winograd, 1990), the study participants were invited to complete the EDPI (i.e., EDPI-Phase 1) at the early stage of their engagement of the project (i.e., project proposal submission). The data analysis process began as soon as all data were collected. Approaching the end of the semester, the advising professors were requested to rate the level of difficulty of students' projects by completing the RRSDP.

Data Analysis

The results of this investigation were based on the data collected on all study participants who completed the EDPI and RRSDP. In order to facilitate analysis and discussion of the results, data from each instrument were reviewed separately and then combined to determine if any relationship existed. The analysis processes were conducted for each group of students. In other words, data from each group of students (i.e., ECE, ME, and CS) were reviewed and analyzed separately. Because most students worked in a team, each team member received the same score for the RRSDP. Both team performance and peer evaluations were collected from the advising professor. From these analyses, the research questions were examined and answered.

Data collected from each subscale of EDPI (i.e., self-efficacy, self-confidence, task value, planning dimension, monitoring dimension, and regulating dimension) were entered into SPSS and calculated for their mean and standard deviation. A standardized mean for each feature of metacognitive scale (i.e., self-appraisal or self-management of cognition) measured was used before comparisons of results across three groups of students were made. Descriptive statistics that summarized students' cumulative GPA, self-appraisal, and self-management were included in the early stage of the analysis processes.

The Hierarchical Linear Model (HLM) was used to evaluate any relationship between variables (research questions 1 and 2, see Chapter 1). Two-tailed Pearson Correlations between each subscale of students' self-appraisal of cognition and correlation between students' overall self-appraisal and self-management, as well as correlation between the two metacognitive features and level of design project difficulty were calculated using the standardized mean. Further, hierarchical linear regression (Elazar, 1997) was conducted to investigate the relative importance of the contribution of each subscale of students' CSA (i.e., self-confidence, self-efficacy, and task value) towards the students' CSM. A one-way Analysis of Variance (ANOVA) and a Multivariate Analysis of Variance (MANOVA) tests were used to determine whether metacognitive change existed among electrical-computer, mechanical engineering, and computer science students (research question 3, see Chapter 1). Several Paired-Samples *t* tests were conducted to evaluate if metacognitive change occurred during the project engagement (research question 4, see Chapter 1). Students' responses to the two open-ended questions found at the EDPI-Phase 2 instrument were analyzed and grouped according to common themes. These common themes were used only to support arguments in the discussion section of Chapter 5.

Role of the Researcher

Although the researcher is pursuing an advanced study in the field of education, he has an engineering education background. In addition to bachelor's and master's degrees in electrical engineering, the researcher has more than 15 years of teaching experience in the field of engineering, primarily in electrical and general engineering courses. Despite the researcher's background in the field of engineering education and teaching, efforts were made to reduce the researcher's bias in the subject matter, and only the problem solving efforts by the study participants were considered. The design problems to be solved came from the students, and no hints or guiding comments were given to the study participants. All students invited to participate were informed about the researcher's educational background and role in the study.

CHAPTER 4

RESULTS

The results of this study are based on the data collected from 168 engineering students who completed the Engineering Design Project Inventory (EDPI) – Phases 1 & 2 and three engineering professors who completed the Rubric for Rating Students' Design Project (RRSDP). In order to facilitate analyses of the statistical test results, each data set was reviewed separately. Following the analyses of data, each research question was examined and answered. As this study used two of Winograd's (1990) metacognitive features (i.e., cognitive self-appraisal and self-management), with each addressing three metacognitive components (i.e., self-efficacy, self-confidence, task-value, planning, monitoring, and regulating strategies), the data analysis processes were conducted at multiple levels. Moreover, as this study also evaluated the metacognition of three groups of students (i.e., electrical-computer engineering, mechanical engineering, and computer science), numerous statistical tests were conducted for each of these groups.

The presentation of the findings of this study is organized by first giving the descriptive statistics, which are intended to help readers better understand the student participants, their projects, and the overall metacognitive changes across the three groups of engineering students while engaged in their projects. Following the descriptive statistics, numerous inference statistics are presented and used to answer each of the four research questions (presented in Chapter 1) of the study. Tables and graphs are included in this chapter to provide a visual profile of the data.

Descriptive Statistics

Students' Cumulative Grade Point Average

There was only one demographic item included in the EDPI - Phase 1 instrument: students' cumulative grade point average (GPA). Among the 168 students, 162 responded to the demographic item. There were eight scales used to identify each student's cumulative GPA. Each scale was used to identify a specific range of GPA (Table 3). All numbers were rounded to the nearest hundredth.

The mean of students' cumulative GPA was 6.74 ($SD = 1.72$), (Table 4 and Figure 2). The average cumulative, which was between GPA scales of 6 and 7, implied that the average cumulative GPA of the student participants in this study was between 3.00 and 3.49. In Figure 2, this cumulative GPA was plotted, and it should be noted that the curve was skewed to the left. More than 75 percent of the 162 students had a cumulative GPA of 3.00 or more; only one student had cumulative GPA below 2.00.

Level of Difficulty of the Design Projects (LDDP)

Six indicators were used to evaluate the level of difficulty of students' design projects (LDDP). Each indicator used a 4-point Likert scale. The maximum score to indicate the highest possible level of difficulty (i.e., the most difficult design problem) was 24; the minimum possible score to indicate the lowest level of difficulty (i.e., the least difficult design problem) was 6. From the Rubric for Rating Students' Design Project (RRSDP) collected from the professors, it was found that the mean of the LDDP was 16.07 ($SD = 3.20$), (Table 5). Among the 168 students, 88 had an LDDP of 16 or higher (i.e., 52% of the students).

Table 3

Nine Scales Used to Identify Students' Cumulative GPA

Scale	Range of cumulative GPA
1	< 2.00
2	2.00-2.24
3	2.25-2.49
4	2.50-2.74
5	2.75-2.99
6	3.00-3.24
7	3.25-3.49
8	3.50-3.74
9	3.75-4.00

Table 4

Students' Cumulative GPA

	N	Range	Min.	Max.	Mean	*SD*	Variance
Cumulative GPA	162	8	1	9	6.7407	1.72146	2.963

Table 5

Level of Difficulty of Students' Design Projects (LDDP)

	N	Range	Min.	Max.	Mean	*SD*	Variance
Level of project difficulty	168	18	6	24	16.0655	3.20393	10.265

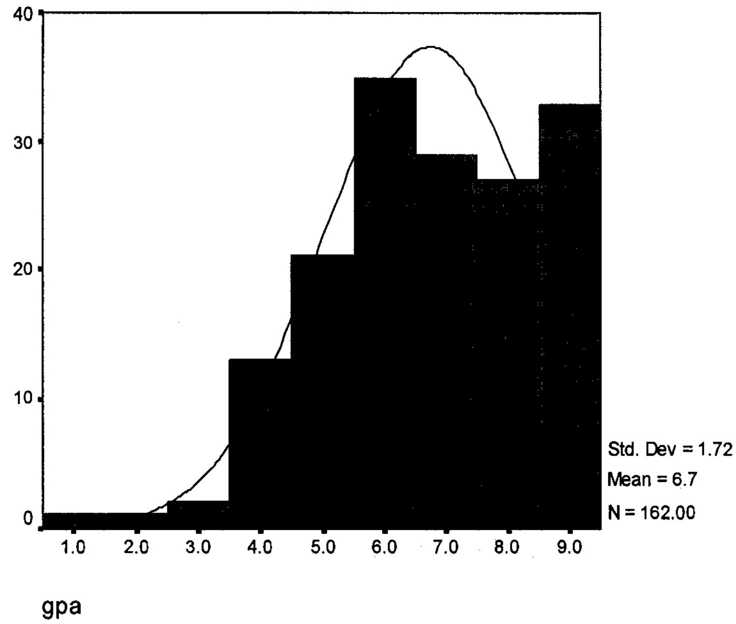

Figure 2. Students' cumulative GPA.

Cognitive Self-Appraisal and Self-Management

Descriptive statistics on students' cognitive self-appraisal and self-management were individually calculated. META was a variable to indicate an overall measure of students' metacognition. Suffix *1* was used to indicate metacognition measured at the early phase of the project, while suffix *2* was used to indicate metacognition measured at the final phase of the project. Similarly, suffixes *_ECE*, *_ME*, and *_CS* were used to represent electrical-computer engineering, mechanical engineering, and computer science students, respectively.

Table 6 presents students' overall metacognition at the final stage of the project. META2 was = 5.34 (*SD* = *.73*), which was slightly lower than the similar measure at the time when they began working on their design projects, META1, (*M* = *5.48*, *SD* = *.61*). However, when evaluating students' overall metacognition at the individual group level, it was found that computer science students had slightly lower overall metacognition at the early stage of the project (*M* = *5.38; SD* = *.60*) than their counterparts from electrical-computer ($M = 5.42$; $SD = .56$) and mechanical engineering ($M = 5.60$; $SD = .63$). On the contrary, computer science students had slightly higher overall metacognition at the final stage of the project ($M = 5.47$; $SD = .58$) than their counterparts from electrical-computer engineering ($M = 5.32$; $SD = .76$) and mechanical engineering ($M = 5.25$; $SD = .80$). The increase of computer science students' overall metacognition while engaged in their project could also be identified at the metacognitive features level. While both mechanical and electrical-computer engineering students experienced a negative change in their CSA and CSM during the project, computer science students, on the other hand, showed an increase: CSA_CS increased from 5.41 ($SD = .71$) to 5.52 ($SD = .64$), and CSM_CS increased from 5.35 ($SD = .66$) to 5.40 ($SD = .62$) during the project. In the following sections of this chapter, these measures will be evaluated once again through statistical tests designed to answer research questions 3 and 4.

Relationship Between Cognitive Self-Appraisal (CSA) and Cognitive Self-Management (CSM)

Bivariate correlation tests were conducted to determine whether there was any significant relationship between cognitive self-appraisal (CSA) and cognitive self-management (CSM) among electrical-computer engineering, mechanical engineering, and computer science students while they were engaged in the design projects. In this investigation, the relationship between students' CSA and CSM was evaluated at two different levels: (1) CSA and CSM of all students regardless of their academic field and (2) CSA and CSM of each group of students.

Table 6

Metacognitive Scales of the Three Groups of Engineering Students

Metacognitive Components	*N*	Minimum	Maximum	Mean	*SD*
META1	168	3.91	6.82	5.4772	.60604
META2	168	3.15	6.82	5.3400	.72617
META1_ECE	48	4.29	6.82	5.4191	.56053
META2_ECE	48	3.50	6.56	5.3266	.75646
META1_ME	66	4.15	6.62	5.5985	.63310
META2_ME	66	3.15	6.82	5.2455	.80078
META1_CS	54	3.91	6.50	5.3807	.59687
META2_CS	54	3.97	6.53	5.4673	.58301
CSA1_ECE	48	3.89	6.84	5.4496	.68485
CSA2_ECE	48	3.32	6.79	5.3925	.88576
CSA1_ME	66	3.58	6.89	5.6563	.76003
CSA2_ME	66	2.68	6.79	5.2177	.97126
CSA1_CS	54	2.68	6.68	5.4084	.70546
CSA2_CS	54	3.68	6.58	5.5224	.63815
CSM1_ECE	48	4.40	6.80	5.3806	.54646
CSM2_ECE	48	3.27	6.33	5.2431	.71094
CSM1_ME	66	4.07	6.80	5.5253	.61096
CSM2_ME	66	3.47	6.87	5.2808	.75791
CSM1_CS	54	3.60	6.53	5.3457	.65654
CSM2_CS	54	3.67	6.53	5.3975	.61552

Cognitive Self-Appraisal (CSA) and Cognitive Self-Management (CSM) of all Students

Two bivariate correlation tests were conducted to evaluate whether there was any significant relationship between cognitive self-appraisal (CSA) and cognitive self-management (CSM) of all students employed at the early stage of the project (CSA1 and CSM1) and at the final stage of the project (CSA2 and CSM2). Each of these correlation tests is presented individually in the following paragraphs.

Correlation between CSA1 and CSM1. A two-tailed Pearson correlation analysis indicated a significant correlation between CSA and CSM of electrical-computer engineering students at the early stage of the project, $r\ (168) = .60,\ p < .01$, (Table 7). A curve-fit graph that shows the observed and linear curves of the correlation of these two variables is presented in Figure 3. The finding suggests that, at the early stage of the project, students' cognitive self-appraisal was significantly correlated with self-management.

Table 7

Correlation Between Students' CSA and CSM at the Early Stage of the Project

Test components		CSM1
CSA1	Pearson Correlation	.595**
	Sig. (2-tailed)	.000
	N	168.000

** $p < .01$, two tailed.

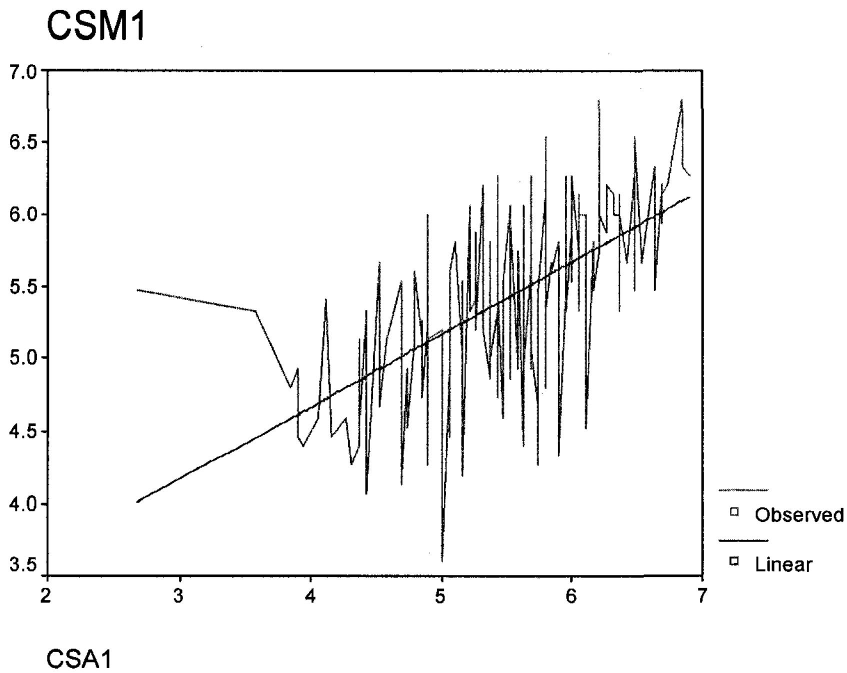

Figure 3. Correlation between CSA1 and CSM1.

Correlation between CSA2 and CSM2. A two-tailed Pearson correlation analysis indicated a significant correlation between CSA and CSM of electrical-computer engineering students at the final stage of the project, $r\ (168) = .69,\ p < .01$, (Table 8). A curve-fit graph that shows the observed and linear curves of the correlation of these two variables is presented in Figure 4. This finding suggests that, at the final stage of the project, students' CSA was significantly correlated with CSM.

Six bivariate correlation tests were conducted to evaluate whether there was any significant relationship between CSA1 and CSM1 among electrical-computer engineering students (CSA1_ECE and CSM1_ECE), mechanical engineering students (CSA1_ME and CSM1_ME), and computer science students (CSA1_CS and CSM1_CS) at the early and final stages of the project. Each of these correlation tests is presented individually as the following.

Table 8

Correlation Between Students' CSA and CSM at the Final Stage of the Project

Test components		CSM2
CSA2	Pearson Correlation	.685**
	Sig. (2-tailed)	.000
	N	168.000

** $p < .01$, two tailed.

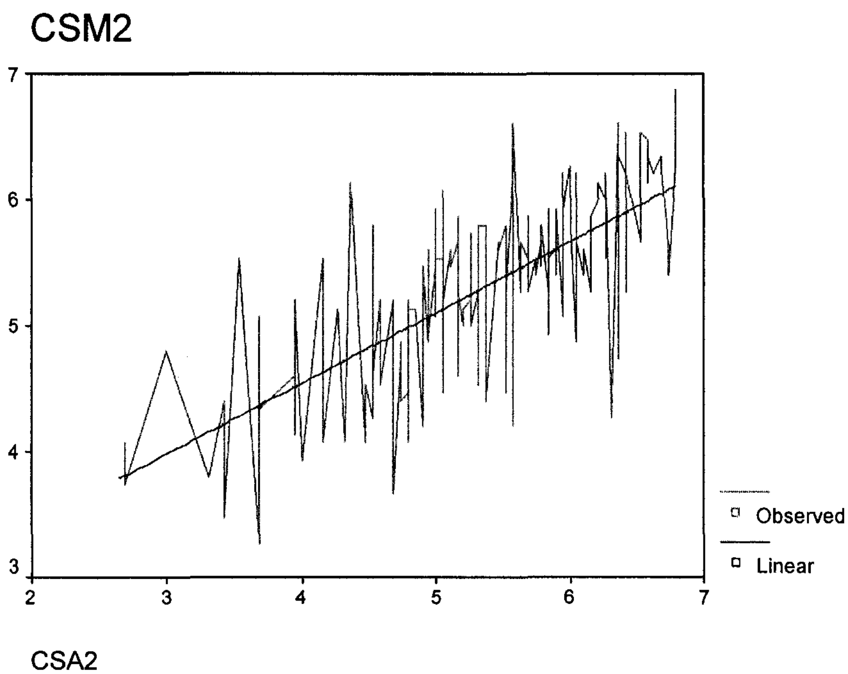

Figure 4. Correlation between CSA2 and CSM2.

Correlation between CSA1_ECE and CSM1_ECE. A two-tailed Pearson correlation test indicated a significant correlation between CSA and CSM of electrical-computer engineering students at the early stage of the project, $r\ (48) = .59,\ p < .01$, (Table 9). A curve-fit graph that shows the observed and linear curves of the correlation of these two variables is presented in Figure 5. The finding suggests that, at the early stage of the project, students' CSA was significantly correlated with CSM among electrical-computer engineering students.

Table 9

Correlation Between CSA1_ECE and CSM1_ECE

Test components		CSM1_ECE
CSA1_ECE	Pearson Correlation	.594**
	Sig. (2-tailed)	.000
	N	48.000

** $p < .01$, two tailed.

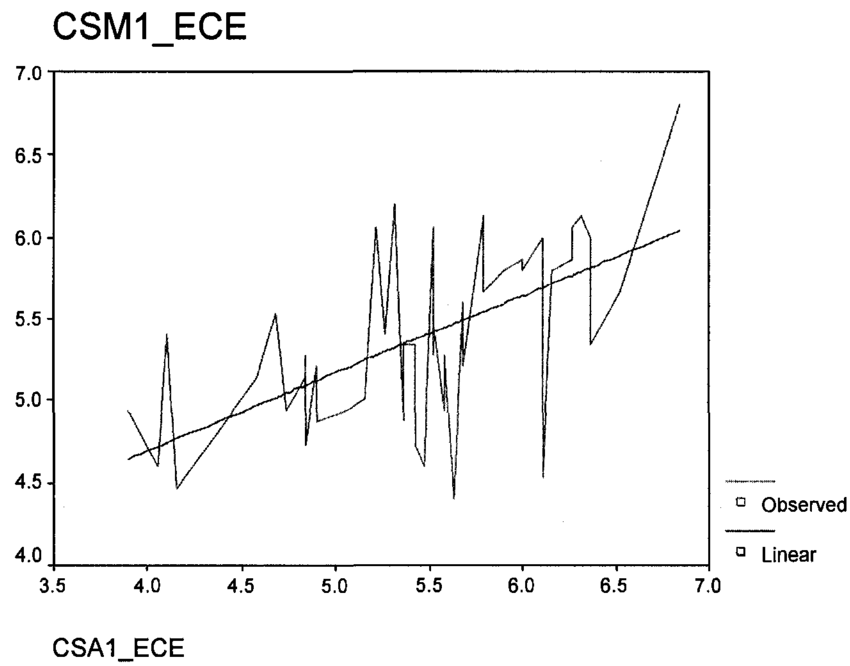

Figure 5. Correlation between CSA1_ ECE and CSM1_ECE.

Correlation between CSA1_ME and CSM1_ME. A two-tailed Pearson correlation test indicated a significant correlation between CSA and CSM of mechanical engineering students at the early stage of the project, $r\ (66) = .65$, $p < .01$, (Table 10). A curve-fit graph that shows the observed and linear curves of the correlation of these two variables is presented in Figure 6. The finding suggests that, at the early stage of the project, CSA was significantly correlated with CSM among mechanical engineering students.

Table 10

Correlation Between CSA1_ME and CSM1_ME

Test components		CSM1_ME
CSA1_ME	Pearson Correlation	.645**
	Sig. (2-tailed)	.000
	N	66.000

** $p < .01$, two tailed.

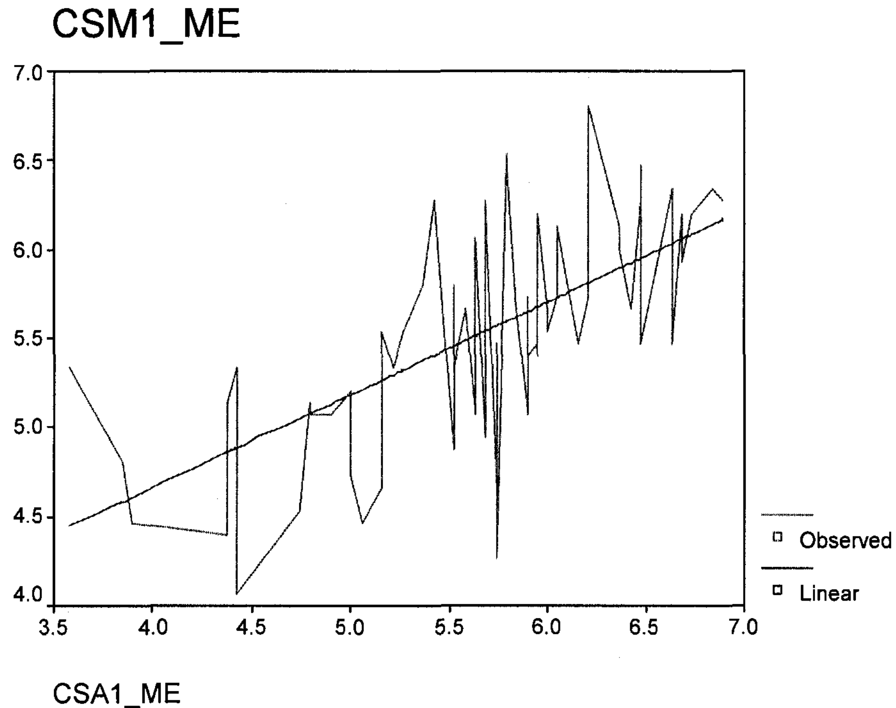

Figure 6. Correlation between CSA1_ ME and CSM1_ME.

Correlation between CSA1_CS and CSM1_CS. A two-tailed Pearson correlation test indicated a significant correlation between CSA and CSM of computer science students at the early stage of the project, $r\ (54) = .51,\ p < .01$, (Table 11). A curve-fit graph that shows the observed and linear curves of the correlation of these two variables is presented in Figure 7. This finding suggests that, at the early stage of the project, CSA was significantly correlated with CSM among computer science students.

Table 11

Correlation Between CSA1_CS and CSM1_CS

Test components		CSM1_CS
CSA1_CS	Pearson Correlation	.512**
	Sig. (2-tailed)	.000
	N	54.000

** $p < .01$, two tailed.

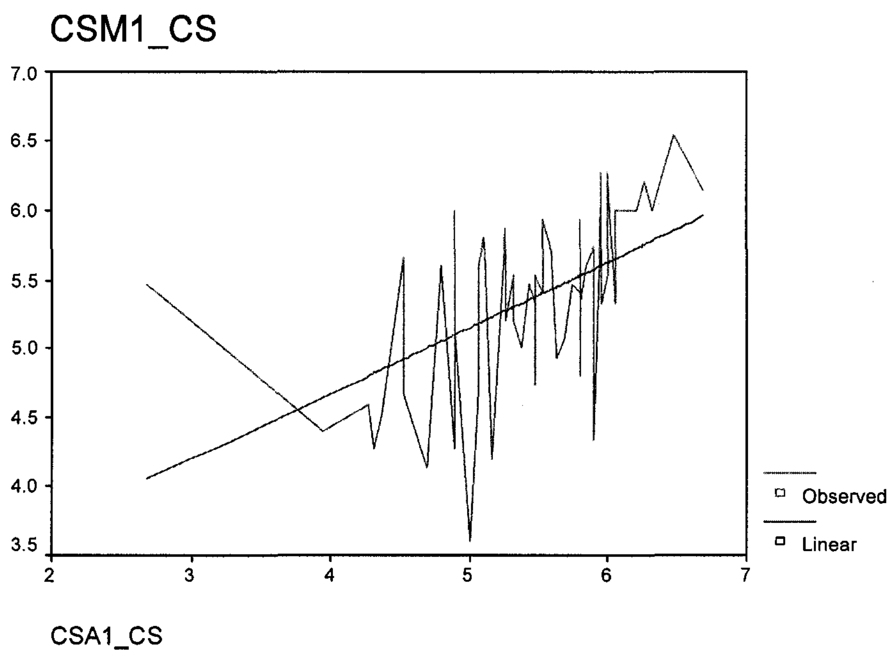

Figure 7. Correlation between CSA1_ CS and CSM1_CS.

Correlation between CSA2_ECE and CSM2_ECE. A two-tailed Pearson correlation test indicated a significant correlation between CSA and CSM of electrical-computer engineering students at the final stage of the project, $r\ (48) = .73, p < .01$, (Table 12). A curve-fit graph that showed the observed and linear curves of the correlation of these two variables is presented in Figure 8. The finding suggests that, at the final stage of the project, students' CSA was significantly correlated with CSM among electrical-computer engineering students.

Table 12

Correlation Between CSA2_ECE and CSM2_ECE

Test components		CSM2_ECE
CSA2_ECE	Pearson Correlation	.737**
	Sig. (2-tailed)	.000
	N	48.000

** $p < .01$, two tailed.

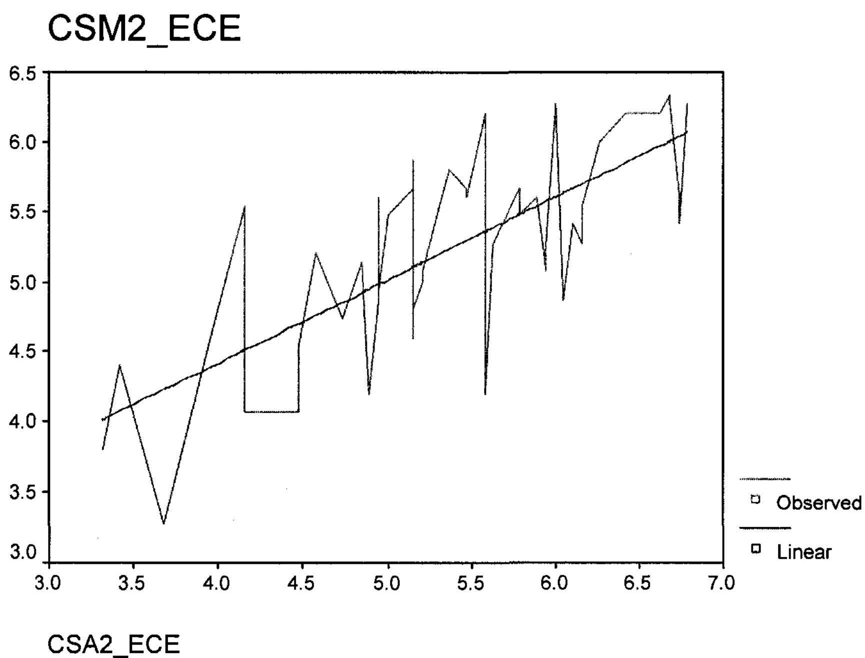

Figure 8. Correlation between CSA2_ ECE and CSM2_ECE.

Correlation between CSA2_ME and CSM2_ME. A two-tailed Pearson correlation test indicated a significant correlation between CSA and CSM of mechanical engineering students at the final stage of the project, $r\ (66) = .65,\ p < .01$, (Table 13). A curve-fit graph that shows the observed and linear curves of the correlation of these two variables is presented in Figure 9. The finding suggests that, at the final stage of the project, CSA was significantly correlated with CSM among mechanical engineering students.

Table 13

Correlation Between CSA2_ME and CSM2_ME

Test components		CSM2_ME
CSA2_ME	Pearson Correlation	.647**
	Sig. (2-tailed)	.000
	N	66.000

** $p < .01$, two tailed.

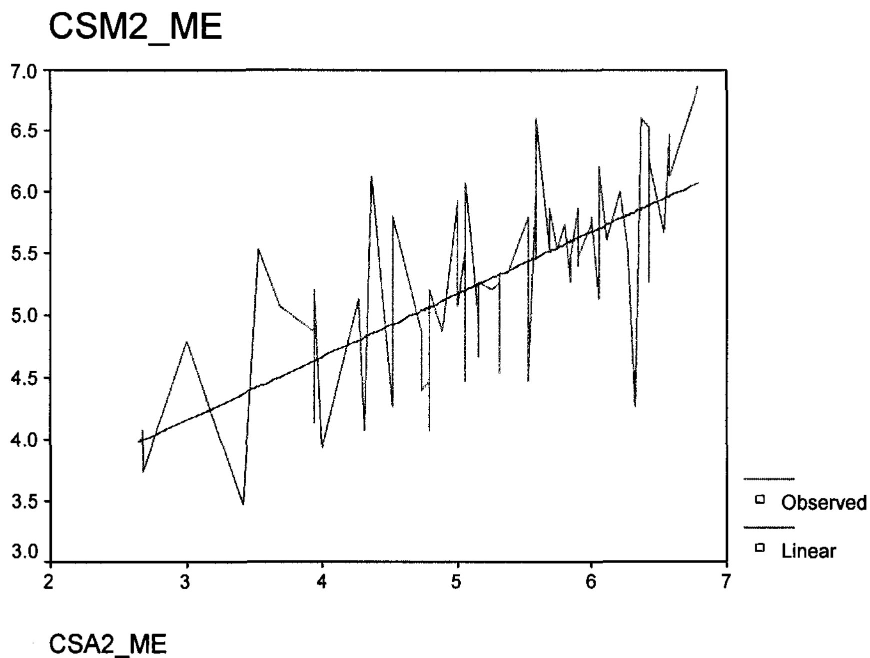

Figure 9. Correlation between CSA2_ ME and CSM2_ME.

Correlation between CSA2_CS and CSM2_CS. A two-tailed Pearson correlation test indicated a significant correlation between CSA and CSM of computer science students at the final stage of the project, $r\ (54) = .72, p < .01$, (Table 14). A curve-fit graph that shows the observed and liner curves of the correlation of these two variables is presented in Figure 10. The finding suggests that, at the final stage of the project, CSA was significantly correlated with CSM among computer science students.

Table 14

Correlation Between CSA2_CS and CSM2_CS

Test components		CSM2_CS
CSA2_CS	Pearson Correlation	.718**
	Sig. (2-tailed)	.000
	N	54.000

** $p < .01$, two tailed.

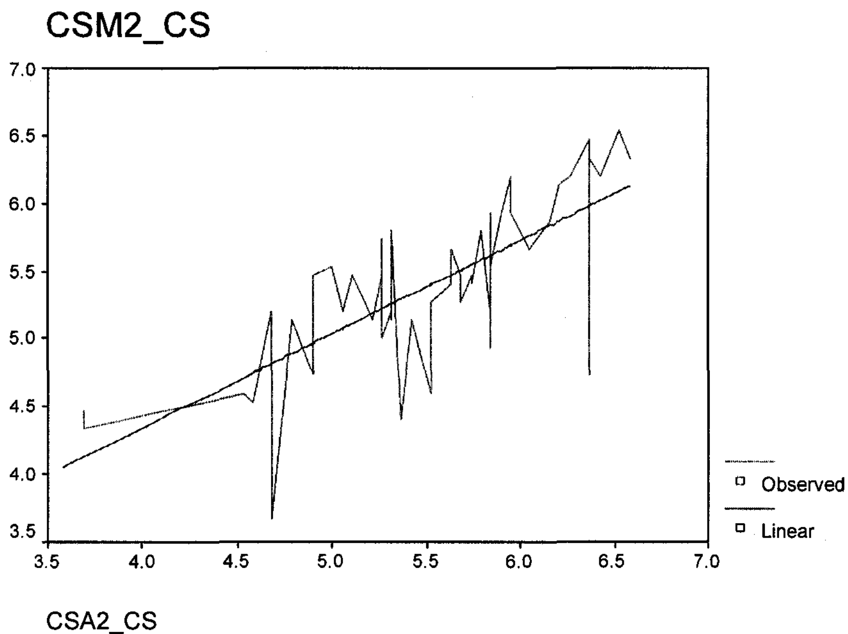

Figure 10. Correlation between CSA2_ CS and CSM2_CS.

From the previous series of two-tailed Pearson correlation tests, it was concluded that there was a significant relationship between CSA and CSM in the three groups of engineering students during their engagement in the design project. A strong indication of a significant relationship between CSA and CSM was found when the correlation test was conducted for all 168 students. It was also found when a similar test was conducted for students in each individual group. The consistencies in the statistical tests indicate that the three groups were homogeneous. Two scatter-plot graphs that mapped CSA1 and CSM1 (Figure 11) and CSA2 and CSM2 (Figure 12) show that each of these groups was not distinctly clustered together, but rather they were mixed with one another.

A strong indication of a relationship between CSA and CSM was also shown at both extreme phases of the project: the early and final stages. The finding indicated a strong relationship between these two metacognitive features consistently at the beginning and end of the project, and that it might also exist throughout the project time. The existence of this relationship does not automatically lead to the existence of a strong causal relationship between CSA and CSM.

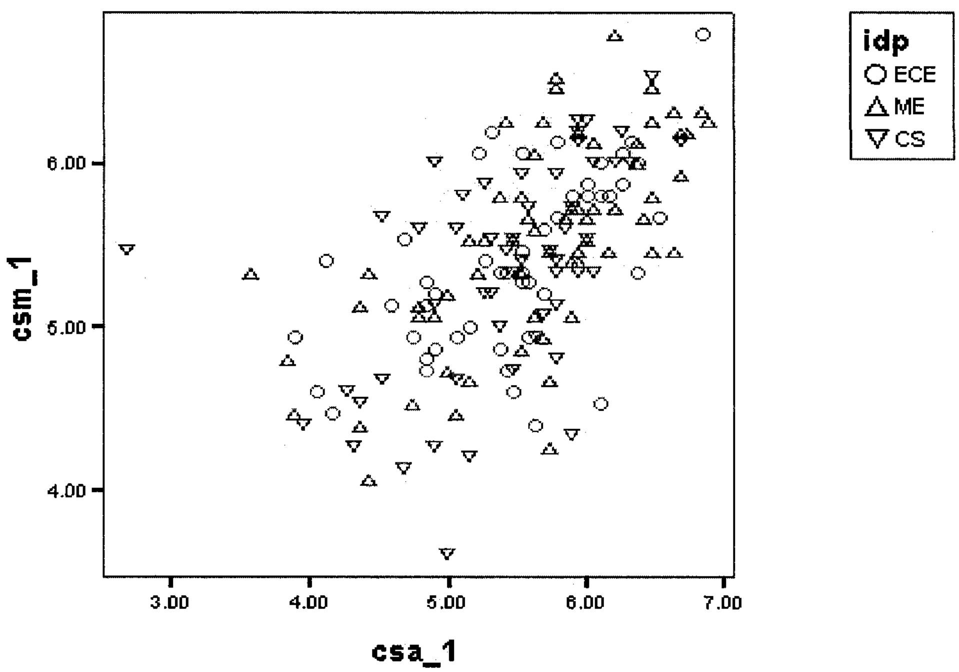

Figure 11. Scatter-plot graph of CSA1 and CSM1.

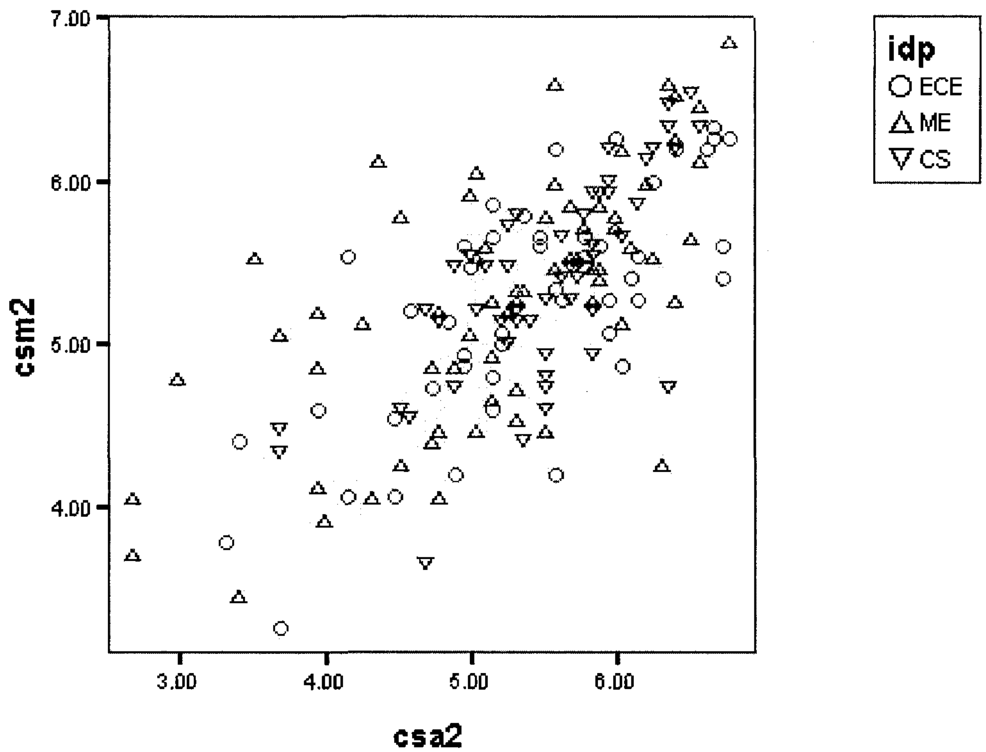

Figure 12. Scatter-plot graph of CSA2 and CSM2.

Relative Importance of SE, SC, and TV Towards CSM

A simple regression test was conducted to determine the relative importance of the contribution of each subscale of students' cognitive self-appraisal (i.e., self-confidence, self-efficacy, and task value) towards cognitive self-management. The results of the analysis revealed that at the early stage of the project, task-value was a highly significant predictor of the self-management score ($\beta = .32, p = .00$), followed by self-efficacy ($\beta = .29, p = .02$), and then self-confidence ($\beta = .17, p = .18$). At the final stage of the project, task-value was ranked first ($\beta = .28, p = .00$), followed by self-confidence ($\beta = .28, p = .00$), and self-efficacy ($\beta = .26, p = .02$). It is obvious from this simple regression test that, although task-value was ranked first as a significant predictor of students' CSM, the differences among these regression coefficients were quite small. The three subscales of self-appraisal constituted about 35 percent (at the early stage of the project) and 46 percent (at the final stage of the project) of overall students' self-management.

Relationship Between Metacognition and Level of Difficulty of the Design Projects (LDDP)

The possible existence of a significant relationship between metacognition and the level of difficulty of the design projects (LDDP) was evaluated through a series of correlation tests conducted at three different levels. First, a series of correlation tests was conducted to evaluate a possible significant relationship between students' overall metacognition and the level of difficulty. Second, similar correlation tests were conducted to evaluate possible significant relationships between the metacognition of each group of students and the level of difficulty at the early and final stages of the project. Finally, a series of correlation tests were conducted to evaluate possible significant relationships between students' CSA and CSM and the level of difficulty for each group of students.

Correlation Between Students' Overall Metacognition and LDDP

Two two-tailed Pearson correlation tests were conducted to evaluate possible significant relationships between students' overall metacognition at the early stage of the project (i.e., META1) and the level of difficulty of the design projects (LDDP) and students' overall metacognition at the final stage of the project (i.e., META2), and the level of difficulty of the design projects (LDDP). No significant relationship was found between students' overall metacognition and the LDDP at the early stage $r\ (168) = -.023$, $p > .05$, (Table 15). Furthermore, no significant relationship was found between students' overall metacognition and the LDDP at the final stage of the project, $r\ (168) = -.02$, $p >$

.05, (Table 16). The finding suggests that there was no significant relationship between students' metacognition and the LDDP at both the early and final stages of the project.

Table 15

Correlation Between META1 and LDDP

Test components		LDDP
META1	Pearson Correlation	-.023
	Sig. (2-tailed)	.763
	N	168.000

Table 16

Correlation Between META2 and LDDP

Test components		LDDP
META2	Pearson Correlation	-.015
	Sig. (2-tailed)	.842
	N	168.000

Correlation Between Group's Metacognition and LDDP

Six Pearson correlation tests were conducted to evaluate a possible significant relationship between the group's metacognition at the early stage of the project (i.e., META1_EC, META1_ME, and META1_CS) and the LDDP and students' overall metacognition at the final stage of the project (i.e., META2_ECE, META2_ME, and META2_CS) and the LDDP. No significant relationship was found between each group's metacognition and the LDDP for electrical-computer engineering, mechanical engineering, and computer science students (Tables 17 and 18). This finding suggests that there was no significant relationship between students' metacognition and the LDDP for electrical-computer engineering, mechanical engineering, and computer science students at both the early and final stages of the project.

Correlation Between two Metacognitive Features and LDDP

Twelve Pearson correlation tests were conducted to evaluate the possible existence of a significant relationship between CSA and the LDDP, and between CSM and the LDDP at both the early and final stages of the project. Nor was a significant relationship found between the two metacognitive features and the LDDP of electrical-computer engineering, mechanical engineering, and computer science students at both stages of the project (Tables 19, 20, 21, and 22). The finding suggests that there was no significant relationship between CSA and the LDDP at all levels of investigations: among groups (i.e., electrical-computer engineering, mechanical engineering, and computer science students), metacognitive features (i.e., CSA and CSM), and time of investigations (i.e., the early and final stages of the project).

From the previous series of two-tailed Pearson correlation tests, it was concluded that there was no significant relationship between metacognition and the LDDP among the groups of students during the design project. This absence of a significant relationship between metacognition and LDDP was also found at CSA and CSM levels at the beginning and end of the design project.

Table 17

Correlation Between LDDP and META1 for Each Group

IDP	Test components		META1
ECE	LDDP	Pearson Correlation	-.077
		Sig. (2-tailed)	.601
		N	48.000
ME	LDDP	Pearson Correlation	-.051
		Sig. (2-tailed)	.685
		N	66.000
CS	LDDP	Pearson Correlation	.032
		Sig. (2-tailed)	.817
		N	54.000

Table 18

Correlation Between LDDP and META2 for Each Group

IDP	Test components		META2
ECE	LDDP	Pearson Correlation	-.091
		Sig. (2-tailed)	.536
		N	48.000
ME	LDDP	Pearson Correlation	-.084
		Sig. (2-tailed)	.504
		N	66.000
CS	LDDP	Pearson Correlation	.018
		Sig. (2-tailed)	.895
		N	54.000

Table 19

Correlation Between LDDP and CSA1 for Each Group

IDP	Test components		CSA1
ECE	LDDP	Pearson Correlation	-.113
		Sig. (2-tailed)	.446
		N	48.000
ME	LDDP	Pearson Correlation	-.085
		Sig. (2-tailed)	.499
		N	66.000
CS	LDDP	Pearson Correlation	.088
		Sig. (2-tailed)	.529
		N	54.000

Table 20

Correlation Between LDDP and CSM1 for Each Group

IDP	Test components		CSM1
ECE	LDDP	Pearson Correlation	-.001
		Sig. (2-tailed)	.993
		N	48.000
ME	LDDP	Pearson Correlation	.014
		Sig. (2-tailed)	.910
		N	66.000
CS	LDDP	Pearson Correlation	-.053
		Sig. (2-tailed)	.705
		N	54.000

Table 21

Correlation Between LDDP and CSA2 for Each Group

IDP	Test components		CSA2
ECE	LDDP	Pearson Correlation	.051
		Sig. (2-tailed)	.730
		N	48.000
ME	LDDP	Pearson Correlation	-.133
		Sig. (2-tailed)	.288
		N	66.000
CS	LDDP	Pearson Correlation	.065
		Sig. (2-tailed)	.638
		N	54.000

Table 22

Correlation Between LDDP and CSM2 for Each Group

IDP	Test components		CSM2
ECE	LDDP	Pearson Correlation	.140
		Sig. (2-tailed)	.343
		N	48.000
ME	LDDP	Pearson Correlation	.015
		Sig. (2-tailed)	.906
		N	66.000
CS	LDDP	Pearson Correlation	-.047
		Sig. (2-tailed)	.738
		N	54.000

Metacognitive Differences Among Different Groups of Engineering Students

Six one-way ANOVA tests were conducted to determine whether metacognitive differences existed among electrical-computer, mechanical engineering, and computer science students during their engagement in a design project. The one-way ANOVA tests were conducted to evaluate (a) overall metacognition (i.e., META1 and META2) of each group of students at the early and final stages of the project, (b) cognitive self-appraisal (i.e., CSA1) and cognitive self-management (i.e., CSM1) of each group of students at the early stage of the project, and (c) cognitive self-appraisal (i.e., CSA2) and cognitive self-management (i.e., CSM2) of each group of students at the final stage of the project.

From the six statistical tests, it was found that there were no significant differences in overall metacognition level among the three groups of students at both the early and final stages of the project. No significant differences were found between META1_ECE, META1_ME, and META1_CS, $F(2, 165) = 2.26, p > .05$; no significant differences were found between META2_ECE, META2_ME, META2_CS, $F(2, 165) = 1.40, p > .05$; no significant differences were found between CSA1_ECE, CSA1_ME, and CSA1_CS, $F(2, 165) = 2.05, p > .05$; no significant differences were found between CSM1_ECE, CSM1_ME, and CSM1_CS, $F(2, 165) = 1.48, p > -.05$; no significant differences were found between CSA2_ECE, CSA2_ME, and CSA2_CS, $F(2, 165) = 1.93, p > -.05$; and no significant differences were found between CSM2_ECE, CSM2_ME, and CSM2_CS, $F(2, 165) = .70, p > .05$, (Table 23). Because there were no significant differences found in any of the six statistical tests, no further post-hoc tests were conducted.

To confirm the ANOVA test results, a multivariate analysis of variance (MANOVA) test was conducted. MANOVA is an extension of the ANOVA test that evaluates two or more dependent variables simultaneously. From the multivariate tests, both the intercept and the factor effect (i.e., between three groups of students) were significant, Wilks' Lambda ($F = 3784.68, p < .05$) and ($F = 2.955, p = < .05$), respectively. From the result, it may be concluded that each effect is significant. However, when looking at the Tests of Between-Subjects Effects, the results of the Corrected Model and Between-Subject Factors were the same as the ANOVA results (Table 23). Thus, the earlier finding was confirmed (i.e., that the three groups of students did not exhibit significant differences in CSA and CSM while engaged in the design project).

Metacognitive Change During Project Engagement

Four levels of investigations employing Paired-Samples *t* tests were conducted to evaluate if a metacognitive change occurred during the project engagement. The first level of investigations was to evaluate if significant metacognitive change occurred for all students and each individual group of students. At the first level, four Paired-Samples *t* tests were conducted, and the results are shown in Table 24. A significant change of overall metacognition of all students was indicated, $t\ (167) = 3.050, p < .05)$. When looking at individual groups of students, there was no significant change of overall metacognition for electrical-computer engineering students, $t\ (47) = 1.14, p > .05$, and computer science students, $t\ (53) = -1.30, p > .05$, however, there was evidence of a significant metacognitive change for mechanical engineering students, $t\ (65) = 4.78., p <$

.05 during the project. The finding suggests that only mechanical engineering students showed a significant metacognitive change during the design project.

Table 23

One-Way ANOVA Test on META1, META2, CSA1, CSM1, CSA2, and CSM2 for Each Group

Test Components		Sum of Squares	*df*	Mean Square	*F*	Sig.
META1	Between groups	1.127	2	.563	2.260	.108
	Within groups	56.662	165	.343		
	Total	57.789	167			
META2	Between groups	1.959	2	.980	1.403	.249
	Within groups	84.949	165	.515		
	Total	86.908	167			
CSA1	Between groups	2.136	2	1.068	2.050	.132
	Within groups	85.967	165	.521		
	Total	88.103	167			
CSM1	Between groups	.316	2	.158	1.481	.230
	Within groups	52.968	165	.321		
	Total	53.284	167			
CSA2	Between groups	2.806	2	1.403	1.933	.148
	Within groups	119.777	165	.726		
	Total	122.583	167			
CSM2	Between groups	1.212	2	.606	.695	.500
	Within groups	78.214	165	.474		
	Total	79.426	167			

At the second level of investigations, eight Paired-Samples *t* tests were conducted to evaluate if students' CSA and CSM, self-efficacy, self-confidence, task-value, planning, monitoring, and regulating strategies changed significantly during their engagement in the design project. The findings show that there were significant changes in students' overall CSA, $t\ (167) = 2.73, p < .05$, and CSM, $t\ (167) = 2.59, p < .05$, (Table 25). When looking at the individual components of CSA and CSM, it was found that there were significant changes in overall students' self-confidence, $t\ (167) = 2.37, p$

$< .05$, task-value, $t\ (167) = 3.16,\ p < .05$, and planning strategy, $t\ (167) = 3.72,\ p < .05$. No significant changes in self-efficacy, $t\ (167) = 1.50,\ p > .05$, monitoring strategy, $t\ (167) = 1.49,\ p > .05$, and regulating strategy, $t\ (167) = .51,\ p > .05$, were found between the early and final stages of the project. The finding suggests that both CSA and CSM changed during the design project. Among the three CSA components, self-efficacy and task-value were the ones that showed a significant change during the design project. Among the three CSM components, planning was the only one that showed a significant change during the design project.

At the third level of investigation, six Paired-Samples *t* tests were conducted to evaluate if each group of students changed significantly insofar as their CSA and CSM while engaged in the design project. The findings (Table 26) show that only mechanical engineering students had both CSA, $t\ (65) = 4.67,\ p < .05$, and CSM changes, $t\ (65) = 3.28,\ p < .05$, during the project. Electrical-computer engineering and computer science students showed no significant change of CSA and CSM. The finding suggests that, among these three groups of students, only mechanical engineering students experienced a significant change of CSA and CSM during design project.

At the fourth level of investigations, six Paired-Samples *t* tests were conducted for mechanical-engineering students. The objective was to find out which of the metacognitive components of CSA and CSM had significantly changed. The findings (Table 27) show that all three metacognitive components of CSA and two components of CSM had significantly changed. The statistical tests showed the following results: self-efficacy, $t\ (65) = 3.35,\ p < .05$; self-confidence, $t\ (65) = 3.66,\ p < .05$; task-value, $t\ (65) = 5.09,\ p < .05$; planning, $t\ (65) = 3.07,\ p < .05$; monitoring, $t\ (65) = 2.73,\ p < .05$; and regulating, $t\ (65) = 1.71, p > .05$. This finding suggests that all three CSA components of mechanical engineering students' as well as their planning and monitoring strategies had significantly changed during the design project.

From the previous series of Paired-Samples *t* tests, it was concluded that only mechanical engineering students changed their metacognition during engagement in the design project. The metacognitive change included the change of students' self-efficacy, self-confidence, and task-value, as well as planning and monitoring strategies.

Table 24

Paired-Samples t Tests on META1 and META2 of all Students and Individual Groups

Pair	Paired differences							
				95% Confidence interval of the difference				
	Mean	*SD*	Std. Error Mean	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1 META1 – META2	.1373	.58328	.04500	.0484	.2261	3.050	167	.003
Pair 2 META1_ECE – META2_ECE	.0925	.56395	.08140	-.0712	.2563	1.137	47	.261
Pair 3 META1_ME – META2_ME	.3529	.59949	.07379	.2056	.5003	4.783	65	.000
Pair 4 META1_CS – META2_CS	-.0866	.48827	.06645	-.2199	.0467	-1.303	53	.198

Table 25

Paired-Samples t Tests on CSA, CSM, SE, SC, TV, P, M, and R for all Students

Pair	Paired differences							
				95% Confidence interval of the difference				
	Mean	*SD*	Std. Error Mean	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1 CSA1 – CSA2	.1519	.72163	.05568	.0420	.2619	2.729	167	.007
Pair 2 CSM1 – CSM2	.1187	.59478	.04589	.0281	.2092	2.586	167	.011
Pair 3 SE1 – SE2	.0985	.85345	.06585	-.0315	.2285	1.497	167	.136
Pair 4 SC1 – SC2	.1476	.80811	.06235	.0245	.2707	2.368	167	.019
Pair 5 TV1 – TV2	.2524	1.03524	.07987	.0947	.4101	3.160	167	.002
Pair 6 P1 – P2	.2202	.76687	.05917	.1034	.3370	3.722	167	.000
Pair 7 M1 – M2	.0825	.71565	.05521	.0265	.1915	1.494	167	.137
Pair 8 R1 – R2	.0337	.85053	.06562	-.0958	.1633	.514	167	.608

Table 26

Paired-Samples t Tests on CSA and CSM of Individual Groups

Pair	Paired differences							
				95% Confidence interval of the difference				
	Mean	*SD*	Std. Error Mean	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1 CSA1_ECE – CSA2_ECE	.0570	.65762	.09492	-.1339	.2480	.601	47	.551
Pair 2 CSM1_ECE – CSM2_ECE	.1375	.54965	.07933	-.0221	.2971	1.733	47	.090
Pair 3 CSA1_ME – CSA2_ME	.4386	.76306	.09393	.2510	.6262	4.670	65	.000
Pair 4 CSM1_ME – CSM2_ME	.2444	.60588	.07458	.0955	.3934	3.278	65	.002
Pair 5 CSA1_CS – CSA2_CS	-.1140	.60059	.08173	-.2780	.0499	-1.395	53	.169
Pair 6 CSM1_CS – CSM2_CS	-.0519	.58902	.08016	-.2126	.1089	-.647	53	.520

Table 27

Paired-Samples t Tests on all CSA and CSM Components of Mechanical Engineering Students

	Paired differences							
				95% Confidence interval of the difference				
Pair	Mean	*SD*	Std. Error Mean	Lower	Upper	*t*	*df*	Sig. (2-tailed)
Pair 1 SE1 – SE2	.3754	.90996	.11201	.1517	.5991	3.352	65	.001
Pair 2 SC1 – SC2	.3636	.80682	.09931	.1653	.5620	3.662	65	.001
Pair 3 TV1 – TV2	.6273	1.00085	.12320	.3812	.8733	5.092	65	.000
Pair 4 P1 – P2	.2727	.72293	.08899	.0905	.4504	3.065	65	.003
Pair 5 M1 – M2	.2532	.75460	.09288	.0677	.4387	2.726	65	.008
Pair 6 R1 – R2	.1768	.83966	.10335	-.0296	.3832	1.710	65	.092

CHAPTER 5

DISCUSSION

This chapter is organized into three sections: conclusions and discussion of the findings, recommendations for engineering education and practice, and recommendations for future research. A thorough discussion is presented following the conclusions of the findings as a response to each of the four research questions presented in Chapter 1. In the recommendations section, the potential use of the findings of this study was explored to foster better design processes and outcomes in the engineering instructions. At the end of the chapter, suggestions about potential future studies in the area of metacognition are also discussed.

Conclusions

Conclusion #1: Cognitive Self-Appraisal and Cognitive Self-Management are Closely Related

Results of bivariate correlation tests revealed the existence of a significant relationship between cognitive self-appraisal (CSA) and cognitive self-management (CSM) of electrical-computer engineering, mechanical engineering, and computer science students while engaged in the design project. A significant relationship was found consistently at the early and final stages of the project. The results of these tests indicated the presence of a high correlation of both significance values, p, and correlation coefficients, r. The findings confirm the relationship between students' developmental attribution beliefs and strategic knowledge highlighted in numerous studies (Chambres, Bonin, Izaute, & Marescaux, 2002; Chan & Moore, 2006; Jonassen, Strobel, & Lee, 2006; Ross, Green, Salisbury-Glennon, & Tollefson, 2006).

Paris and Winograd (1990) argued that two essential features of metacognition (i.e., self-appraisal and self-management of cognition) capture the information processing account of declarative and procedural knowledge. While self-appraisal includes personal reflection about one's knowledge and abilities, self-management refers to how self-appraisal is put into action. In this study, a significant relationship was found between CSA and CSM in the three groups of engineering students during their engagement in senior design projects.

When looking at the students as one entire sample population, the results of the correlation tests showed that their CSA was significantly correlated with CSM. A significant relationship between the two metacognitive features was also found during the final stage of the design project and in the individual groups of students. A significant relationship between CSA and CSM across the three groups at both ends of the project processes was consistently indicated as well. The finding indicated consistent awareness on the part of the students regarding their thinking and the use of that awareness to control what they were doing throughout the project. Students with a low CSA had a low CSM, and vice-versa. In other words, the students' awareness of knowledge states and abilities impacted the way they planned, monitored, and made necessary adjustments. A similar finding was also discovered in a longitudinal study conducted by Chan and Moore (2006). The study found the existence of a relationship of attributional beliefs, strategic knowledge, and achievement across primary and high school students. Students who were taught cognitive and metacognitive strategies for learning along with attempts to convince students to attribute success and failure to effort and effective or noneffective use of strategies can succeed in breaking the vicious cycle of entrenched, learned helplessness belief and their negative impacts on learning strategies and academic achievement.

The findings also reinforced the conclusions of another study that suggested that college students adjust their study strategies according to their understanding of the state of the self-appraisal and the problems (Ross, Green, Salisbury-Glennon, & Tollefson, 2006). Another study conducted by Chambres, Bonin, Izaute, and Jean-Marescaux (2002) found that even a fictitious position of expertise promotes metacognition and student effectiveness. For instance, students randomly said to be experts in English performed better than those said to be nonexperts. In addition to better English performance, the students answered the test questions.

The significant relationship between students' CSA and CSM that was found in this study did not imply a causal relationship. Rather, the findings indicated that the two metacognitive features are interdependent. In other words, the statistical tests employed in this study were not meant to determine any causal conclusions. Specifically, the findings showed that when students feel that they have the adequate knowledge, ability, and interest to solve the design problems, they more likely to be motivated to engage in the problem successfully through adequate planning, monitoring, and making necessary adjustments in their thinking.

According to Linnenbrick and Pintrich (2002), self-efficacy and task-value are parts of intrinsic motivation that enable students to be successful in learning. Furthermore, the authors argued that together with self-confidence, self-efficacy and task-value are attributed to strategy use. Several correlation tests highlighted the fact that the three aspects of students' CSA were significantly correlated to the metacognitive strategies used.

Conclusion #2: Students' Metacognitive Abilities Does not Relate to the Level of Difficulty of the Design Project

Statistical results revealed no significant relationship between the variables of students' metacognition and the level of difficulty of the design project (LDDP). The researcher first evaluated the relationship of the two variables by looking at all students as a single sample population. From the statistical tests, no correlation was found between overall students' metacognition and the LDDP. In addition, no significant relationships were found between students' CSA and the LDDP, nor between students' CSM and the LDDP. Similar results were also found when correlation tests were conducted for each individual group of student samples. From those several correlation tests, no significant relationships between the two variables were found.

When no significant relationships were found between students' metacognition and the LDDP, an additional correlation test was conducted to determine whether there existed a significant relationship between students' metacognition change and the LDDP. Metacognitive change is identified as the difference between the score of students' metacognition at the early and final stages of the project (i.e., Meta 1 – Meta2). One may expect that the LDDP may correlate to the level of metacognition employed by the students. Once again, two-tailed Pearson correlation tests identified no significant relationship between students' metacognitive change and the LDDP. Similar results also occurred regarding finding a significant relationship between students' CSA or CSM change and the LDDP.

The absence of any significant relationship between the two variables is inconclusive. This may be due to two influencing sources: factors internal to the students and an outside agent's determination of problem difficulty. Internal factors may involve students' lack of experience in predicting the complexity of their design projects, overconfidence, and trial-and-error working tactics (see Table 28). Because of these factors, students may not anticipate the unexpected during the project. The development of metacognitive skills enables students to select appropriate plans for solving the problem, and identify and overcome obstacles to the process (Davidson & Sternberg, 1998). The determination of problem difficulty by the professors may also be the influencing source of the absence of significant relationships between students' metacognition and LDDP. Students' metacognition and the level of problem difficulty were evaluated by two different groups of individuals. The two groups of individuals may perceive the level of difficulty of the design problem differently. Therefore, their judgments regarding the level of difficulty of the design problem may vary. Consequently, the results of the correlation tests conducted may not show the real relationship between students' metacognition and LDDP.

Despite the absence of significant relationships between students' metacognition (including its features of CSA and CSM) and the LDDP, the researcher found it interesting to evaluate further the correlation factor between the two variables. Negative correlation factors were found between the LDDP and CSA1 and between the LDDP and CSM1. Negative correlation factors were also found between the LDDP and CSA2 (Table 16). The negative correlation indicated the condition where the more complex the design problem, the lower the students' CSA.

However, when evaluating the correlation between students' CSM at the final stage of the project (i.e., CSM2) and LDDP, a positive correlation factor was found. Students' CSM2 increased as the LDDP increased. The positive correlation factor may indicate a sign where the engineering students might have changed their CSM as the project progressed. The self-management change might have occurred as a result of the increase in the students' awareness about the complexity of the project and their development of metacognitive skills that enabled them to select an appropriate plan for solving the problem and identifying and overcoming obstacles to the process (Jonassen, 2000). The ability of students to form good plans, use a variety of strategies, monitor and revise an ongoing performance help guide and coordinate thinking (Baker & Brown, 1984).

Conclusion #3: Electrical-Computer Engineering, Mechanical Engineering, and Computer Science Students do not Employ Different Metacognitive Skills While Engaged in Their Design Project

Results of one-way ANOVA and MANOVA tests showed that electrical-computer engineering, mechanical engineering, and computer science students did not exhibit significant differences in CSA and CSM while engaged in the design project. Despite the belief of numerous researchers that design solutions do not occur in a vacuum and that each individual who engages in a design activity brings a "culture medium" with him or her, this study found no evidence of metacognitive difference employed by the three groups of engineering students. From ANOVA and MANOVA tests reported in Chapter 4, it was concluded that electrical-computer engineering, mechanical engineering, and computer science students exhibited no significant metacognitive difference. There are three possible reasons for the absence of significant metacognitive differences among these three groups of engineering students. First, the finding is an important new contribution to studies about the role of individuals' and groups' "culture medium" in design education. The term "culture medium" indicates the notion of the cultural information that individuals and groups hold as part of their make-up (Strickfaden, Heylighen, Rodgers, & Neuckermans, 2005). The culture medium may exist in any individual or group, and it includes many facets of an individual's behavior gained through engaging in various social situations and interactions.

As this finding may come as a surprise to many of us, the cultural capital might also have existed in these engineering students and might have been a major contributing factor contributing to the students' design activities. The absence of any significant difference in employing metacognition among the groups may be due to a common metacognitive skill that the engineering students possess. Nevertheless, the culture medium might exist among individuals and groups of students, but may not significantly impact their metacognitive ability. It would be interesting to investigate whether any significant difference in metacognition exists between engineering and non engineering students. The influencing factors, such as the utilization of a strategy that dynamically changes as a response to changing working conditions or an initiative that focuses on smaller sections of the project to solve complex problems (see Table 29) may be part of the computer science students' culture medium. Another example of a culture medium that exists among computer science students is the common practice of modifying a piece of an existing program to create a new one (Jones, 1988).

Second, the level of self-appraisal and self-management regarding working in such a design project might be similar across the senior students. The students who participated in the senior design courses were in their senior year and, therefore, a homogenous metacognitive level may have existed among them. As their learning experienced enriched, their metacognition improved. Clearly, metacognitive ability is learnable (Masui & DeCorte, 1999) and develops with age and experience (Garner & Alexander, 1989). Third, a high percentage of undergraduate engineering students transferred within the College of Engineering during the first 2 years of their academic pursuit, a fact that might contribute to the insignificant metacognitive change among the three groups of students. As students change majors during their undergraduate study, students enrolled in the College of Engineering become a single homogeneous community with similar metacognitive skills. Thus, this may lead to metacognitive indifference among electrical-computer engineering, mechanical engineering, and computer science students.

Conclusion #4: Only Mechanical Students Change Their Metacognitive Skills While Engaged in the Design Project

Results of Paired-Samples *t* tests found a significant change in students' overall metacognition between the early and final stages of the design project. Similar significant changes were also found for the individual metacognitive features measured at those two points in time. The Paired-Samples tests confirmed this analysis by indicating a significant change in students' CSA and CSM. In other words, the students exhibited a significant change in CSA and CSM during the design project.

From the responses to the two open-ended questions found at the end of the EDPI-Phase 2 survey instrument, the researcher concluded possible reasons for the metacognitive changes. In the appendix of the second survey instrument, two questions were posted: (a) From the time you were preparing the proposal to the time you were completing the project, did your feeling about your ability to solve the design project change? and (b) From the time you were preparing the proposal to the time you were completing the project, have your strategies to solve the design project changed? For both questions, all student participants were asked to respond by circling a "yes" or "no" as their response, and then they were asked to explain in what way, how, and why they have (or have not) changed. The two questions were purposely constructed to reflect the possible changes of students' CSA and CSM during the project. It was purposely avoided to use certain technical terminologies such as self-efficacy, self-confidence, task-value, planning, monitoring, and regulating in the questions in the sentences. Simple and common lay language was used to construct the questions.

From the responses gathered, the researcher identified 18 distinct themes of responses that described the influencing factors for the change in students' CSA (Table 28) and 23 distinct themes of response that described the influencing factors for their CSM change (Table 29). From the 168 participating students, all of them responded to the questions and there were only 2 students who did not provide an explanation that justified their responses.

For each table, the themes were then grouped into two categories: internal and external factors. The intent of the proposed categorization was to put together themes according to their source. The internal factors were reactions that students created inside themselves in response to the design project. They were actions that the students chose, which might have been influenced by their culture medium. These factors may be viewed as the influencing factors that might have produced negative or positive self-appraisal, and that changed students' cognitive self-management. The external factors, on the other hand, were the influencing factors that initially came from outside the students' personal well-being, and that might have also affected the students' ability to achieve strategic goals and objectives. The external factors may include socio-cultural aspects provided by the context of the project or things that are domain specific provided by the problem to be solved. The beta (β) in Table 28 indicated the influencing factors that lowered students' confidence to solve the design problem.

When looking across the three groups of students, 5 common factors (4 internal and 1 external) were found that might have caused CSA changes and 10 (8 internal and 2 external) factors that might have caused CSM changes during the project. Low CSA during the project may result from a lack of understanding of the complexity of the project at the earlier stage. Students might not have had sufficient knowledge, skills, and experience in evaluating the nature of such an ill-structured problem. From their comments (Table 28) it was obvious that some of the students misjudged their ability to foresee the complexity and solve the problem. As a result, these students might not have anticipated any large-scale challenges when they began preparing their project proposal. As students explored their work and faced unanticipated challenges, their CSA lowered. It was found that students' self-confidence and task-value lowered from the time they began their project. Other common factors that may have increased students' self-appraisal are the personal gain of new knowledge or skills as well as the ability to make small progress during the project.

As far as students' self-management change is concerned, the students showed that they planned, monitored, and made necessary adjustment in their thinking while working on the design project. The students responded to various factors that might have hindered their moving forward in the design process. As necessary corrections or revisions were made, their self-appraisal increased. Some of the common factors that forced the students to change their self-management included the desire to improve the design outcomes as well as the design processes. Trying to find alternative designs and strategies was considered during the project. Across the groups of students, some of them admitted that they used a trial-and-error strategy to solve their design problem, and this had forced them to often change their self-management.

When evaluating the possibility of significant metacognitive changes during the project across the three groups of students, it was found that a significant metacognitive change occurred only in mechanical engineering students. This finding raised the question of why only this group of students experienced metacognitive change. One may wonder what is so unique about mechanical engineering students, and was the significant change in metacognition due to the nature of the design activities or working styles that differed across the three engineering fields?

According to Kerns, Kerns, Pratt, Somerville, and Crisman (2002), the nature of the design problems associated with the field of electrical-computer engineering and mechanical engineering is somewhat different. Most electrical-computer engineering designs involve problems that are initiated by a specification that needs to be solved. Furthermore, the problems typically have a wide range of possible solutions that generally involve the use of electronic components and ways to manipulate electric signals. Mechanical engineering designs, on the other hand, may require the designers to deal with issues that are much more visible and intuitive rather than with problems involving currents and voltages. Unlike electrical-computer and mechanical engineering, Guidon and Curtis (1988) argued that software design is an opportunistic discovery process. Anyone who engages in software design activities may find that the parameters of the problem often emerge during attempts to build solutions. This kind of unique design activity might lead the computer science study participants to believe that they needed to dynamically change their design strategy as a response to a changing current working condition. This group of students also argued that they often faced new, unforeseen problems and that they preferred to focus on smaller sections of the project and completed the task piece by piece.

In one study conducted by Case and Gunstone (2002), it was suggested that the degree of metacognitive development might vary based on a shift in a student's approach to learning. The findings of this study may explain why mechanical engineering students exhibited a significant metacognitive change. In this particular study, metacognitive development was defined as a development in one's metacognitive abilities that may be indicated by the move to greater knowledge, awareness, and control of one's own learning. The notion of metacognitive development is somewhat congruent with what was referred to as metacognitive change in this present study. In regard to learning approaches, Case and Gunstone evaluated three approaches: conceptual, algorithmic, and information-based. While a conceptual approach relies heavily on the intention to understand what is learned, algorithmic- and information-based approaches focus on remembering either solution methods (for algorithmic-based approach) or specific pieces of information (for information-based approach). Case and Gunstone found that students who used a conceptual approach or an information-based approach throughout the course did not exhibit metacognitive development. Metacognitive development was found only in students who, during their learning, shifted from an algorithmic approach to a conceptual approach.

Table 28

Themes That Described the Reason why Students Changed Their CSA

Various factors that influenced the change of students' CSA	ECE	ME	CS
Internal Factors			
Misjudging complexity of the task $^{\beta}$	√	√	√
Gaining new knowledge, skills, and ability	√	√	√
Lacking knowledge and skills $^{\beta}$	√	√	√
Making intermediate accomplishments/progress	√	√	√
Changing ideas $^{\beta}$	√		
Being fearful of failing or not being able to meet own expectations $^{\beta}$	√		
Having unclear understanding about project's objectives at early stage of the project $^{\beta}$			√
Not being able to concentrate on the project $^{\beta}$		√	√
Feeling of being an inventor $^{\beta}$		√	
Misjudging own ability $^{\beta}$	√	√	
Being overconfident at the early stage of the project $^{\beta}$	√		
Being able to complete the project	√		
Making inaccurate planning/design strategies $^{\beta}$	√		√
Being successful in applying new strategies		√	
External Factors			
Problem complications/difficulties $^{\beta}$	√	√	√
Lacking time $^{\beta}$	√		
Lacking of supporting resources (i.e., tools, equipment) $^{\beta}$		√	
Receiving help from others		√	

Table 29

Themes That Described the Reason why Students Changed Their CSM

Various factors that influenced the change of students' CSM	ECE	ME	CS
Internal Factors			
Applying totally new strategies	√	√	√
Experiencing difficulty during design process	√	√	√
Applying newly learned knowledge	√	√	√
Having a bad or nonworking design	√	√	√
Applying trial-and-error technique	√	√	√
Improving efficiency of the design approach	√	√	√
Improving effectiveness of the design approach	√	√	√
Trying to find alternative solutions	√	√	√
Simplifying the design strategies or solutions		√	√
Changing the focus of the work based on the level of work priority	√		√
Dynamically changing the strategy as a response to changing current working conditions			√
Facing new, unforeseen problems			√
The need to focus on smaller sections of the project			√
Improper initial planning			√
Improving the quality of the design outcomes	√	√	
Focusing too heavily on one single solution		√	

(table continues)

Table 29 *(continued)*

Various factors that influenced the change of students' CSM	ECE	ME	CS
External Factors			
Employing new equipments, design materials, or requirements	√	√	√
The objectives/requirements of the project changed	√	√	√
Facing constraints on time and supporting resources		√	√
Fulfilling demands from the project sponsors/professors		√	√
Receiving suggestions or help from others	√	√	
Inefficient teamwork		√	√
Task became more diverse	√		

The significant metacognitive change exhibited by the mechanical engineering students in the present study may be associated with the presence of a shift in a student's approach to learning. During the design project, the mechanical engineering students might have used an algorithmic approach at the start of the project, focusing on remembering set solutions to apply to problems they encountered, rather than aiming for a conceptual understanding of the project and its details. Working with issues that are much more visible and intuitive (Kerns, Kerns, Pratt, Somerville, & Crisman, 2002) might have led the mechanical engineering students to initially focus more on the potential components or parts needed in the design. More thought and concern might have been employed in evaluating and solving individual parts of the project than evaluating the project as one mechanical system. As the design project progressed, the students might have managed to implement such a conceptual approach.

Another factor that may cause metacognitive change that occurs exclusively among mechanical engineering students is the students' group size. As it was strongly advised by the Senior Design coordinating professor, mechanical students had more members in their design project team than electrical-computer engineering and computer science students. A relatively large number of team members might have triggered students to have more interactions and, consequently, knowledge sharing, including metacognitive knowledge, occurred and effectively changed their metacognition during the project. Although these assertions may be speculative in nature, there are no sufficient resources available to further our understanding on this issue. As no other data were found that may help to suggest a significant change of metacognition occurred in mechanical engineering students, further study may need to be conducted.

Recommendations

In evaluating the results of this study, a number of recommendations can be made to engineering design educators and researchers who wish to pursue further research in this area.

Recommendations for Engineering Design Educators

As design projects are a common type of assignment given to students in any field of study in engineering, and the application of metacognition is uniquely important in this kind of ill-structured problem (Jonassen, 2000), therefore, it is worthwhile to consider applying the skill in engineering design activities. In regard to the utilization of the findings of this study, three recommendations are proposed to engineering educators.

The first recommendation is related to the significant relationship between students' cognitive self-appraisal and self-management. From this study and previous studies about students' metacognition, it is apparent that there is a significant relationship between one's CSA and CSM and, moreover, that the two features of metacognition consequently influence the quality of students' learning performance. Although self-efficacy, self-confidence, and task value contribute less than 50 percent of overall students' self-management, the three self-appraisal factors have been shown to play an essential role in shaping students' self-management.

When looking at the themes that described why their self-appraisal and self-management changes, it is apparent that some of these issues may be minimized or even avoided before a student begins work on a project. Issues such as misjudging the complexity of the project may lead to misjudging self-efficacy. Because students seldom realize how complex their project will become, they may not make an effort to prepare themselves with resources to fill in the future knowledge gaps. It is suggested that the professors allocate time early in the project to emphasize the importance of exercising their metacognitive skills to students. To accomplish this, students may need to devote time to thinking and discussing their design projects with their teammates or instructors, especially at the earlier stage of the project. Some of the self-appraisal and self-management issues may be discussed more openly at the early stage of the project to help make better planning and smooth the design process at the later design stages.

The second recommendation is associated with the utilization of metacognition across different fields of engineering education. The absence of any significant differences of metacognition among electrical-computer engineering, mechanical engineering, and computer science students may indicate the possibility of an identical level of metacognitive skill by all of the senior students. Although this finding did not automatically prove the presence of metacognitive differences across students of different academic levels (i.e., freshman, sophomore, junior, or senior), the metacognitive skill employed by students across different academic levels may be quite different indeed. This assertion is made from the assumption that the amount of a student's learning experience increases as his or her academic level advances. Garner and Alexander (1989) argued that students' metacognitive skills develop with age and experience. This is to suggest that, if it cannot be avoided altogether, different amounts and qualities of metacognitive ability may be encountered in teaching a group of mixed-academic-level students. Consequently, different teaching strategies or expectations may be needed to bridge the gap between students who possess more- and less-advanced metacognitive skill. Allowing students to work in a group that is comprised of students with different levels of metacognitive abilities may help overcome challenges that this group may experience in managing the design project.

The third recommendation regards efforts to improve students' design strategies. A trial-and-error working tactic may be appropriate for solving some engineering design tasks that involve the use of new technologies or procedures; however, for most design tasks, the working tactic may lead students to make unnecessary adjustments to their cognitive self-management. This unnecessary adjustment may also result in an increase in students' anxiety and eventually ineffectively use their limited resources and time to complete the projects. To avoid using such tactics, during the proposal stage, students may be required to inventory all tasks and possible methods needed for the project. Requiring students to research existing solutions of similar design tasks and provide the rationale for selecting a particular strategy will help students be more prepared, avoid making improper initial planning, and avoid focusing on a single solution. Consequently, as the projects progress, students will be able to execute numerous working scenarios to overcome whatever challenges they may face while engaged in the projects. A project proposal will become an important roadmap that not only showing activities and working schedule, but moreover, will include strategies, alternatives, and resources to complete the projects.

A modular design approach, which is a common *mantra* used in engineering design education, may need to be reemphasized in order to effect simpler, cleaner, maintainable, and upgradeable designs. Modular design is an approach that subdivides one complex system into several smaller, less-complex systems that can be independently created and used to drive multiple functionalities. Failure to modularize ill-structured projects may cause students to feel overwhelmed and tasks to become more diverse and difficult to manage. Furthermore, implementing a modular design helps engineering educators better identify and appraise students' design progress and outcomes.

Recommendations for Researchers in Engineering Education

Two recommendations are offered for future research. First, this study has offered some insight into how students' metacognition is used in an engineering design project; however, due to the limited number of student participants employed in this study, researchers may want to conduct a similar study that involves a larger number of engineering study participants from several colleges and universities. Two or more assessors may be needed to evaluate the level of difficulty of the project for future research. Inviting students to evaluate the level of difficulty of their own design project may need to be considered so that the level of metacognition and difficulty of the problem are both based on students' perceptions. A similar study that involves ill-structured problems and other types of problems with various level of difficulty in other fields of engineering and sciences may also need to be considered to improve the generalizability of the findings and our understanding about the use of metacognition in solving ill-structured problems. Furthermore, a mixed-method approach of study may also be considered to encourage a deeper understanding about why metacognition change happens only for one particular group of students and not for the others.

Second, a follow-up study may be conducted to further our understanding about the relationship between metacognition and students' design performance. Although there are numerous existing studies that investigate how metacognition impacts performance, similar studies may focus on the investigation about how each of the components of the self-appraisal and self-management from various groups of engineering students relate to design performance. A standard method of assessing students' design performance needs to be formulated to increase the validity of the data.

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APPENDIX A

ENGINEERING DESIGN PROJECT INVENTORY
(EDPI) – Phase 1

The following statements describe your motivation for, attitudes about, and problem-solving strategies of the design problem **you are about to solve**. Remember, there are no right or wrong responses, just respond to the statements **as accurately as possible**.

Use the scale below to respond to the statements. If you think the statement is **very true of you**, circle **7**; if a statement is **not at all true of you**, circle **1**. Otherwise, circle the number between 1 and 7 that best describes you.

Please write the last 4-digits of your UIN in the box provided.

Last 4-digit of your UIN:

Please complete the following demographic information.

Demographic information:

Circle your cumulative GPA	< 2.00	2.00-2.24	2.25-2.49	2.50-2.74	2.75-2.99
	3.00-3.24	3.25-3.49	3.50-3.74	3.75-4.00	

1	2	3	4	5	6	7
not at all true of me						**very true of me**

#	**STATEMENTS** **Please think of own your design problem while reading these statements**	**YOUR RESPONSES** **1 = not at all true of me** **7 = very true of me**
1	I will be able to think up creative and effective solutions to this design problem.	**1 2 3 4 5 6 7**
2	Before I approach this design problem, I will carefully examine the complexity of the problem.	**1 2 3 4 5 6 7**
3	I will have the ability to solve this design problem even though no solution may be immediately apparent.	**1 2 3 4 5 6 7**
4	I will think of related knowledge that could help me to solve this problem.	**1 2 3 4 5 6 7**
5	I will have the relevant knowledge and problem-solving skills needed to solve this design problem.	**1 2 3 4 5 6 7**
6^{α}	While solving this problem, I may often miss important details because I am thinking of other irrelevant things.	**1 2 3 4 5 6 7**

#	STATEMENTS Please think of own your design problem while reading these statements	YOUR RESPONSES 1 = not at all true of me 7 = very true of me
7	It will be important for me to learn much from this design problem.	1 2 3 4 5 6 7
8	I will ask myself questions to ensure that I understand the context of this problem and have the required knowledge to solve it.	1 2 3 4 5 6 7
9	In the future, I will be happy with the decisions I make in this design problem.	1 2 3 4 5 6 7
10	When I become confused while working on this problem, I will go back and try to resolve my confusion.	1 2 3 4 5 6 7
11	My plans to solve this design problem will work.	1 2 3 4 5 6 7
12	Before I approach this problem, I will try to determine the various components of this problem.	1 2 3 4 5 6 7
13	I will be able to use my prior knowledge to solve this design problem.	1 2 3 4 5 6 7
14	I will try to change the way I approach this problem in order to produce a high-quality solution.	1 2 3 4 5 6 7
15	I will be very interested in solving this design problem.	1 2 3 4 5 6 7
16	I will often question my personal solution to this problem.	1 2 3 4 5 6 7
17	Given enough time and effort, I will be able to solve this design problem.	1 2 3 4 5 6 7
18	While solving this problem, I will often check if the approach I am using is working.	1 2 3 4 5 6 7
19	When faced with an unfamiliar situation, I have confidence that I will be able to handle any problems that arise.	1 2 3 4 5 6 7
20	I will change the way I approach this problem as needed.	1 2 3 4 5 6 7
21	Considering the complexity of the problem and my teacher's expectations of my performance, I am certain that I will be able to solve this design problem.	1 2 3 4 5 6 7
22	I will plan my approach to this problem rather than immediately starting to work on it.	1 2 3 4 5 6 7
23	Being able to successfully solve this problem is very important to me.	1 2 3 4 5 6 7

#	STATEMENTS **Please think of own your design problem while reading these statements**	YOUR RESPONSES **1 = not at all true of me** **7 = very true of me**						
24	I will set goals for myself in order to direct my activities in each problem-solving phase.	1	2	3	4	5	6	7
25	I will trust my ability to solve this design problem.	1	2	3	4	5	6	7
26	Before working on the problem, I will try to determine which parts of this problem I do not fully understand.	1	2	3	4	5	6	7
27	After making a decision, I am confident that my expected outcome will match the actual outcome.	1	2	3	4	5	6	7
28	I will try to determine what problem-related theoretical knowledge and technical skills I do not possess.	1	2	3	4	5	6	7
29	I will be confident when dealing with the unexpected events that will occur during this problem-solving process.	1	2	3	4	5	6	7
30	If I get confused while solving this problem, I will make sure I resolve my confusion afterwards.	1	2	3	4	5	6	7
31	Engaging in this design problem will enhance my problem-solving skills.	1	2	3	4	5	6	7
32	In the future, when confronted with an unexpected problem, I am sure that I will be able to handle the situation.	1	2	3	4	5	6	7
33	Learning new knowledge and skills from solving this problem will be very important to me.	1	2	3	4	5	6	7
34	I will be able to master the skills learned from this design problem.	1	2	3	4	5	6	7

APPENDIX B

ENGINEERING DESIGN PROJECT INVENTORY
(EDPI) – Phase 2

The following statements describe your motivation for, attitudes about, and problem-solving strategies of the design problem **you solved**. Remember, there are no right or wrong responses, just respond to the statements **as accurately as possible.**

Use the scale below to respond to the statements. If you think the statements is **very true of you**, circle 7; if a statement is **not at all true of you**, circle 1. Otherwise, circle the number between 1 and 7 that best describes you.

Please write the last 4-digits of your UIN in the box provided.

Last 4-digit of your UIN:

1	**2**	**3**	**4**	**5**	**6**	**7**
not at all true of me						**very true of me**

#	**STATEMENTS** **Please think of own your design problem while reading these statements**	**YOUR RESPONSES** **1 = not at all true of me** **7 = very true of me**
1	I was able to think up creative and effective solutions to this design problem.	**1 2 3 4 5 6 7**
2	Before I approached the design problem, I carefully examined the complexity of this problem.	**1 2 3 4 5 6 7**
3	I had the ability to solve this design problem even though no solution was immediately apparent.	**1 2 3 4 5 6 7**
4	I thought about related knowledge that helped me to solve this problem.	**1 2 3 4 5 6 7**
5	I am certain that I had the relevant knowledge and problem-solving skills needed to solve this design problem.	**1 2 3 4 5 6 7**
6^{α}	While solving this problem, I often missed important details because I was thinking of other irrelevant things.	**1 2 3 4 5 6 7**
7	It was important for me to learn much from this design problem.	**1 2 3 4 5 6 7**
8	I asked myself questions to ensure that I understood the context of this problem and had the required knowledge to solve it.	**1 2 3 4 5 6 7**

#	STATEMENTS Please think of own your design problem while reading these statements	YOUR RESPONSES 1 = not at all true of me 7 = very true of me
9	In the past, I was happy with the decisions I made in this design problem.	1 2 3 4 5 6 7
10	When I became confused while working on this problem, I went back and tried to resolve my confusion.	1 2 3 4 5 6 7
11	My plans to solve this design problem worked.	1 2 3 4 5 6 7
12	Before I approached this problem, I tried to determine the various components of this problem.	1 2 3 4 5 6 7
13	I was able to use my prior knowledge to solve this design problem.	1 2 3 4 5 6 7
14	I tried to change the way I approached this problem in order to produce a high quality solution.	1 2 3 4 5 6 7
15	I was very interested in solving this design problem.	1 2 3 4 5 6 7
16	I often questioned my personal solution to this problem.	1 2 3 4 5 6 7
17	Given enough time and effort, I was able to solve this design problem.	1 2 3 4 5 6 7
18	While solving this problem, I often checked if the approach I was using was working.	1 2 3 4 5 6 7
19	When faced with an unfamiliar situation, I had confidence that I handled any problems that arose.	1 2 3 4 5 6 7
20	I changed the way I approached this problem as needed.	1 2 3 4 5 6 7
21	Considering the complexity of the problem and my teacher's expectations of my performance, I am certain that I was able to solve this design problem.	1 2 3 4 5 6 7
22	I planned my approach to the problem rather than immediately starting to work on this problem.	1 2 3 4 5 6 7
23	Being able to successfully solve this problem was very important to me.	1 2 3 4 5 6 7
24	I set goals for myself in order to direct my activities in each problem-solving phase.	1 2 3 4 5 6 7
25	I trusted my ability to solve this design problem.	1 2 3 4 5 6 7
26	Before working on the problem, I tried to determine which parts of this problem I did not fully understand.	1 2 3 4 5 6 7
27	After making a decision, I was confident that my expected outcome matched the actual outcome.	1 2 3 4 5 6 7

#	STATEMENTS **Please think of own your design problem while reading these statements**	YOUR RESPONSES **1 = not at all true of me** **7 = very true of me**						
28	I tried to determine what problem-related theoretical knowledge and technical skills I did not possess.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
29	I was confident when dealing with the unexpected events that occurred during the problem-solving process.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
30	If I got confused while solving the problem, I made sure I resolved my confusion afterward.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
31	Engaging in this design problem enhanced my problem-solving skills.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
32	In the past, when confronted with an unexpected problem, I was sure that I could handle the situation.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
33	Learning new knowledge and skills from solving this problem was very important to me.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
34	I was able to master the skills learned from this design problem.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

Please answer the following two questions in as much detail as possible.

1. From the time you were preparing the proposal to the time you are completing the project, have *your feeling about your ability* to solve the design project changed? Yes No (circle one)
   Please explain in what way, how and why they have (or have not) changed.

2. From the time you were preparing the proposal to the time you are completing the project, have *your strategies to solve the design project* changed? Yes No (circle one)
   Please explain in what way, how and why they have (or have not) changed.

>>>Thank you so much for your participation in this study<<<

APPENDIX C

RUBRIC FOR RATING STUDENTS' DESIGN PROJECT

RUBRIC FOR RATING STUDENTS' DESIGN PROJECT

Last 4-digit of students' UINs

Please rate your students' design project using Jonassen's (2004) variable attributes of problems.

Variable Attributes of Problems (according to Jonassen, 2004)	Indicators	Your Rating Please circle the number that you think is appropriate to indicate the level of difficulty of the problem that the above students are working on.
Ill-structuredness Ill-structured problems often possess aspects that are unknown (Wood, 1983) and they possess multiple solutions or solution methods (Kitchner, 1983).	The number of unknown aspects or problem-elements in the design problem is	few many 1 2 3 4
	The number of methods or approaches that may be used to solve the design problem is	few many 1 2 3 4
	The number of potential solutions for the design problem is	few many 1 2 3 4

Variable Attributes of Problems (according to Jonassen, 2004)	Indicators	Your Rating Please circle the number that you think is appropriate to indicate the level of difficulty of the problem that the above students are working on.
Complexity Problem complexity is determined by the number of issues, functions, or variables involved in the problem, the degree of connectivity among those variables, and the stability among the properties of the problem over time (Funke, 1991).	The number of issues, functions, or variables involved in the problem is	few ... many 1 2 3 4
	The level of uncertainty about which concepts, rules, and principles that are necessary to solve the design problem is	low ... high 1 2 3 4
Dynamicity Problems vary in their stability or dynamicity. While the task environment and its factors change over time, the solver must continuously adapt his or her understanding of the problem and search for new solutions.	The likeliness of needing continuous adaptability for understanding of the problem and searching for new solutions is	unlikely ... likely 1 2 3 4
	TOTAL RATING	... / 24

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Oenardi Lawanto was born in Surabaya, Indonesia on July 20, 1961. He graduated from Iowa State University in 1986 with a Bachelor of Science degree in Electrical Engineering (BSEE). He earned a Master of Science in Electrical Engineering (MSEE) degree from the University of Dayton in 1988. After completing his bachelor's and master's degrees, Oenardi taught at the University of Surabaya in Indonesia. During his service at the University of Surabaya, he was elected as the chair of the department of Electrical Engineering for two terms. Besides his interest in electrical engineering, he has been involved in efforts to develop a student-centered learning environment through several activities, including researches, workshops, and seminars. He is an alumnus of several workshops jointly organized by the World Bank Institute (WBI), University of Illinois at Urbana-Champaign, USA, the Asian Institute of Technology (AIT), Thailand, and Singapore Polytechnic. While working on his doctoral study, he worked as a development and teaching assistant at the Human Resource Education (HRE) Online programs at the University of Illinois at Urbana Champaign.