The Pennsylvania State University

The Graduate School

College of Education

LEARNING ON THE JOB: COOPERATIVE EDUCATION, INTERNSHIPS AND ENGERINEERING PROBLEM-SOLVING SKILLS

A Dissertation in

Higher Education

by

Alexander C. Yin

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

Doctor of Philosophy

December 2009

The dissertation of Alexander C. Yin was reviewed and approved* by the following:

Lisa R. Lattuca
Associate Professor of Higher Education
Dissertation Adviser
Chair of Committee

J. Fredericks Volkwein
Professor of Higher Education

Peggy Van Meter
Associate Professor of Educational Psychology

Aleksandra B. Slavković
Assistant Professor of Statistics

Dorothy H. Evensen
Professor of Higher Education
Professor-in-Charge of the Higher Education Program

*Signatures are on file in the Graduate School

ABSTRACT

Cooperative education (co-op) and internships are forms of experiential education that allow students to complement their classroom experiences with work experience. This study examines the influence of co-op and internships on engineering problem-solving skills by answering the following research questions: 1) Does experience in cooperative education or internship programs influence students' self-perceptions of their engineering problem-solving skills? 2) How do students with cooperative education or internship experience differ in their perception and understanding of their engineering problem-solving skills as compared to students with no experience?

The design of this study included a quantitative and a qualitative component. I conducted a quantitative analysis to answer the first research question utilizing multivariate regression and multi-nominal logit models to examine whether significant differences existed between students with engineering work experience and students with no engineering work experience with regard to assessments of their 1) basic skills, 2) design and problem-solving skills, and 3) engineering thinking skills. The key variables came from a set of three scales and their respective items from the nationally representative *Engineering Change* (EC2000) dataset, which contains survey responses from 4,461 senior engineering students from the class of 2004 in seven engineering disciplines (aerospace, chemical, computer, electrical, industrial, and mechanical) from 39 accredited institutions.

The second research question was addressed through qualitative data collection and analysis. I interviewed three groups of senior electrical engineering students at a single research I university: 1) students who completed three rotations in the co-op program, 2) students who completed at least one internship, and 3) students who completed neither co-op nor internship. In

total, I interviewed 17 undergraduate engineering students, including 1) four students who completed at least three cooperative education rotations, 2) eight students who completed at least one internship, and 3) five students who completed neither cooperative education nor internship.

The quantitative analysis indicates that students who spent more time in a cooperative education or internship program rate their understanding of engineering problem-solving more highly than those who have not participated in such programs. The more time spent in these work-related experiences, the more highly students rated their understanding of essential aspects of the engineering design process, and their abilities to apply systematic design procedure to open-ended problem; design solutions to meet desired needs; ensure that a process or product meets a variety of technical and practical criteria; and compare and judge alternative outcomes.

The qualitative analysis suggested that students' classroom and work (co-op and internship) experiences differentially influenced three types of knowledge: theoretical, practical, and procedural knowledge. “Theoretical knowledge” refers to the theories, laws and principles of the field. The majority of the students reported that classroom experiences in solving textbook problems helped them develop this type of knowledge. Students with work experience described how their work assignments often required them to consider contextual factors as well as technical ones when solving problems on the job. This kind of “practical knowledge” encouraged students to address a variety of relevant factors when solving problems. They contended that these contextual factors were not always prominent in classroom assignments or homework problems. Finally, “procedural knowledge” can be defined as knowledge of how to solve problems. When comparing the groups, students with co-op and internship experiences were more likely to understand the importance of problem-solving processes (such as defining the problem or applying systematic procedures) than students without work experience.

The findings from both the qualitative and quantitative components of the study are consistent. The quantitative analysis showed that time spent in a co-op or internship was significant for the majority of survey items related to procedural knowledge but not significant for items related to theoretical knowledge. This aligns with the findings from the interviews. Co-op and internship students reported that their work experience taught them that in order to succeed on the job, they needed to develop both procedural knowledge and theoretical knowledge. Procedural knowledge gained through engagement in engineering practice at a co-op or internship increased students' confidence in their problem-solving ability.

Understanding how cooperative education and internship program influences students' perception of their engineering problem-solving skills has practical implications. For curricular designers, knowing how individuals perceive their different types of knowledge necessary to solve problems allows for a more intentional design of curricular and co-curricular activities to develop students' competency within an academic domain. I recommend curricular designers focus on strengthening and enhancing students' theoretical knowledge, practical knowledge, procedural knowledge through classroom activities such as writing assignments that ask students to explain their problem-solving process. Program-level recommendations include incorporating more project-based or lab-like courses into the curriculum, so students have more opportunities to actively engage in solving real-world problems. Future research should examine the long-term effects of co-op and internship programs on students' perception of engineering problem-solving skills once they have graduated and worked in the profession.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1:

INTRODUCTION

Business leaders and policy makers in the United States are concerned that the country is losing its global advantage in the technological industries. Student enrollments and the number of graduates in science, technology, engineering, and mathematics (STEM) fields collectively have shown little growth and have even declined in the past ten years (Committee on Science, Engineering and Public Policy, 2007). This has resulted in a shortage of qualified STEM workers for industry. To address this pipeline issue, Congress created the National Science and Mathematics Access to Retain Talent Act (SMART), which provides grants to students seeking a bachelor's degree in one of the STEM fields. Increasing the pipeline will be fruitless, however, if the graduates are unprepared for Friedman's (2006) "flat world," in which globalization and technology have leveled the playing fields for all countries to compete economically and industrially.

The National Academy of Engineering (NAE, 2004, 2005) is concerned with both the pipeline of engineering students and the characteristics needed by the successful engineer of the future. According to the NAE (2004) report, *The Engineer of 2020: Visions of Engineering in the New Century*, these characteristics include strong analytical skills; practical ingenuity; creativity; communication skills; principles of business and management; leadership; high ethical standards; professionalism; dynamism; agility; resilience; flexibility; and life-long learning. The report illustrates the engineering community's commitment not only to increase the number of engineering graduates, but also to graduate competent engineers who will succeed in the global economy of 2020. The urgency to prepare the *Engineer of 2020* has been a community effort as the Accreditation Board for Engineering and Technology (ABET) has shifted its accreditation criterion from institutional resources (e.g., faculty credentials and library size) to student learning outcomes (Lattuca, Terenzini, & Volkwein, 2006). Many of the *Engineer of 2020* skills align with ABET's criteria for student learning outcomes (Table 1) (ABET, 2007).

Table 1: Characteristics Needed by the Successful Engineer

Attributes of the Engineer of 2020 (NAE, 2004)	**ABET (2007, p.2) Crierion 3. Program Outcomes and Assessment**
• Strong analytical skills	• an ability to apply knowledge of mathematics science, and engineering
• Principles of business and management	• an ability to design and conduct experiments, as well as to analyze and interpret data
• Leadership	• an ability to design a system, component, or process to meet desired needs
• Practical ingenuity	• an ability to function on multi-disciplinary teams
• High ethical standards	• an ability to identify, formulate, and solve engineering problems
• Professionalism	• an understanding of professional and ethical responsibility
• Communication skills	• an ability to communicate effectively
• Creativity	• the broad education necessary to understand the impact of engineering solutions in a global and societal context
• Life-long learning	• a recognition of the need for, and an ability to engage in life-long learning
	• a knowledge of contemporary issues
	• an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Cooperative Education

The emphasis on technical knowledge and professional skills such as teamwork and communication in the *Engineer of 2020* learning outcomes and ABET criteria suggest that learning experiences which stress these kinds of activities will be more effective for developing the necessary engineering workforce. Cooperative education (co-op) or internship programs provide off-campus work experiences that engage students in solving authentic engineering problems that elucidate textbook problems seen in the classroom. For example, if a textbook chapter focuses on electromagnetic fields, the problem sets from that chapter will deal with this topic (and not some other engineering topic such as optics). The problem's scope (i.e., the issue is related to electromagnetic fields) is defined for the student. Thus, in working textbook problems, students may not develop the flexibility in problem identification to solve real-world problems. On the other hand, co-op students and interns assigned to a real-world task, such as designing a new computer hardware component, must learn to identify the most salient issues related to circuit devices, design, cost, and hardware compatibility in order to complete the assignment. Working on authentic tasks from industry may help students develop the flexibility and confidence to solve engineering problems.

Purpose

The objective of this study is to answer the following two questions: 1) Does experience in cooperative education or internship program influences students' self-perceptions of their engineering problem-solving skills? 2) How do students with cooperative education or internship experience differ in their perceptions and understanding of their engineering problem-solving skills as compared to students with no experience?

Hypothesis

I hypothesize that, on average, students who have participated in a cooperative education or internship program will perceive their problem-solving skills to be better than those who have no cooperative education or internship experience. A possible explanation for this improvement is that students become more interested and develop advanced strategic processes within their engineering discipline by participating in “authentic” projects (i.e., assignments with real consequences) during their cooperative education rotation or internship.

History of Cooperative Education

In 1906, Herman Schneider, an engineering faculty member at the University of Cincinnati, developed the first cooperative education program. He felt the training for engineering students was incomplete without them gaining any practical experience (Cooperative Education & Internship Association, 2003). Schneider believed that students working in industry could gain "experience" in applying the knowledge learned in the classroom (Smollins, 1999). Today, students from many different fields of study enroll in a co-op or internship program to gain experience in their field of study. Cooperative education is a form of experiential learning that provides students with opportunities to combine their academic education with practical experience (Kerka, 1999). The National Commission on Cooperative Education (NCCE, 2002) defines cooperative education as:

> A structured educational strategy integrating classroom studies with learning through productive work experiences in a field related to a student's academic or career goals. It provides progressive experiences in integrating theory and practice. (¶ 2)

ABET's Baccalaureate Model for engineering cooperative education programs requires a formalized employer role and an alternating pattern between work and academic experiences with students gaining at least one year of experience (NCCE, 2002). The typical engineering co-op model entails a student alternating semesters between classes and working full-time (40 hours a week) at a company.

The primary purpose of internships and cooperative education is to provide students with industry experience that allows them to apply engineering fundamentals taught in the classroom. Students in internships are only committed to a company for a single semester or a set period (e.g., summer internships), as opposed to co-op students who work at least three semesters. Thus, internship students may work at a single company for a single semester or summer. In contrast, co-op students have the option to work at the same company or at multiple companies over three semesters. For this reason, co-op programs may influence students' outcomes more than internships programs, particularly if a student only completes a single internship. Many co-op students earn academic credit or a certificate of completion for their participation in the program, because the work experience relates to their field of study (i.e., an electrical engineering student co-op at Hewitt Packard). Internship students, however, can decide whether or not they want to receive academic credit for interning at a company. This type of flexibility allows students to work at companies that may not be related to their field of study (e.g., English majors interning at Xerox).

For the first phase of this study, cooperative education programs will include internships, because internship experiences have the same objectives as cooperative education programs. The goal of the second phase of this study, however, is to understand the differences between the two experiential education programs.

Research on Cooperative Education

Engineering programs have often advised and encouraged students to participate in cooperative education programs because of the anticipated academic, professional, and personal outcomes (NCCE, 2002) (see Table 2).

Research on the benefits of engineering students' participation in a co-op suggests that co-op students have more job interviews (Schuurman, Pangborn & McClintic, 2007), higher starting salaries (Blair & Millea, 2004; Blair, Millea, & Hammer, 2004; Friel, 1995; Schuurman, Pangborn & McClintic, 2007) and higher grade point averages (Blair & Millea, 2004; Blair, Millea, & Hammer, 2004) compared to students who do not participate in these programs. Friel (1995) surveyed 691 cooperative education directors who reported that co-op students are perceived to be more professional, more skilled problem solvers, better able to manage projects, and more technically knowledgeable than students without cooperative education experience. Pierrakos, Borrego, and Lo (2008) discovered that co-op students perceive their co-op experiences as helpful in aiding their development of problem-solving skills.

Table 2: Anticipated Students Outcomes from Participating in a Cooperative Education Experience*

Academic Outcomes	• Ability to integrate classroom theory with workplace practice • Clarity about academic goals • Academic motivation • Technical knowledge through use of state-of-the-art-equipment
Professional	• Clarity about career goals • Understanding of workplace culture • Workplace competencies • New or advanced skills • Career management • Professional network • After-graduation employment opportunities
Personal	• Maturity • Determination of strengths and weaknesses • Development/enhancement of interpersonal skills • Financial earnings • Responsibilities • Productive and responsible citizenship • Lifelong learning skills

* Source: National Commission on Cooperative Education (2002)

Justification for the Study

A major limitation of both the Friel (1995) and Schuurman et al. (2005) analyses is the lack of statistical control for student academic ability, which potentially confounds the effects of student ability and cooperative education participation. Additionally, much of the research on cooperative education is descriptive, summarizing the effects of co-ops on student learning outcomes. For example, the percentage of employers who say cooperative education students have higher problem-solving ability than students who do not participate in a co-op. This type of analysis provides evidence that suggests co-op students' problem-solving skills improve, but provides little to no understanding of how this skill is developed in the co-op work setting. Consider the complexity of a skill like problem-solving in engineering, which includes elements such as applying knowledge of mathematics and physical sciences, applying discipline-specific engineering knowledge, understanding essential aspects of the engineering design process, applying systematic design procedures to open-ended problems, designing solutions to meet desired needs, defining key engineering problems and formulating a range of solutions to an engineering problem (Donald, 2002). Existing studies of cooperative education have not examined aspects of problem-solving that are enhanced by the experience. This study will fill that gap.

Work experience may allow engineering majors to understand better science fundamentals and the important assumptions underlying the equations they use. The experience gained may provide the context needed for students to understand and apply engineering equations, possibly making them competent problem solvers. For example, a student may not begin to understand the importance of power until he designs a chip that overheats and melts a circuit board. The lesson learned from not accounting for power might help this student become a better chip designer in the future. Exploring cooperative education and internship programs for engineers may provide insights as to how experiential learning programs may affect and develop student-learning outcomes. Specifically, this study will examine how work experience gained through cooperative education or internship influences students' perception of their engineering problem-solving skills.

Understanding how co-op might influence students' perception of key engineering skills could benefit other professional disciplines that combine academic and practical experience at the undergraduate level (e.g., education and nursing). Nursing, social work, and education programs typically require students to participate in some form of experiential learning through a supervised practicum. Majors in other applied fields, such as business, also encourage student internships. Benner’s (2004) study of nurses and Berliner’s (1991) study of teachers illustrate how practical experiences influence professional development. Both studies found that the professionals were not experts within their respective fields until they gained work experience.

CHAPTER 2:

REVIEW OF THE LITERATURE

From designing a bridge, to creating new processing chip, to maximizing the efficiency of a car engine, problem-solving is an important engineering skill. A meta-analysis of twelve studies indicated that the vast majority of engineering graduates perceive problem-solving as a key learning outcome and necessary for proficiency in the field of engineering (Passow, 2007). This is consistent with the emphasis of the new accreditation criteria of the Accreditation Board of Engineering and Technology (ABET), which requires programs to demonstrate their ability to graduate students who are capable of identifying, formulating, and solving engineering problems (ABET, 2007). Without problem-solving skills, a student will not succeed in the engineering profession. This dissertation focuses on engineering problem-solving skills, which although taught through coursework, may be enhanced by participating in co-curricular activities, in particular internships and cooperative education experiences.

In this literature review, I first define problem-solving. The first section of this review defines engineering and examines the connection between it and problem-solving. I then explore theories and research in the development of expertise and on the influence of experiential education to develop my hypotheses about how internship and cooperative education, as types of experimental education might influence students' perception of their expertise in problem-solving. The second section examines the literature on expert-novice theories to conceptualize the attributes of an expert problem solver. An institution’s goal is to develop a student’s problem-solving skills to a competency level that will prepare him or her for the engineering profession. However, few stakeholders expect colleges and universities to graduate students at expert levels in their fields of study. A more reasonable goal is to develop students who are proficient in problem-solving (i.e., not a novice) and on the trajectory to becoming experts.

Alexander's (1997, 2003) Model of Domain Learning (MDL) explains the progression towards expertise in an academic domain. The MDL explains how an individual's interests, knowledge, and strategic processes changes as he or she progress towards expertise in a particular domain of knowledge, such as engineering. The MDL, however, offers few hypothesis on what affects and motivates these changes. Hence, the third section of this literature review explores experiential education, such as cooperative education and internships, as possible mechanisms for moving learners towards expertise.

Finally, I propose a conceptual model to explain how participation in a cooperative education program develops engineering problem-solving skills. The final section of this chapter presents a conceptual framework that synthesizes insights from the Model of Domain Learning and experiential education to posit an explanation of why and how cooperative education influences the development of engineering students' problem-solving skills. The conceptual framework hypothesizes that the experience gained through cooperative education provides meaningful opportunities for change in their interests, knowledge, and strategic processes, thus influencing the development of their problem-solving skills.

Engineering and Problem-solving

A main objective of the engineering curriculum is to enable students to learn mathematics, physical science, and discipline-specific engineering in order for them to apply their knowledge to solve problems. The United States Department of Labor's (2008) *Occupational Outlook Handbook* describes engineers as "apply[ing] the principles of science and mathematics to develop economical solutions to technical problems." Although engineering draws on the theories and concepts of a number of science fields, it differs from the sciences (e.g., biology, chemistry, physics), which are mainly concerned with theory creation or explanation of natural phenomenon (Donald, 2002). Engineering then is the application of science and mathematics to solve problems.

Defining Problem and the Different Types of Problems

In our daily routine, we encounter a variety of problems on a regular basis. These problems can range from balancing a checkbook to deciding the quickest route home. Chi and Glaser (1985) define a problem as “a situation in which you are trying to reach some goal, and must find a means for getting there (p. 229).” In engineering programs, students may encounter various types of problems, from well-defined to ill-defined, in their courses. A well-defined, well-structured, or closed problem is when the “given state, goal state, and allowable operators are clearly specified (Mayer & Wittorck, 2006, p. 288).” For example, a student using Ohm's Law (voltage is equal to current times resistance, V=IR) to calculate the voltage when current and resistance is known. The given state in this example is the current and resistor values; the goal state is to calculate voltage; and the allowable operator is Ohm’s Law. A well-defined problem will have a single correct solution. An ill-defined, ill-structured, or open problem differs from a well-defined problem in that the “given state, goal state, and/or allowable operators are not clearly specified (Mayer & Wittorck, 2006, p. 288).” Engineers will most likely encounter ill-defined problems in their profession (Heywood, 2005; Jonassen, Strobel, & Lee, 2006). Ill-defined problems rarely have a single correct solution.

Problem-solving Definition and Problem-solving Process

Mayer and Wittrock (2006) define problem-solving as “the cognitive process directed at achieving a goal when no solution is obvious to the problem solver (p. 287).” This definition suggests that problem-solving has four characteristics. Problem-solving is 1) cognitive (i.e., it is an internal process that occurs in the person's mind), 2) process-oriented (the manipulation of knowledge), 3) goal-directed (i.e., the process is guided by the person's goals), and 4) personal (dependent on the person's skills and knowledge). According to Donald (2002), the problem-solving process in engineering involves the following thinking skills:

a) Breaking down complex problems to simpler ones
b) Appling fundamentals to new problems
c) Identifying critical variables, information, and/or relationships involved in a problem
d) Knowing when to use a formula, algorithm, or other rule
e) Recognizing and understanding organizing principles (laws, methods, rules, etc.) that underlie problems
f) Developing a course of action based on the understanding of a whole system
g) Drawing conclusions from evidence or premises
h) Ensuring that a process or product meets a variety of technical and practical criteria
i) Comparing and judging alternative outcomes

For students to succeed in the engineering profession, they will need to develop their problem-solving ability to a proficient level before graduation.

If we apply Mayer and Wittrock's (2006) definition of problem-solving to Donald's (2002) engineering problem-solving process, we would expect an engineer to break a complex problem, such as how to design and build a bridge (thinking skills a, above) down into sub-goals and identify the critical variables, information, or relationships involved in the problem (c). This cognitive process of simplifying the problem occurs within a person's mind. An engineer will address the situation by applying her knowledge in mathematics, physical sciences, and structural engineering (b) to formulate a range of solutions that will meet the desired needs and safety specifications for the bridge (f and h). In other words, the manipulation of information is goal-directed. The ease of this process is dependent on the engineer's level of expertise in content knowledge (declarative knowledge) and procedural knowledge (i.e., she knows when to use a particular algorithm, formula or process) (d and e). Evaluation of the process and judgments of alternative outcomes (i) may be influenced by the engineer's personal skills and bias on whether the project is a success or not (i.e., maybe the bridge met the functional specifications but failed from an aesthetic perspective).

There are distinctive differences between novices and experts in problem-solving (Chi, Feltovich & Glaser, 1981). For example, Altman, Adams, Cardella, Turns, Mosborg, and Saleem (2007) found that advanced engineers approached problem scoping (i.e., identifying variables, information, and/or relationships involved in a problem) differently from engineering students. These differences between groups may be attributed to the advanced engineers' knowledge. To understand the development of problem-solving skills, the following section examines expertise theories and the characteristic differences (e.g., interest, knowledge, and strategies) between novices and experts.

Perspectives on the Nature of Expertise

Most early research on expert-novice theory explains differences between novice and expert problem solvers. Compared to novices, experts possess more declarative knowledge, have a more logical organization in the hierarchal structure of knowledge, spend more time planning and analyzing, recognize problem formats more easily, focus on problems at the conceptual level as opposed to surface details, monitor their performance on problems more often, and have a better understanding of strategy use (Chi, Glaser & Farr, 1988). These differences suggest advanced engineers are better problem solvers because their knowledge structures are not only more complete, but organized into more meaningful patterns than those of beginning engineering students. For example, a student may approach an assignment using methods based on his experience solving problems with similar mechanical features, i.e., he is solving the problem using methods based on surface features. An experienced engineer may approach the problem by recognizing common theoretical properties (i.e., Newton's Laws) and then she may use problems with similar mechanical features to solve the problem. Thus, experts' subject-matter knowledge has more breadth and depth in a domain than a novice (Alexander, 1997). Understanding the problem at the conceptual level allows the expert to solve the problem with more effective and efficient strategies, such as using the correct formula rather than employing a trial and error method.

Existing expert-novice studies often examine an individual's abilities to solve well-defined physics and mathematics problems, that is, to solve problems that have only one "right" solution (see Chi, Feltovich & Glaser, 1981 and Hardiman, Dufresne & Mestre, 1989 as examples). Although asking students to solve what are known as "closed form" problems may help build fundamental knowledge and skills, they are not the types of problems engineers face in industry, which are more likely to be ill-structured and open to multiple solutions (Jonassen, Strobel, & Lee, 2006). In addition, studies that compare expert-novice behaviors provide descriptions of the differences between novices and experts, but do not explain how learners progress toward expertise in a domain.

Dreyfus and Dreyfus's Five-Stage Model of the Acquisition of Expertise

One model that attempts to explain the progression of novice to expert is Dreyfus and Dreyfus' (2005) Five-Stage Model of the Acquisition of Expertise, which proposes that expertise in a skill is gained through experience. The main objective of the Dreyfus model is to explain why experts respond to problems in an intuitive fashion, in other words, why they cannot explain the rationale for their actions. The model has been applied to nursing (Benner, 1982; Benner, 2004), adjustment to a business workplace setting (Houldsworth, O'Brien, Butler & Edwards, 1997) and teacher education (Berliner, 1991). The five stages of this model (novice, advanced beginner, competent, proficient, and expert) are described in Table 3. Through experience, this model suggests, learners both improve their pattern recognition of problems within the field, and become more invested in acquiring the skill. The learner organizes knowledge based on her experience through practice (e.g., working in the profession), which in turn improves problem identification. As the learner progresses towards expertise she reacts instinctively when faced with a problem, as opposed to spending time in addressing the issue. The experience gained also influences the learner's interest in acquiring the skill and her development towards expertise.

Table 3: Dreyfus and Dreyfus' Five-Stage Model of the Acquisition of Expertise

Levels of Proficiency	Description
Novice	Use rules to govern actions.
Advanced Beginner	Begins to understand when to apply rules given the situation
Competent	To handle the mass amount of information and rules, leaner begins to devise plans or choose a perspective to address or ignore elements of the task. Person also becomes more emotionally involved with the task and takes responsibility for his/her actions.
Proficient	Person is able to identify the problem immediately, but must make a decision on how to respond to the situation.
Expert	An expert not only identifies the problem immediately, but also responds to the situation instinctually, i.e., does not have to decide consciously what procedures to solve the given task.

One advantage of the Dreyfus and Dreyfus model is that it provides observable descriptions of learners as they progress through the stages toward expertise. Dreyfus and Dreyfus (2005) suggest that their model can be applied to a professional curriculum like medicine, as Benner (1982; 2004) has done in her studies of nurses.

In Table 4, I suggest how Dreyfus and Dreyfus' model may be applied to the development of expertise in engineering problem-solving skills. In the first stage – novice – an electrical engineering student begins to learn the fundamental knowledge of the profession in his introductory engineering courses. For example, in the intro class, the student learns Ohm's Law (voltage equals current times resistance) for circuit analysis through lectures and completing problem sets on the topic. These problem sets usually deal with ideal situations (e.g., the student does not need to account for non-ideal resistors) where a single solution exists. Since some students do not have experience in building circuits, the course instructor may not require students to account for non-ideal resistors (i.e., account for tolerances) in their analysis. The student may progress towards the second stage – advanced beginner – after building a circuit in his electrical engineering lab, where they learn to account for non-ideal resistors when utilizing Ohm's Law. Students at the advanced beginner level may not understand the practical implications of Ohm's Law. Understanding, for example that the circuit's voltage output is important for a system's power analysis, until they gain experience in the field (the progression towards the competent stage). Our student becomes proficient (fourth stage) when he begins to understand how his circuit design is relevant in the greater context of the project. Thus, he understands not only the practical implications of Ohm's Law relevant to his project's component, but also the implications of his design on other components. For example, a proficient electrical engineer understands the need to sacrifice power because the product's structure cannot handle the heat generated from the source. According to Dreyfus and Dreyfus, a student does not reach expertise until such design decisions become instinctive.

Table 4: Dreyfus and Dreyfus' Model Applied to Engineering Education

Levels of Proficiency	Description
Novice	In classroom, doing problem sets, but focus on surface issues (i.e., this is a spring or an incline plane problem).
Advanced Beginner	Combines knowledge learned from textbook problems and lab experience to understand problems better from a practical perspective (i.e., account for non-ideal resistors).
Competent	Begins to understand why these concepts are important for the long-term goals of engineering projects.
Proficient	Begins to see problem in the larger context and understands their component is only part of the larger project.
Expert	Examines problems at the concept level (Newton's 2nd law of conservation) and relies on experience for solutions.

Although, this model effectively explains how novices and experts respond to a situation, suggesting that a person progresses to a new stage of proficiency by gaining experience through practice, it explains neither how this occurs nor the types of experiences that may influence an individual's development towards expertise in a skill. Dreyfus and Dreyfus' model, however, suggests the importance of gaining experience - one of the objectives of cooperative education (Table 2) - in the development of expertise in a skill.

Still, the Dreyfus and Dreyfus model does not offer an explicit explanation or an in-depth description of the amount and type of knowledge or skill a person must have to reach each level of proficiency. Alexander's (2003) Model of Domain Learning, in contrast, not only examines how a person's knowledge changes as he progresses toward expertise, but also provides insights on changes in that person's interest and strategic processing. Understanding these other dimensions may offer explanations on how engineering students may progress towards expertise in problem-solving.

Alexander's Model of Domain Learning

Dreyfus and Dreyfus' (2005) Five-stage Model of the Acquisition of Expertise and Alexander's Model of Domain Learning (MDL) differ from traditional expert-novice theories in that they examine the development of expertise as opposed to examining common characteristics of experts (Alexander, 2003). The scope of Alexander's model, however, is focused on expertise developed within an academic domain. Traditional expert-novice theories and Dreyfus and Dreyfus's (2005) model can be applied to nonacademic domains (e.g., chess, driving a car). The motivation behind Alexander's MDL, which is purposefully limited to academic domains, is to improve student learning and development, as opposed to goals of traditional expert-novice theories, which program novices to mimic expert performances (Alexander, 2003). MDL incorporates many of the cognitive characteristics (such as knowledge and strategic processing) of the traditional novice-expert theory, but it also includes an affective component, such as a learner's motivation to progress towards expertise within the domain. Thus, MDL proposes three elements that characterize students' level of proficiency: Subject-matter knowledge, Interest, and Strategic Processing (Alexander, 1997; Alexander, 2003).

Subject-matter knowledge. In the MDL, subject-matter knowledge is separated into two categories: breadth knowledge and topic knowledge (Alexander, 1997; Alexander, 2003). Breadth refers to the person's declarative, procedural, and conditional knowledge of the field, while topic knowledge refers to the person's depth of knowledge in a specific area within the field. For example, an electrical engineer specializing in systems and controls is expected to understand the basic concepts of all the different subfields of electrical engineering such as electromagnetism, circuits, signal processing, and so on (breadth), but may be more knowledgeable about classical controls theory, a specific concept within systems and controls (depth).

Interest. Interest influences learning by affecting a person's attention, goals, and levels of learning (see for example, Hidi & Renninger, 2006). In MDL, interest may be either situational or personal (Alexander, 1997; Alexander, 2003). Situational interest refers to temporary stimulation aroused by the learner's environment (Hidi, 1990). For example, people may show interest in engineering because they received good grades in mathematics and science during high school. In contrast, personal interest or individual interest is "the investment one has in a particular domain or some facet thereof" (Alexander, 2003, p. 11). In contrast, a student who majors in civil engineering with the goal of using the degree to improve water and sanitation conditions in a developing nation exhibits personal interest. Situational and personal interests are not mutually exclusive, but rather are orthogonal; a person may have a personal and a situational interest of the subject at the same time (Hidi, 1990). For example, a co-op student who must complete a given task because of external influences (the boss wants the job completed by noon on Friday) may also want to complete the task because it challenges her to apply what she learned in the classroom, and is thus perceived to contribute to her overall development as an engineer.

Strategic Processing. Strategic processing procedures used to learn, transform, or transfer information link the other two components of MDL as they are purposefully invoked by the learner to gain knowledge (Alexander, 1997; Alexander, Graham, & Harris, 1998). For instance, students who are interested in building bridges are more likely to apply strategies to learn and understand the engineering concepts (such as conservation of forces) behind its construction. Early expert-novice theory postulated that one difference between novices and experts is that experts are more likely to apply deeper-level processes (e.g., understanding concepts) as opposed to surface-level processes (e.g., memorizing of problem features). For example, if a novice statistician receives a project to examine what treatment is best at producing a high crop yield, she may first attempt to examine problems based on other crop yield projects (surface-level process), which may not yield the appropriate analysis. A more advanced statistician, however, may immediately notice that the problem is a split-block design (a deeper-level process), which is similar to an analysis she may have done to examine which pedagogy is best at improving student learning. Thus, the difference in how a learner defines a problem will influence her choice of a strategic process to solve it.

Cooperative education provides an opportunity to evaluate students' strategic processing by examining their ability to transfer knowledge from one context to another. Gick and Holyoak define transfer as "a phenomenon change in the performance of a task as a result of the prior performance of a different task" (as cited in Billing 2007, p. 496). During students' cooperative rotations, they are often asked to apply engineering fundamentals (most likely learned in courses) to problems they have never seen before. Students will need to recognize the underlying laws, concepts, and methods to solve these engineering problems successfully. If the students are able to solve their work assignment successfully, they may have exhibited evidence of high road transfer, which Salomon and Perkins' (1989) define as "intentional mindful abstraction of something from one context and application in a new context (p.113)." If they apply abstract concepts learned in the classroom to work assignments, this may suggest that co-op students are using a deep-level strategic process. On the other hand, the students may have used a trial and error method to complete the assignment, i.e., they were able to solve the problem because it had similar surface features as a problem they saw in class. In either case, cooperative education provides opportunities to assess the students' strategic processes in solving a problem and understand whether student transit from surface-level to deeper-level strategies through the experience gained.

The transition from surface-level to deeper-level strategies, though, may not only be unidirectional. The classroom experience may not simply influence the student's co-op work experience, but the work experience may influence the student's classroom experience, too. This is likely to occur in co-op programs that alternate course work and work experiences over several terms or years of the undergraduate program. For example, a student completing a co-op at a company such General Motors (GM) may better abstract concepts about observers and controllers (Control Theory) after finishing her work assignment in designing brake sensors. Her work experiences provide a context that may help her comprehend these theories. Case in point: she may not comprehend why GM designs brake sensors in a certain fashion since she lacked knowledge in designing an observer/controller for a nonlinear system. When the controls class begins the unit on Lyapunov stability theory, which is applicable to nonlinear systems, she may better abstract the concepts because she can connect the theory to her experience of designing brake sensors. Having practical experience may provide contexts that allow students to develop strategies to understand the concepts taught by her professor. Thus, co-op experiences may allow students to apply the theoretical fundamentals learned in the classroom and thus improve their understanding of key concepts. The opportunities to develop high road transfer then are not only applicable from the classroom to co-op experiences, but vice versa.

Another strategic process that may be affected by cooperative education is self-regulation. These strategies involve the regulation of a person's own cognitive, motivation, behavior, and social environment (Alexander, Graham, & Harris, 1998). Studies in mathematics (Perels, Gürtler, Schmitz, 2005) and science education (Schraw, Crippen, & Harley, 2006) at the elementary level provide evidence that teaching self-regulation strategies can improve students' problem-solving skills. As they complete their work assignments, co-op students may become aware of their limitations on their own abilities and knowledge. Tasks that are difficult to complete suggest declarative and/or procedural knowledge deficiencies in a subject area. To address these weaknesses, students can respond either by learning the material (e.g., taking courses, asking a mentor) or switch to a field within the domain in which they are more interested. Both would be evidence of self-regulation strategies. At the postsecondary level, cooperative education may create an environment or situation in which students learn self-regulation strategies.

Levels of MDL. Similar to the Dreyfus and Dreyfus stage model of expertise, MDL is a stage model, but it differs from Dreyfus and Dreyfus's model by postulating three levels of proficiency: Acclimation, Competence, and Proficiency/Expertise. The MDL model is an improvement over the Dreyfus and Dreyfus model because it conceptualizes the learner's characteristic differences between the levels of proficiency more broadly. Whereas, Dreyfus and Dreyfus view individual's change as exclusively cognitive, the MDL hypothesis that individuals developing expertise in a given domain will show changes in their knowledge, interest, and strategic processing (Alexander, 1997; Alexander, 2003).

In the acclimation stage, a learner may be familiar with a certain topic within a domain but does not understand how the topic fits in the context of the field. The student may also be learning the domain because of situational interest (i.e., required course) as opposed to learning for personal interest. Since the learner is becoming acclimated to the field she may use surface-level features to learn and solve problems, reflecting her lack of knowledge of the domain's fundamentals. The student progresses towards competency from acclimation when she begins to develop knowledge breadth in the field. As her knowledge becomes more organized and she develops deeper-level strategies, she may begin to learn and solve problems more easily. Her interest in learning also becomes less situational and more personal. An expert in the domain is someone with a highly organized knowledge, where she can evaluate and discover new knowledge. This person is highly motivated to search for new problems in the field. Table 5 shows how the components change as a person progresses through the different levels of expertise. Analyses of people at various levels of expertise has shown these stages to be relatively valid within the domains of human immunology/human biology, and physics (Alexander, Jetton, & Tamara, 1995), and special education (Alexander, Sperl, Buehl, Fives, & Chiu, 2004).

Table 5: Alexander's (1997, 2003) Model of Domain Learning

Levels of Expertise	**Characteristic**		
	Knowledge	**Interest**	**Strategic Processing**
Acclimation	Low domain knowledge. May have high knowledge in certain topics.	Interest is more situational than personal.	More likely to depend on surface features to learn.
Competence	Knowledge becomes more organized around abstract concepts.	Situational interest is likely to be the motivation to learn as personal interest develops.	Surface-level process strategies are less likely utilized as deep-level processing strategies become more developed (i.e., forward reaching transfer).
Proficiency/Expert	Highly-organized knowledge structure, where person is well-versed in evaluating the validity and merit of new knowledge in the field.	Personal interest drives the person to become a problem finder in the field.	Mainly uses deep-level strategic processing.

The MDL model acknowledges that interaction occurs between the components of the model. For example, a student's personal interest in a field may influence how she learns the material by examining the material for deeper concepts, which in turn increases her knowledge within the domain. Studies of students in educational psychology undergraduate courses have shown that a high interest in the domain and deeper-level strategic processing lead to higher domain knowledge (Alexander & Murphy, 1998; Alexander, Graham, & Harris, 1998).

As already mentioned, early expert-novice theories did not explain how individuals progressed through the different levels of proficiency. Alexander, Murphy, Woods, Duhon, and Parker (1997) and Murphy and Alexander (2002) have shown through formal instruction (i.e., lecture) that the MDL can predict increases in subject-matter knowledge, deeper-level strategic processing, and interest for students studying educational psychology. The Model of Domain Learning suggests how individuals may become experts in a domain, yet it still does not suggest any mechanisms beyond classroom instruction that may influence students' interest, knowledge, and strategic processing. Although little research has been conducted utilizing MDL in nonacademic settings, it may be an appropriate model to apply to cooperative education. Alexander (1997) writes, "There also needs to be more instances when students are set free to seek knowledge in the domain for their own purposes or for its own sake" (p. 232). Cooperative education provides engineering students the outlet to explore the field of engineering in authentic work situations. The question becomes, based on the MDL, what activities might increase or improve students' interest, knowledge, and strategic processing so that they move toward expertise in a given domain.

Experiential Education

One possible avenue to expert-level problem-solving skills in engineering is students' participation in experiential education activities such as cooperative education or design competitions. According to Carver (1996), the four salient pedagogical features of experiential education are 1) authenticity, 2) active learning, 3) drawing upon student experience, and 4) connecting the experience with future opportunities. Experiential learning involves authentic tasks, activities that have real consequences, such as designing and building a sailboat that either floats or sinks. Students may be motivated to complete authentic tasks because they provide a more meaningful and personal experience than textbook problems. For example, a student achieves greater personal satisfaction in completing the sailboat project than finishing a problem set on form drag (a concept that needs to be addressed for a functional boat). In completing the authentic tasks, students mentally and/or physically engage in learning rather than passively learning material through a lecture or textbook. In completing the sailboat, the student must draw on knowledge learned in courses (such as form drag), applying it to solve the problem presented. Learning occurs not only through the experience gained from working on the project and from self-reflection on how the experience may relate to future opportunities. Returning to the sailboat example, the student will be able to self-assess the project by observing whether the project met its goals or not. This evaluation process may lead the student to adjust the boat's design. In sum, experiential learning involves active learning tasks with real consequences, where learning occurs through the activity and student's self-reflection in connecting the experience with future endeavors.

Similarly, a cooperative education student actively learns through assignments given to him by his employer. These authentic experiences have real consequences for the company and the student's goals. Project tasks and responsibilities assigned depend on the co-op student's level of experience and knowledge in the field. The employer provides feedback on the extent to which the student successfully completed the task. Ideally, the student learns from the experience by reflecting on his strengths and weaknesses, and he may develop a plan to address his deficiencies. This plan for the future might include, for example, enrolling in courses that address his lack of knowledge in a subject, seeking a mentor to help him see the project through to completion, or even switching majors because he has discovered he does not like the work associated with the profession.

Model of Domain Learning and its relation to Experiential Learning

As discussed earlier, MDL includes many of the cognitive characteristics of expert-novice themes, but also includes an affective component (the role of interest) as well as a strategic processing element. Expert-novice theory, posits that a person's representations or knowledge in a domain develop through experience (Chi, Feltovich, & Glaser, 1989; Dreyfus & Dreyfus, 2005). For example, Benner (1982) found that competency in the nursing profession (i.e., handling patients) could not be attained exclusively through the study of theories of illnesses in textbooks and lectured; nurses gained competency through practice. Similarly, Donald (2002) found that engineering students often seek opportunities to understand the context surrounding the scientific concepts to help aid them in comprehending the application of engineering and scientific concepts. In the MDL, such activities improve the learner's knowledge organization.

In the classroom, a student's organization of knowledge is likely to be influenced by his professors and the manner they present the material (Stark & Lattuca, 1997). Experiential learning provides opportunities for students to organize knowledge based on their own personal experiences. This may allow students to develop linkages among formerly abstract concepts. For example, electrical engineering students studying differential equations and Laplace transformations may not realize the subjects' importance and application to electrical engineering until the students are required to design a stable system for manufacturing. Without the experience of designing a manufacturing system either in a design course or in the work setting, electrical engineering students may only understand Laplace transformations as a method to solve a differential equation. With some work experience, they will soon realize that Laplace transformations are not only important for manufacturing systems, but for any analysis related to system stability (e.g., weapon design, elevator design, medical devices, etc.).

The MDL suggests that interest is a component of expertise in a domain and that non-academic experiences may be a route to expertise. Experiential learning opportunities like internships or cooperative education may thus influence a student’s interest in a field. In exploring their field through cooperative education, a student’s personal interests may become stronger or may diminish. For example, some engineering students enter the field without understanding the profession (Seymour & Hewitt, 1997). After an internship or a single co-op rotation, some of these students may realize that they do not like the work tasks associated with engineering, while others may recognize they have a passion for the field. The interested student may continue to discover aspects of engineering she enjoys and pursue those interests through courses, future internships or co-op opportunities, or student clubs and organizations.

Finally, experiential learning may influence the students’ learning strategies. Students who gain engineering experience through internships, co-ops, or design competitions may be better able to prioritize and organize knowledge taught in the classroom than those with little or no experience in the field. Instead of focusing on surface level details, students with engineering experience can extract the concepts by relating the theories to previous endeavors with similar problems. Hence, they may have a better comprehension of the theories underlying the concepts taught in the classroom. For example, computer science students with programming experience may concentrate on understanding the concepts behind the discipline (such as linked lists, records, loops, recursion, object-oriented programming), rather than worrying about the language itself (e.g., Java, Pascal, C, C++, Visual Basic), because they realize they will be able to program in other languages rather easily if they understand these underlying concepts of computer science. Learning other computer languages will be a matter of understanding the syntax.

Self-Perception of Problem-Solving Skills and Experiential Learning

Bandura's (1997) self-efficacy theory postulates that an individual’s confidence rises when he has mastered a skill through experience. Self-efficacy studies in STEM fields involving students in chemistry (Zusho, Pintrich, & Coppola, 2003), computer science (Dunlap, 2005), engineering (Hutchison, Follman, Sumpter, & Bodner, 2006; Hutchison-Green, Follman, & Bodner, 2008) and mathematics (Pajares & Miller, 1994) have found a mastery experience to be influential in a person's self-efficacy. These findings are not limited to STEM fields as Usher and Pajares (2008), in a review of the literature, found a mastery experience to be the most prevalent source of developing a person's self-efficacy. Engineering students, thus, who had little success in solving problems are likely to perceive themselves as weak problem-solvers; while, students who had success in solving problems are likely to perceive themselves as good problem-solvers.

Understanding students' perceptions of their efficacy in different domains is important, because Zusho et al. (2003), Hutchison et al. (2006), and Pajares and Miller's (1994) also found evidence to suggest that self-efficacy is a good predictor of achievement. Self-efficacy, then, can serve as a reasonable proxy for gauging problem-solving ability because individuals who are more confident in their ability are also more likely to perform better than individuals who are less confident in their ability

Solving problems, whether in the classroom or in a work setting, provides opportunities for students to practice and master their problem-solving skills. Experiential learning, such as cooperative education and internships, further provide authentic problems, which students are more likely to encounter on the job. Thus, students with work experience may perceive themselves as having better problem-solving skills than students with little or no work experience because they had the opportunity to enhance their skills through solving real-world problems.

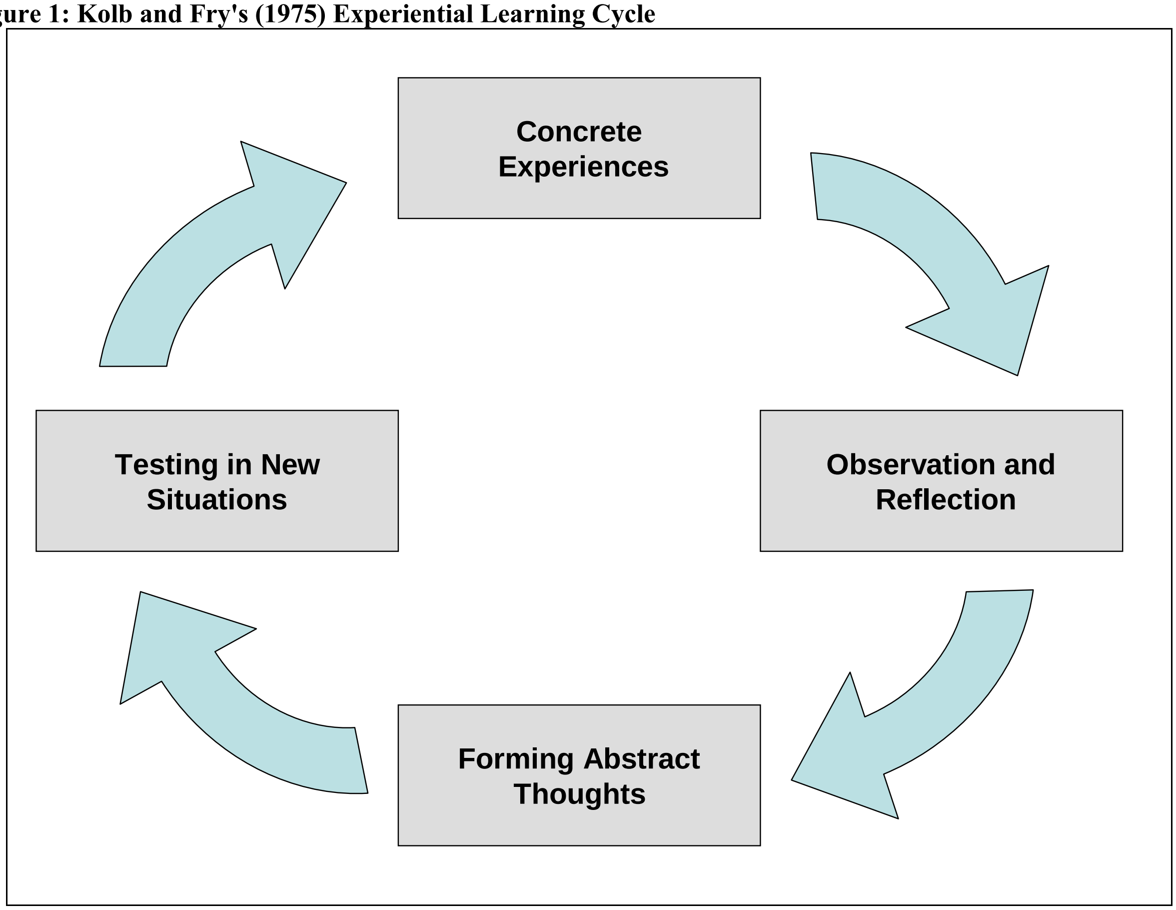
Kolb and Fry's Experiential Learning Cycle

Experience, then, is an important component to the process of developing expertise in a field. Kolb and Fry's (1975) experiential learning continuous cycle (Figure 1) may provide further insight on the non-recursive[1] relationship between cooperative education and classroom experiences. In the classic co-op experience, a student alternates periods of work and schooling, in Kolb and Fry's terms moving between concrete experiences and periods of reflection on those experiences. Specifically, Kolb and Fry's learning cycle consists of four components: 1) Concrete experiences 2) Observation and reflection, 3) Forming abstract thoughts and 4) Testing in new situations (Merriam & Caffarella, 1999). Concrete experience is the actual activity or task which engages the person in learning. During observation and reflection (similar to Carver's (1996) concept of drawing on individual's experience), individuals reflect on what happened during their concrete experience. After the reflective observation period, a person learns from the activity by abstracting or forming ideas from the experience. The final component involves the

[1] Variables have a non-recursive relationship when both variables have a reciprocal or bi-directional relationship with the other. In a recursive relationship, in contrast, one variable has a unidirectional influence on the other variable (Kline, 2005).

person attempting to connect and planning to test these new ideas to future opportunities. The cycle begins again, when the person tests the new idea; thus forming a new concrete experience. Kolb and Fry's model is a spiral because each learning cycle yields a different concrete experience, which leads to a new idea or the enhancement of a concept.

Figure 1: Kolb and Fry's (1975) Experiential Learning Cycle



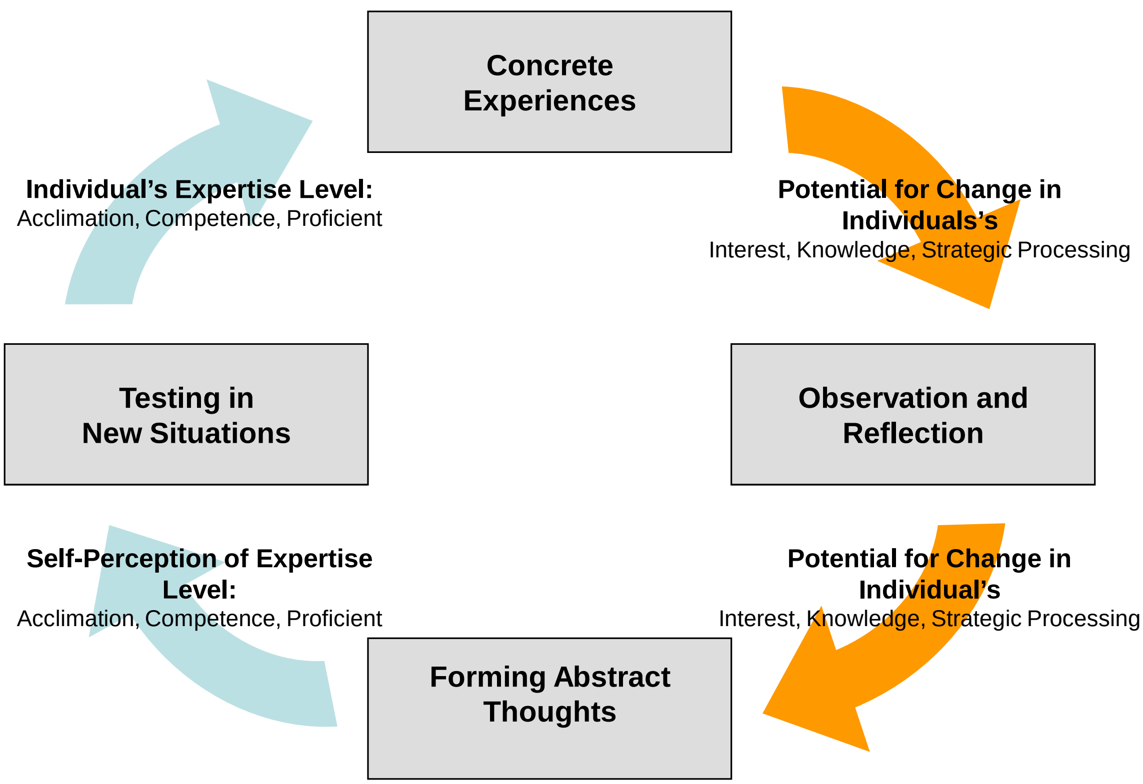
Conceptual Framework

The conceptual framework proposed for this study posits a spiral learning cycle, wherein classroom experiences influence the cooperative education experiences, and vice versa. This cycle considers learning outcomes as intermediate products of the educational experience. I propose a conceptual framework (Figure 2) that synthesizes the Models of Domain Learning (Alexander, 1997, 2003) and the Experiential Learning Cycle (Kolb & Fry, 1975) to guide this study of the influence of cooperative education on engineering students' progression towards expertise in problem-solving. The model of experiential learning is the foundation for the conceptual framework, which posits learning occurs in four phases (Concrete experience, Observation and reflection, Forming abstract thoughts, and Testing in new situations) in a spiral fashion. The components of the MDL model (interest, knowledge, and strategic processing) and expertise levels (acclimation, competence, and proficient) are viewed as potential influences on the transitions between phases of the learning spiral. Each iteration through the cycle enhances or increases the learner's interest, knowledge, and strategic processing skills within an academic domain. A person's expertise level, then, is not static, but instead develops gradually through gained experience. The spiral nature of this framework is important, because it provides a possible explanation on how students progress towards expertise in a domain.

As suggested in Figure 2, the potential for change in a student's interest, knowledge, and/or strategic processing may occur after a concrete experience (Box 1). This potential change in interest, knowledge, and/or strategic processing (Arrow 1) may be enhanced or diminished after a period of observation and reflection of the experience. The observation and reflection phase (Box 2) may transpire immediately or be over a prolonged period after the concrete experience. Any changes in the MDL components (Arrow 2) will most likely affect the student's ability to form abstract thoughts (Box 3). The knowledge and experience gained may help the student progress towards expertise and influence his perception of expertise (Arrow 3). The student's perception of his expertise level may have an effect on his ability to apply his skills in the future (Box 4). The student's actual expertise level (Arrow 4) will influence his next concrete experience. The cyclic spiral begins again when the student has another concrete experience and enhances his interest, knowledge, and strategic process.

Depending on the individual, the concrete experience may vary from solving a single textbook problem to encompassing a series of problems solved. For example, a cycle may begin with an individual solving a circuit problem and spiral continues when she/he attempts to solve another circuit problem. The potential to gain knowledge occurs each time the individual solves a new circuit problem. The concrete experience may also encompass the collective experience of solving all textbook circuit problems, and a new cycle begins when the individual utilizes the knowledge to design and build circuits. The following section discusses how classroom experiences influence co-op experiences and vice versa in the development of engineering problem-solving skills.

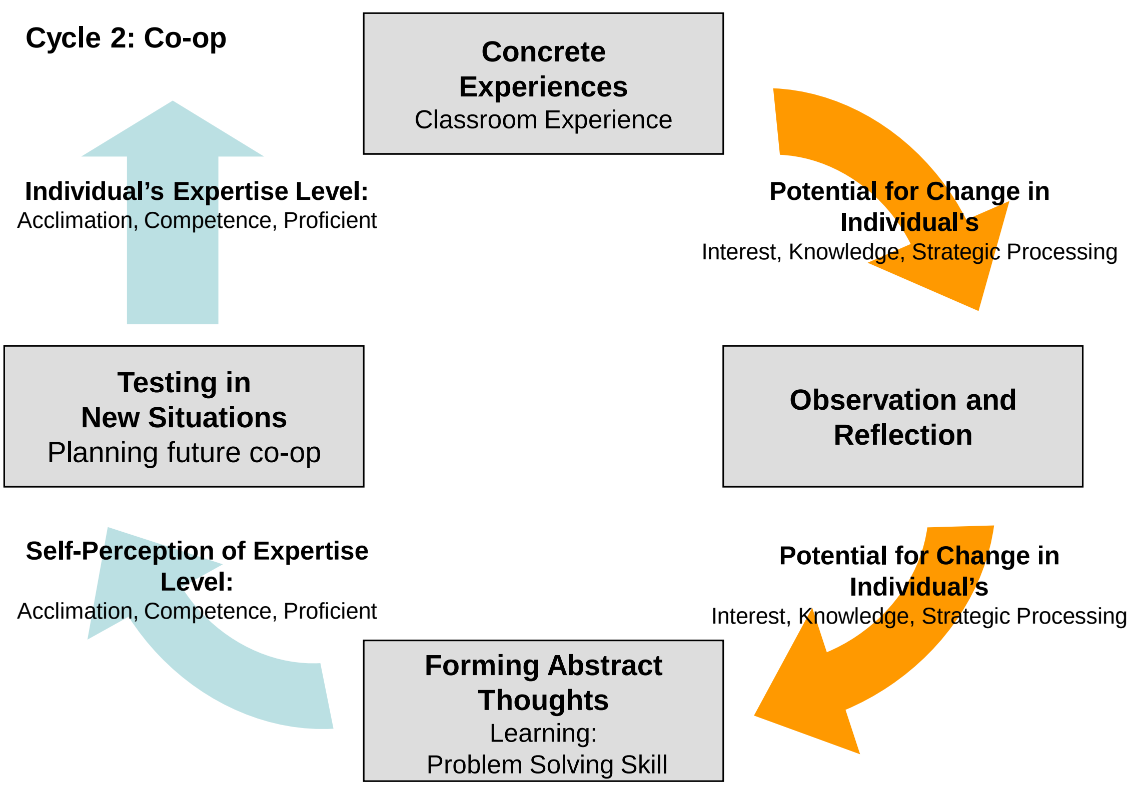
Figure 2: The Role of Experience in Domain Learning and Expertise: A Proposed Conceptual Framework



The Spiral Interaction between Classroom and Co-op Experiences

For most co-op students, the first cycle occurs in the classroom; this in turn influences learning in a second cycle, which occurs in a cooperative education work setting. This continuous cycle does not end, as the third cycle (when the student is back in an academic setting) should be influenced by the student's work experience. This type of spiral persists until students complete their cooperative education obligation (i.e., at least three work rotations).

Figure 3: Cycle 1 – Classroom Experiences

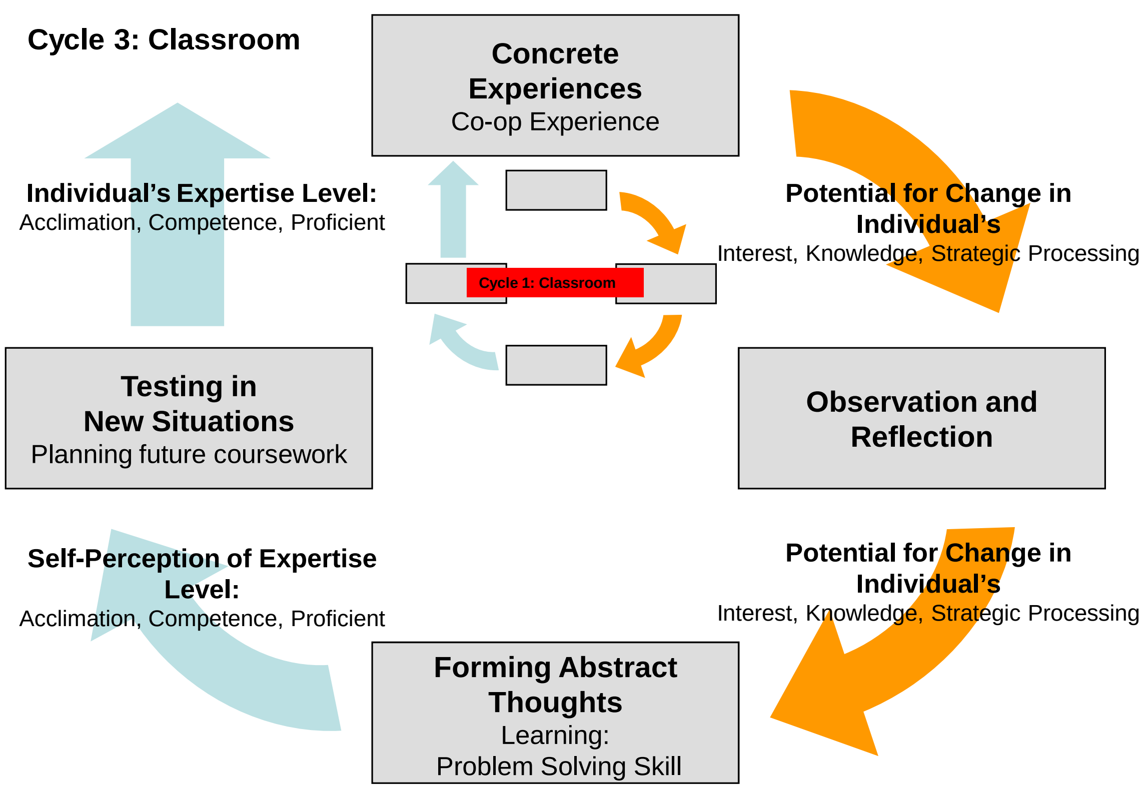


During the first cycle (Figure 3), the student learns through lectures, homework assignments, and other course-related activities (the concrete experience). He observes and reflects on those engineering concepts he understands to be important to his future. The combination of the classroom experience and the reflective observation phase may influence changes in his interest in the field, his knowledge, and his strategic processing; these in turn affect his understanding of key concepts in engineering from courses in calculus, physics, and computer science, for example. How well he comprehends these concepts will determine his perception of skill level (i.e., acclimation, competence, or proficient), which will affect his decision making about educational experiences and planning. For example, if a student perceives he has mediocre communication skills, and understands written communication skills to be essential to the work of an engineer, he may decide to enroll in an intensive writing course.

MDL suggests, however, that a students' level of knowledge will not be the only factor that influences his plans. His level of interest in the field may influence whether he pursues a certain field or topic within engineering, while his preferred strategic processing skills (i.e., how he learns) may determine his choice of educational experiences (e.g. co-op, internships, courses, design competition). In addition, the interaction between the environmental contexts (e.g., company's expectations, curricular policies) affect the student's perceived skill level and influence the following concrete experience (Cycle 2). Case in point: the student's co-op company will more than likely assign a task that is appropriate to his skill level. The company will not ask a first-year student who has had few engineering courses to design a component where subject knowledge on Fast Fourier Transforms (an advanced engineering topic) is necessary.

Cycle 2 for co-op students permit them to gain experience in a work setting (Figure 4). The work assigned to a cooperative education intern provides an authentic experience for the student, who must attempt to apply the knowledge learned in the classroom to a given work-related task (i.e., the learning that occurred in the first cycle). Both during the task and after it is completed, the employer will most likely provide feedback to the intern. The experience gained may affect the student's interest, knowledge, and strategic processing skills in the academic discipline. These potential changes in the components described in MDL may lead him to abstract lessons and ideas from the task. For example, during a reflective observation phase, he may come to understand the importance of heat transfer laws, or why a crucial component in his design melted (i.e., a change in knowledge). The co-op experiences may also increase a student's personal interest in a specific topic, which may then lead him to enroll in courses that cover his desired subject (i.e., planning for future coursework).

Figure 4: Cycle 2 – Cooperative Education Experiences



With the experience gained through the co-op, the student may progress towards another expertise level. At a higher expertise level, the student (continuing the example from the previous paragraph) may be more interested and motivated to learn about thermodynamics and the theories behind heat transfer so as to understand why that crucial component in his design melted (i.e., the influence of the student's expertise level on the concrete experience for cycle 3).

The changes in his knowledge from his co-op experiences may allow him to understand that the formulas he encounters in the classroom are not merely used to solve textbook problems, but instead have real serious implications if applied improperly in the design process (the observations and reflections for cycle 3). The material learned in the classroom may also increase his breadth and depth of domain knowledge. The combination of the material taught in the classroom and the student's previous experience may lead to a more organized hierarchical knowledge structure (i.e., a better familiarity with engineering concepts). This in turn may help the student to develop and utilize deeper level strategic processes to solve problems. Thus, the changes in a student's interest, knowledge and strategic processing skills will influence his ability to improve his problem-solving skills.

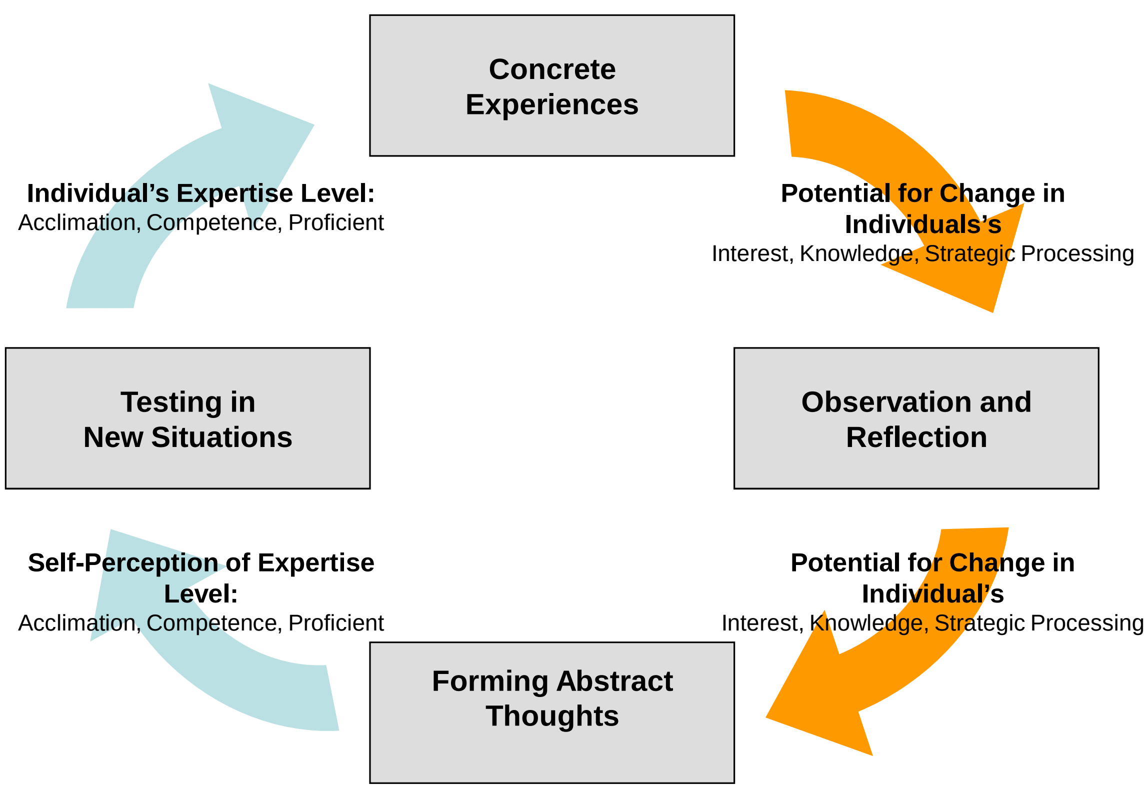
This conceptual framework proposes an explanation of how cooperative education develops student's problem-solving skills. Expert-novice theories are important to this framework because they identify observable characteristics and differences between novices and experts in the learner's knowledge and problem-solving process. The goal of this study is not only to examine whether cooperative education improves students' problem-solving skills, but also to examine whether these improvements contribute to students' development as experts in the field, by investigating their self-perception of their problem-solving ability. In addition to increased declarative knowledge, this study also seeks to examine whether or not cooperative education increases students' personal interest(s) in the field and improves their strategic processing skills following Alexander's Model of Domain Learning.

CHAPTER 3:

METHODS

The conceptual framework (Figure 5) for this study hypothesizes that an engineering student's participation in a cooperative education program improves his or her problem-solving skills. This framework assumes problem-solving skills improve because the experience gained through cooperative education/internships builds upon and enhances the student's existing interest, knowledge, and strategic processes as specified in the Model of Domain Learning that undergirds this framework.

Figure 5: The Role of Experience in Domain Learning and Expertise: A Proposed Conceptual Framework



Through a mixed methods approach, this study will attempt to answer the following two research questions:

1. Does experience in cooperative education or internship programs influence students' self-perceptions of their engineering problem-solving skills?
2. How do students with cooperative education or internship experience differ in their perceptions and understanding of their engineering problem-solving skills as compared to students with no experience?

There are two components to this study. The first examines national data to answer the first research question utilizing a series of multi-level and logit models. Answering this question will determine whether cooperative education has a positive influence on an important engineering skill. The second component utilizes qualitative data to understand how experiential programs, such as cooperative education and internships, influence students' self-perception of their problem-solving skills. If the evidence from the quantitative analyses suggests students participating in a co-op education/internship program have a better self-perception of their problem-solving skills, then the findings from the second component of this study (How do students with cooperative education or internship experience differ in their perceptions and understanding of their engineering problem-solving skills as compared to students with no experience?) may have meaningful and significant implications for engineering education. (See Table 6 for an overview of the research design).

The data collected from the interviews will be used to support, enhance, or modify the proposed conceptual framework so that it may be further tested and refined in subsequent studies. The combination of the national dataset and interviews with electrical engineering students is a mixed method approach that is effective in answering "what" and "why" questions (Howard &

Borland, 2007). Using both quantitative and qualitative approaches will permit a detailed understanding of how experiential education programs, such as cooperative education and internship experience, influence engineering students' self-perception of their problem-solving skills.

Table 6: Proposed Data Source and Analyses in Addressing Research Questions

Research Question	Data Source	Analyses
Does experience in cooperative education or internship programs influence students' self-perceptions of their engineering problem-solving skills	*Engineering Change (EC2000)* Dataset	Multivariate regression, Proportional-odds cumulative logit and baseline-category logit models
How do students with cooperative education or internship and understanding of their engineering problem-solving skills as compared to students with no experience?	Semi-structured interviews with electrical engineering students in three (3) categories: 1) those who participated and completed at least three cooperative education rotations, 2) those who participated in internships, and 3) those who did neither at a large Research-I university	Qualitative methods utilizing thematic analysis

Collecting objective data on engineering problem-solving ability can be time consuming and expensive. For both components of this study, students were asked about their problem-solving efficacy, instead of assessing their ability through solving problems. Asking students' about their self-efficacy is a reasonable approach for gauging problem-solving ability because research has shown that an individual's confidence rises when he has mastered a skill through experience (Bandura, 1997). Thus, engineering students who had little success in solving problems are likely to perceive themselves as weak problem-solvers; while, students who had success in solving problems are likely to perceive themselves as good problem-solvers.

Data Sources, Design, and Analytical Methods for Quantitative Analysis

The *Engineering Change (EC2000)* dataset is a national dataset that provides an opportunity to study whether cooperative education programs influence students' perceptions of their engineering problem-solving skills. Currently, there are no other national datasets or data that permit this type of analysis.

For the quantitative analysis, I will define cooperative education programs to include internships, because both experiences provide students with opportunities to apply the knowledge and skills learned in the classroom to a work setting. Students in internships, however, are only engaged in the work setting for a single semester or summer, whereas co-op students work for multiple semesters, often with the same employer, so a comparison of the two kinds of experiences is warranted.

Data Sources

The dataset analyzed for this component of the study was developed for the Engineering Change (EC2000) project sponsored by ABET and the National Science Foundation (Grant No. EEC-9812888) and conducted by faculty members in the Center for the Study of Higher Education (CSHE) at the Pennsylvania State University (Lattuca, Terenzini, & Volkwein, 2006). This nationally representative database contains 4,461 survey responses from engineering seniors of the class of 2004 in seven engineering disciplines (aerospace, chemical, civil, computer, electrical, industrial, and mechanical) in 39 accredited engineering institutions. The sample of colleges and universities included institutions classified as Doctoral, Master's, and Bachelors' and Specialized Institutions (The Carnegie Foundation for the Advancement of Teaching, 2009).

Design

Dependent Measures. The Survey of Graduating Seniors (Appendix A) incorporated measures of eleven learning outcomes that all accredited undergraduate programs in engineering must address as specified by the Accreditation Board for Engineering and Technology (ABET) (Lattuca, Terenzini, & Volkwein, 2006). The survey questions were developed in an iterative process, beginning with a literature review of existing instruments that assess these learning outcomes and including consultations with Penn State engineers (see Volkwein, Lattuca, Terenzini, Strauss, & Sukhbaatar, 2004 for a description of the instrument development process.). The survey was then pilot tested to gauge the internal consistency of the learning outcome measures.

In this analysis, I focus on three ABET outcomes: 1) ability to apply knowledge of mathematics, science, and engineering, 2) ability to design a system, component, or process to meet desired needs, and 3) ability to identify, formulate, and solve engineering problems. The eighteen dependent variables that measure these abilities are 2004 seniors' responses to a set of survey items that form three factors: 1) Applying Basic Skills, Design, 2) Problem-solving Skills, and 3) Engineering Thinking Skills (Table 7). Seniors rated their abilities on each of the eighteen items on a five-point scale (where 1 = No Ability, 2 = Some Ability, 3 = Adequate Ability, 4 = More than Adequate Ability, and 5 = High Ability). The Cronbach's alpha for the Applying Basic Skills factor is .74, while the Design and Problem-solving factor's Cronbach's alpha is .92 (Lattuca, Terenzini, & Volkwein, 2006). The Engineering Thinking Skills factor, which corresponds to Donald's (2002) problem-solving process, has a Cronbach's alpha of .94 (Volkwein & Yin, 2007).

Table 7: Items Examined from the Engineering Change (EC2000) Project

Factor	Items
Applying basic skills	• Apply knowledge of math • Apply knowledge of physical sciences
Design and problem-solving skills	• Apply discipline-specific engineering knowledge • Understand essential aspects of the engineering design process • Apply systematic design procedures to open-ended problem • Design solutions to meet desired needs • Define key engineering problems • Formulate a range of solutions to an engineering problem
Engineering thinking skills	• Break down complex problems to simpler ones • Apply fundamentals to problems that I haven't seen before • Identify critical variables, information, and/or relationship involved in a problem • Know when to use a formula, algorithm, or other rule • Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems. • Draw conclusions from evidence or premises • Develop a course of action based on my understanding of a whole system • Ensure that a process or product meets a variety of technical and practical criteria • Compare and judge alternative outcomes • Develop learning strategies that I can apply in my professional life

Independent Measures. Seniors' self-reports of the number of months spent in cooperative education or internships are the independent variables in the analysis. The sample includes 1,803 (40.42%) students who did not participate in a co-op or internship; 743 students (16.66%) who spent 1-4 months in a co-op or internship; 699 (15.67%) students who spent 5-8 months in a co-op or internship; 595 (13.34%) students who spent 9-12 months in a co-op or internship; and 621 (13.92%) students who spent more than 12 months in a co-op or internship.

When examining the influence of cooperative education on the three focal outcomes, I controlled seniors' academic ability and socioeconomic status (SES) in my statistical models. To control for academic ability, seniors' self-reported college grade-point-average (GPA) is included as an explanatory variable in the model. Seniors' college GPA was recorded into the following categories: 3.50-4.00 (A- to A), 3.00-3.49 (B to A-), 2.50-2.99 (B- to B), 2.00-2.49 (C to B-), 1.50-1.99 (C- to C), and Below 1.49 (Below C-). I used seniors' self-reports of their parents'/guardians' annual family income as a proxy for socioeconomic status. Seniors' self reported their family's annual income into the following categories: Below $20,000, $20,001-$30,000, $30,001 – $50,000, $50,001 - $70,000, $70,001 - $90,000, $90,001 - $110,000, $110,001-$130,000, $130,001- $150,000, and More than $150,000. Seniors' major (aerospace, chemical, civil, computer, electrical, industrial, and mechanical) and time spent in design projects and competitions beyond class requirements were also included as explanatory variables in the model to control for the influence of classroom experiences and extracurricular activities.

In my models, I also controlled for institutional characteristics such as Carnegie classification and urbanization. The sample included 27 Research Extensive, three Research Intensive, five Master's and four Bachelor's institutions. Of the 39 institutions, 12 are located in a large city, nine in a midsize city, 12 in a small city, two in a large suburb, one in a midsize suburb, one is on town fringe, one is classified as town distant, and 1 is classified as rural fringe. The U.S. Census Bureau's Population Division assigned the urbanization codes to the geographic regions in which the institution is located.

Analytical Methods

Regression Models. The first step in the quantitative analysis examines the influence of cooperative education on the three focal outcomes (Applying Basic Skills, Design and Problem-solving Skills, and Engineering Thinking Skills) by developing either a multi-level model (MLM, also known as hierarchal level modeling) or a multivariate regression model. The appropriate statistical method will be determined by calculating the intraclass correlation, which is the percentage of the dependent variable's (the focal outcomes) variance attributed to the institutional characteristics (i.e., the 39 institutions in the sample) as opposed to the individual characteristics (i.e., the 4,461 senior responses). If this measure is greater than .05, then MLM is a more appropriate statistical technique than multivariate regression[2].

Besides examining whether time spent in co-op has a positive significant influence on each of the three focal outcomes, the purpose of this step is to examine which of the control variables (academic ability, SES, major, time spent in a design competition, Carnegie Classification, and urbanization) are significant. If a control variable is significant for a focal outcome, then it will be included in the multinomial logistic models for the items within that focal outcome. With ordinal dependent variables, the eighteen items that form the independent measures are fitted with logit models to examine the relationship between the number of months participating in an internship or co-op and seniors' reports of their ability on each of the eighteen items within the three focal outcomes (Table 7).

The items within the focal outcomes are ordinal and cannot be analyzed using linear regression models due to violation of the normality assumption. Ordinal dependent variables can be analyzed utilizing logit models. Two kinds of logit models will be used in this analysis: Proportional-odds cumulative logit model and baseline-category logit model. Using a multinomial logistic model instead of four binary logistic regression models allows the researcher to control for experiment-wise error, which is analogous to utilizing an analysis of variance (ANOVA) over *n* number of independent t-tests.

Baseline-category Logit Model. A baseline-category logit model (Equation 1) is used to examine the influence of time spent in an internship or cooperative education. A baseline-

[2]Multivariate regression underestimates standard error estimates when subjects are not independent of each other (e.g., students nested in institutions) (Ethington, 1997). Multi-level modeling accounts for this violation; however, multivariate regression is fairly robust when the intraclass correlation is less than .05 (Porter, 2005).

category logit model is a subset of multinomial logistic regression models that estimates the likelihood of being in one category (the baseline) compared to another category for all possible combinations with the baseline category. Since the dependent variables for this study have five possible responses, four simultaneous logits will be examined with “High Ability” as the baseline category.

Equation 1: Baseline-category Logit Model for Analyzing Scale Items

$$\text{Log}\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right) = \beta_{10} + \beta_{11} * \text{Co-op} + \beta_{1x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right) = \beta_{20} + \beta_{21} * \text{Co-op} + \beta_{2x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{30} + \beta_{31} * \text{Co-op} + \beta_{3x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(> Adequate\ \ Ability)}{P(High\ Ability)}\right) = \beta_{40} + \beta_{41} * \text{Co-op} + \beta_{4x} * \text{Control Variables}$$

If the internship/cooperative education variable is significant, the parameter estimates for each of the dummy variables for this model will be analyzed to estimate the odds ratio of being in the baseline category (High Ability) as opposed to the comparison category. The odds ratios for this model will allow comparisons between varying levels of time spent in an internship and/or cooperative experience and one of the eighteen items comprising the focal outcomes (Table 7). For example, the analysis will provide information on whether students who spent more than 12 months in cooperative education or internships perceive their ability higher than students who only participate 1-4 months.

Proportional-odds Cumulative Logit Model. For some items within the focal outcomes, a proportional-odds cumulative logit model is a better model than a baseline-category logit model because it satisfies the equal-slopes assumption. A benefit of using proportional logit models is that there are fewer parameters to estimate than a baseline-category logit model, since the proportional-odds cumulative logit model assumes that the slopes for each variable are equal across the different logit equations (Note β's are equal in Equation 2).

This model (Equation 2) describes the log-odds of two cumulative probabilities: the likelihood of being *in the category or below* compared to the likelihood of being *in the category above*. For example, the model will examine the probability of the student rating his ability as high versus his ability in any of the other lower categories (more than adequate ability, adequate ability, some ability and no ability). The cumulative logit for this model is coded such that the log-odds is the likelihood of being *in the category or above* versus the likelihood of being *in the category below*.

Equation 2: Proportional-odds Cumulative Logit Model for Analyzing Scale Items

$$\text{Log}\left(\frac{P(High\ Ability)}{P(> Adequate\ Ability + Adequate\ Ability + Some\ Ability + No\ Ability)}\right)$$

$$= \alpha_1 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + > Adequate\ Ability)}{P(Adequate\ Ability + Some\ Ability + No\ Ability)}\right)$$

$$= \alpha_2 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + > Adequate\ Ability + Adequate\ Ability)}{P(Some\ Ability + No\ Ability)}\right)$$

$$= \alpha_3 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + > Adequate\ Ability + Adequate\ Ability + Some\ Ability)}{P(No\ Ability)}\right)$$

$$= \alpha_4 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

For the proportional-odds ratio logit models developed in this study, a positive odds ratio indicates that seniors are likely to rate their ability *higher* by the odds ratio value for each one-unit increase in the explanatory variable (time spent in a co-op or internship). For example, if β_1 is greater than one, this would suggest that students spending more time in a cooperative education will more likely to rate their ability in a high category (e.g., high ability) than in a category below (more than adequate, adequate, some, or no ability).

Software. For the quantitative analysis, I utilized SAS version 9.1 for windows. When developing the regression models (MLM and multiple regression) for the three focal outcomes, the proc mixed command is used, while the proc logist command is used in developing the logit models for the eighteen items within the focal outcomes (See Appendix C for syntax).

Data Sources, Design, and Methods for Qualitative Analysis

The qualitative analyses utilizes interview data collected from electrical engineering students at a large, Research-I university in a mid-Atlantic state. Semi-structured interviews with students explored the role of experiential education, specifically cooperative education and internships, and its influence on their perceptions and understanding of basic engineering skills, design and problem-solving skills, and engineering thinking skills. Because the quantitative analysis at the national level cannot distinguish between the effects of internships versus cooperative education, one goal of the qualitative analysis was to examine whether differences exists between these groups. To address the second research question, I will interview three groups of seniors in Electrical Engineering at a Research I University: 1) those who participated and completed the cooperative education program, 2) those who completed at least one internship and 3) those who did neither cooperative education nor internship. Interviews with engineering students will be conducted to explore the nature of their collegiate experiences and how they may have contributed to students' perceptions of their problem-solving skills. The interview data can be used to compare and contrast problem-solving skills among students who participated in a single internship, those who completed the cooperative education program and those who did neither.

Defining Problem-solving for Qualitative Analysis. For this portion of the study, I broadly defined problem-solving skills to include all items within the three focal outcomes from the quantitative portion of the study (Table 7). The items within the focal outcomes applying basic skills and design and problem-solving are all important skills in engineering problem-solving.

Changes in the Research Design during the Study

The initial research design for the qualitative component was a two-stage analysis. The first phase would rely on a document analysis of students written co-op reports both to comprehend the types of work experiences (i.e., job responsibilities, assignments, mentoring) that contribute to students' perception of their problem-solving-skills and to inform the development of an interview protocol to be used in the second phase. In the second phase, semi-structured interviews with electrical engineering seniors students would explore the role of co-op education in the development of problem-solving skills specific to engineering.

The Cooperative Education and Professional Internship Program at the study site requires co-op and internship students' to write formal reports at the end of each cooperative rotation or internship experience. The written reports ask students to respond to specific questions about their coursework and work experience. For example, students in the first cooperative education experience are asked "Did you use any skills learned in your courses?" and "Did you feel that you were lacking particular technical skills necessary for the assignment?" (See Table 8 for sample questions; for a complete list of questions see Appendix B.) I expected a document analysis of students' reports at various points in their cooperative education rotation (either the first, second, or third) would reveal relationships among students' co-op or internship experience, their classroom experiences, and problem-solving skills. Co-op students completing three rotations should presumably have datum available at three different time points. Since internships usually consist of a single rotation at a company, these students should presumably have a single datum point available. The students' written responses could therefore inform the development of interview questions about the co-op or internship learning experience, students' perceived skill levels before and after the co-op experience, and their reflections on how to improve their engineering knowledge and skills.

Table 8: Sample Questions Answered in Formal Cooperative Education Reports at Research Site

Report	Question
Internship Reports	• Did you use any skills learned in your courses? • Did you feel that you were lacking particular technical skills necessary for the assignment? • If so, in what engineering course(s) would you expect to learn these skills?
First Formal Co-op Report	• Did you use any skills learned in your courses? • Did you feel that you were lacking particular technical skills necessary for the assignment? • If so, in what engineering course(s) would you expect to learn these skills?
Second Formal Co-op Report	• What courses helped you in your work assignment? • What future courses would you need to meet fully the demands of the job? In other words, which Institution courses would have been of benefit to you in this work assignment? • How did this work assignment affect your choice of future technical electives? Are the desired courses available at Institution? If not, what courses are needed?
Third Formal Co-op Report	• What courses helped you in your work assignment? • How has Cooperative Education influenced your ability to identify, formulate and solve engineering problems? • Describe how your work experience exposed you to the use of techniques, skills and modern engineering tools necessary for engineering practice. • Which of these items were you exposed to at Institution and which were you exposed to only through your cooperative education work experiences?

Sample. The co-op office at the research site provided students' co-op and internship reports; they did not, however, keep cumulative reports for cooperative education students. Thus, the document analysis became a cross-sectional design of participating electrical engineering students who completed a co-op and internship program between fall 2006 and spring 2006 (i.e., a census for two semesters). Attempts to analyze reports in subsequent semesters failed as the co-op office discarded them before they could be collected. Efforts made to collect reports directly from students yielded a single report despite the offer of an incentive from the cooperative education office. Twenty-one available reports were analyzed for protocol development: five reports from students who completed an internship, eleven reports from students who completed the first co-op rotation, three reports from students who completed the second co-op rotation, and two reports students who completed the third co-op rotation.

Data Issues. With a limited number of reports collected for each group, the document analysis could not provide any credible evidence regarding how cooperative education or internship experience influenced engineering students' perception of their basic skills, design and problem-solving, and engineering thinking skills. It did provide themes and topics (e.g., work assignments, mentoring, and work environment) that contributed to the development of the student interview protocol.

Final Research Design

As mentioned in the previous paragraph, I could not conduct a rigorous document analysis that would provide substantial evidence to answer my second research question. Thus, the original research design was modified and the document analysis was used to develop portions of the interview protocol. In the following section, I describe the development of the protocol and the research design for the interviews

Protocol Development

The development of the interview protocol was informed by 1) a literature review on problem-solving, Alexander's (2003) Model of Domain Learning, and Kolb and Fry's Learning Cycle (1975) (see Chapter 2); 2) my expertise in the field of engineering; and 3) a document analysis of students' cooperative education and internship reports. The document analysis identified types of work experiences (i.e., job responsibilities, assignments, mentoring) that influenced students' interest, knowledge, and strategies in the development of their problem-solving skills.

Assessing Problem-solving Skills. The conceptual framework assumes that after a period of observation and reflection on experiences, students learn by abstracting ideas and thoughts about their activity. Theoretically, the knowledge or experienced gained by the student can be assessed to determine her level of expertise. The document analysis suggested that students had increased their knowledge in some fashion as they were able "to get a better understanding," and had "learned many positive aspects" from their co-op experiences. Even though many students wrote about gaining or enhancing their knowledge, however, they often did not provide evidence on how they mastered these ideas. This made assessing students' competency level difficult.

One method for assessing actual problem-solving skills is to ask students to complete a problem-solving task to evaluate that ability. Such an approach, however, is time-intensive and might dissuade potential subjects from participating in the study. More importantly, electrical engineering as a field of study comprises an array of topics, from circuits to digital signal processing. Any problem-solving task devised would need to be constructed so that a given individual's problem-solving ability would not be confounded with her content knowledge. For example, if a task involves knowledge of circuits, a student who specializes in analog circuits may solve the problem more easily than a person who specializes in electromagnetism. Furthermore, the application of engineering knowledge is only one element of the problem-solving process (Table 7) and the goal of this component of study is to examine all elements of problem-solving.

Due to these conceptual and logistical limitations, I designed an interview protocol that asks participants about their confidence in solving problems. Many co-op reports included statements about how the co-op or internship experience gave them “an extra amount of confidence” that made it “possible to go out in the real-world and be successful.” Students more easily commented on changes in their confidence (or self-efficacy) than on the development of their problem-solving skills. Interview questions to gauge students’ confidence regarding their problem-solving skills include: 1) How would you rate your problem-solving ability on a scale from 1-10, with 1 being low ability and 10 being high ability? Why did you rate yourself that way? 2) Tell me how good you are solving a textbook-type problem? What factors have influenced your comfort level? 3) Tell me how good you are solving a non-textbook type problem (i.e., your capstone project)? What factors have influenced your comfort level?

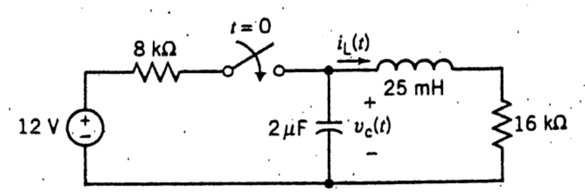
Development of Problem-solving Skills. The analysis of the co-op reports revealed that many students did not articulate how they extracted general lessons from their particular work experiences. Thus, the interviews are needed to gather data on how students move from concrete experience to abstract thinking about that experience. The document analysis suggested that it would be more useful to ask students to think about the steps within the problem-solving process. Students could be asked about “problem-solving components” instead of “problem-solving.” The goal would be to see whether students could articulate how they developed their problem-solving skills. This would allow me to examine the evolution in students’ knowledge, strategic processing, and interest. Sample questions include: “When and how did you learn the components of problem-solving? Can you provide specific examples?” and “When and how did you know your problem-solving skills improved?” To examine similarities and differences in their problem-solving processes between the cooperative education students, internship students, and the comparison group (neither co-op nor internship), students would be asked to describe the steps they would take to solve two different problems: a well-structured and an ill-structured one (Figure 6 and Figure 7). Students would be told that they would not be evaluated on whether they could solve the problem, but that the research is interested in understanding their problem-solving process.

The question for this “think-out-loud” is: What are the steps you would take in solving this problem? Since a student's content knowledge for each of the two given problems may be a confounding issue, a follow-up question would be asked to determine what steps students would take in solving a problem that they had not encountered before. In order to prevent biasing the students’ answer, I purposely did not learn how to solve or solve the problem until after completing the interview portion of the study.

Figure 6 presents the well-structured problem taken from an introductory electrical engineering textbook that students would have encountered in their sophomore or junior year. There are two approaches to solving this problem. The first approach is to understand each of the circuit component’s properties and model the capacitor’s voltage and inductor’s current using differential equations. The second approach is to write two sets equations that model the capacitor’s voltage and inductor’s current at the initial state (0+) and steady-state (∞). Unlike the first approach, the second approach only requires knowledge of algebra to solve the problem, which is considerably easier than using differential equations. Both approaches, though, will lead to a single correct solution, which makes this a well-structured problem.

Figure 6: Well-Structured Problem*

P 7.9-3 The switch in Figure 7.9-3 has been open for a long time before closing at time $t = 0$. Find $v_C(0+)$ and $i_L(0+)$, the values of the capacitor voltage and inductor current immediately after the switch closes. Let $v_C(\infty)$ and $i_L(\infty)$ denote the values of the capacitor voltage and inductor current after the switch has been closed for a long time. Find $v_C(\infty)$ and $i_L(\infty)$.



***Source:** Dorf and Svoboda (1998) Introduction to electric circuits 4th Edition, p. 318

Figure 7: Ill-structured Problem

An integrated biopharmaceutical company manually inspects all incoming materials and final product which pass through their manufacturing site. The first goal of this project is to design an automated pill inspection system for company's quality assurance department using image processing techniques to deliver a software-based rules engine that will detect, classify and quantify defects.

***Source:** Harvey Mudd College (2008) *2008 projects day program.*

The ill-structured problem (Figure 7) is a modified problem statement from a capstone course in electrical engineering. Even though this problem has a definite goal (design an automated pill inspection system), there are many solutions that would achieve the bio-pharmaceutical company's goal. Unlike the well-structured problem, which focuses on one specific area of electrical engineering (circuits), the ill-structured problem involves content knowledge from many of the electrical engineering specialties including systems and control, circuits, digital signal processing, robotics, and artificial intelligence. Cost, time, and company resources are non-technical issues that engineers often encounter when solving problems. Using a "real-world" problem allowed me to evaluate whether students considered these non-technical issues when solving problems, and whether or not differences existed between the groups of participants.

Instrument Description. The semi-structured interview protocol (see Appendix D) will ask students in each group identified for this study (co-op, internship, and neither) to describe how they develop their engineering-related skills through their collegiate experiences, both inside and outside the classroom. Thus, the interviews will allow me to explore alternative activities (e.g., design competitions, research opportunities, types of homework assignments) that may also influence skill development.

The first sixteen questions would provide data that will help examine whether differences exist in participants' engineering-related skills, their enhancement of those skills, and whether differences exist between the three groups. Although the second research question focuses on how co-op and internship experiences influence the improvement of engineering-related skills, the interview protocol does not probe on co-op/internships students' work experience until the seventeenth question. I intentionally designed the protocol in this fashion so that the order of questions would not bias responses from students with work experience. If co-op or internship experience is influential in the development of engineering skills, these experiences would be salient and naturally brought up by the participants in the first sixteen questions. However, if the co-op/internship participants do not talk about their work experiences, question 17-20 would allow me to explore them.

Sample. Purposeful sampling (Krathwohl, 1998) was utilized to locate potential interviewees within each group at the research site. The targeted goal was to interview electrical engineering seniors from each of the three groups: internship only, completed three cooperative education rotations, neither internship nor co-op experience. To control for academic ability, students with a cumulative grade point average (GPA) equal or greater than 3.00 were identified for the study. Engineering is a broad field of study with many subdisciplines (aerospace, biomedical, civil, computer, electrical, mechanical, etc.) that vary in emphasis and environment (Lattuca, Terenzini, Harper & Yin, 2008; Lattuca, Lambert & Terenzini, 2008). The participants for the qualitative component of this study will be limited to students majoring in electrical engineering (EE). The rationale for limiting this sample to EE students includes the researcher's expertise in the domain (I have a bachelor's and master's degree in electrical engineering) and the prohibitive costs (money and time) associated with expanding the study to the other engineering fields. The trade-off to limiting the analysis to electrical engineers is that the conceptual framework developed as a result of the study may not be generalizable to the other engineering professions. The goal of the qualitative component, however, is to explore the role of experiential education, specifically, cooperative education and internships, in developing fundamental engineering-related skills. Donald's (2002) research suggests that the particular skills I am studying, such as engineering thinking skills, are stressed in many subfields of engineering. Thus, explanatory design should yield directions for future research. The electrical engineering department's undergraduate program coordinator at the research site provided a list of potential candidates. I contacted these students by email and offered 25 dollars for their participation in the study.

For seniors with internship and neither internship experience nor cooperative education experience, the GPA criterion was met. At the research site, however, only six senior electrical engineering students had completed three cooperative education rotations, and only three of those students met the GPA criterion. The initial recruitment effort in the study yielded two of those three students. After repeated attempts to recruit the third senior into the study failed, the

GPA criterion was relaxed and the other three cooperative education students were invited to participate. This yielded two additional participants with cooperative education experience.

The final sample comprised of 1) four students who completed at least three cooperative education rotations, 2) eight students who completed an internship, and 3) five students who did neither. Of the seventeen participants, fourteen of the participants are male and three of the participants are female. All three females had internship experience.

Pilot Testing. Due to the limited number of eligible participants for interviews (particularly electrical engineering seniors who completed the cooperative education program), a pilot test of the instrument was limited to two students at the Research-I university and a senior of an electrical engineering program from Georgia Tech who had been working in industry for the past six years. The pilot test indicated the protocol was effective in collecting data on students learning experiences and their development of the three focal outcomes. Consequently no modifications to the instrument were required. Data collected from the two undergraduate seniors pilots were included in the analysis.

Interview Procedures. The initial interviews were conducted in a two-week period (January 16 – January 30, 2009), with the shortest interview lasting 45 minutes and the longest lasting 75 minutes. At the beginning of the session I provided a brief summary of the study's goals to understand how engineering students develop their problem-solving skills. I then asked students to read the informed consent form and for permission to record the interview.

I did not tell students' that I was specifically interested in their co-op or internship experiences until after the first sixteen questions of the interview protocol were completed. So that participants would not be influenced by my interest in how their work experiences influenced the development of their problem-solving skills.

Unless asked, I did not reveal my electrical engineering background to the participants until after the interview was completed. The rationale was to create an environment where they would not feel intimidated by my engineering credentials and would thus speak more freely about their educational experiences and their thought processes for the think-out-loud problems. Revealing my background at the onset of the interview may have created an atmosphere where students thought I was evaluating their electrical engineering content knowledge, when instead I was more interested in their development of their problem-solving skills.

After the interviews, I debriefed session each participant, providing a more detailed description of the study and revealing my educational background in electrical engineering. During the debriefing session, I asked for permission to contact students to participate in a member-check on my analysis of the interview data. Students were then paid 25 dollars for their participation.

Analysis

Coding Schematic. The conceptual framework (Figure 5) guided the development of the coding schematic. The schematic reflects the four components of the Model of Experiential Learning (concrete experience, observation and reflection, forming abstract thoughts, and testing in new situations). It is also designed to capture the themes that may influence the transitions among these phases of the learning process; the substructure codes for each phase reflect the elements of Alexander’s (2003) Model of Domain Learning (MDL). For example, a priori substructure code for the main categories of Concrete Experiences and Observation and Reflection were characteristics of MDL (interest, knowledge, and strategic processing). The subcategories for Abstract Thoughts and Testing in New Situations are MDL’s levels of expertise (acclimation, competence, expert).

As discussed in Chapter 2, a cycle of experience may be conceptualized at either the micro- or macro-level. A micro-level cycle describes a single learning experience, for example, a single assignment in a cooperative education rotation. In contrast, a macro-level cycle encompasses a series of events that form a cumulative experience (i.e. the entire internship, which may consist of a series of work assignments). In the interviews, students' comments about a work assignment were categorized as micro-level events and comments about the cumulative co-op/internship experience were categorized as macro-level experiences.

The learning outcomes from the first phase of this study, which analyzed national-level data, applying basic skills, design and problem-solving, and engineering thinking (Table 7) also served as coding categories. Open coding captured information about other influences on the development of students' the focal learning outcomes such as the company environment (e.g., assigned mentors, resources available, engineers' availability to answer questions, training program) and learning environment (e.g., research experience). By examining how and where the different components of MDL changed, I can use the interview data to support, enhance, or modify the study's conceptual framework.

Member-Checking. As the study neared completion, I emailed summaries of my findings to the two groups of students: those with work experience (co-op or internship) and those without. The summaries reflected my findings for each group. I asked students to verify the accuracy of my description of their development of problem-solving skills and interpretations of their comments. Eight of the seventeen participants responded (two co-op students, four internships students, and two students with no work experience) to my email request. Of these respondents, all confirmed the accuracy of my description and conclusions.

Software. In coding the interview transcripts, I used NVIVO version 8.0.264.0 SP3 developed by QSR International, which is a common qualitative analysis software program.

Limitations of this Study

Students participate in a cooperative education program on a voluntary basis; thus, the population for this study is self-selected. This is a limitation of this study, as students are not randomly assigned either to a cooperative education program, or to an internship program, or to the control group (neither co-op nor internship). These students may thus exhibit characteristics, such as high motivation, that are not common characteristics of the general population of engineering students. This self-selected population may be a rival explanation for advanced problem-solving skills that I might observe among co-op students. To address this limitation, the research design called for interviews with students who did not participate in cooperative education. Every student characteristic that might affect problem-solving ability is not available (e.g., motivation) in the national data set analysis, and influences like student motivation cannot be controlled.

The use of seniors' self-reports of problem-solving skills may be considered a limitation of this study. Self-reports are not direct measures of skills and may not be considered the most accurate measure of an outcome. A growing number of studies, however, suggest that aggregate self-reports are valid proxies of objective measures when comparing differences between groups (Lattuca, Terenzini, & Volkwein, 2006). Since the goal of the quantitative component of this study is to compare differences between groups (students with different amounts of cooperative education and internship experiences) and not to predict problem-solving ability, self-reports are valid measures.

Ideally, the qualitative component of this study would employ a longitudinal data collection strategy, tracking participants through two or three co-op experiences. Students who completed three co-op rotations and wrote reports for each could then be interviewed. Linking these components would have provided opportunities to triangulate the data collected from document analysis and interviews. Examining whether the document analysis aligned with the students' interviews would strengthen this study's validity and conclusions. However, due to data and time constraints, a longitudinal design was not feasible; hence, a cross-sectional design was utilized.

Finally, a limitation of the conceptual framework is that it does not account for external influences that may also affect the development of student learning outcomes. Examples include having family members working in the engineering profession or having a mentor in the profession. All of these factors can also influence the development of students' learning outcomes and should be considered as possible alternative influences on the development of students' problem-solving skills.

CHAPTER 4:

THE ROLE OF COOPERATIVE EDUCATION & INTERNSHIPS IN STUDENTS' SELF PERCETION OF PROBLEM-SOLVING SKILLS

This chapter reports findings related to the first research question posed for this study: “Does experience in cooperative education or internship programs influence students' self-perceptions of their engineering problem-solving skills?" This analysis employs the basic skills, design and problem-solving, and engineering thinking scales in the Engineering Change (EC2000) dataset, a nationally representative database contains 4,461 survey responses from engineering seniors of the class of 2004 in seven engineering disciplines (aerospace, chemical, civil, computer, electrical, industrial, and mechanical) in 39 institutions with ABET-accredited programs. The sample of colleges and universities included Doctoral, Masters, and Bachelors, and Specialized Institutions. The statistical procedures utilized include a multivariate regression to analyze the basic skills, design and problem-solving, and engineering thinking scales and then proportional-odds cumulative logit and baseline-category logit models to analyze the items within those scales.

The first step in the analysis determines the distribution of variance between the individual and organizational level, i.e., how much variation in the dependent measure is attributed to the organizational versus individual characteristics. If the intraclass correlation (organizational variance divided by the sum of the organizational and individual variance) is greater than .05, then developing a multi-level model (MLM, also known as hierarchal level modeling) is a more appropriate statistical method than multivariate regression[3] (Porter, 2005). Table 9 provides the estimated individual (residual column) and organizational (intercept

[3]Multivariate regression underestimates standard error estimates when subjects are not independent of each other (e.g., Graduates nested in institutions) (Ethington, 1997). Multi-level modeling accounts for this violation; however, multivariate regression is fairly robust when the intraclass correlation is less than .05 (Porter, 2005).

columns) variance with the corresponding intraclass correlation calculated for the three scales. The intercept variances for design and problem-solving and engineering thinking skills scales are significant at an alpha of .01, which indicates that there are significant differences among seniors between institutions. The intercept variance for basic skills was not significant, indicating that seniors' basic skills did not differ across institutions.

Even though the organizational variances are significant for design and problem-solving and engineering thinking skills, the intraclass correlations for both were small: .0195 and .0221. This suggests that the organizational characteristics explain 1.95 and 2.21 percent of the overall variance in those scales. Hence the majority of the variance in seniors' basic skills, design and problem-solving, and engineering thinking skills may be attributed to individual characteristics (e.g., college grade point average, socioeconomic status (SES), major, time spent in a design competition). Since the intraclass correlation is below .05, multivariate regression is utilized to examine the influence of time spent in a cooperative education or internship on the three scales and the control variables (i.e., college grade point average, SES, major, time spent in a design competition, urbanization of the institution, and Carnegie Classification).

Table 9: Partition of Variance between Individual and Organizational Level

Measure	Residual			Intercept			Intraclass Correlation
	Estimate	Std. Error	P-value	Estimate	Std. Error	P-value	
Basic Skills	.473150	.010399	.000	.002561	.001527	.094	.0215
Design and Problem-solving	.484506	.010654	.000	.009635	.003317	.004	.0194
Engineering Thinking Skills	.435874	.009588	.000	.009845	.003396	.004	.0221

The following sections examine the multivariate regression models developed for the basic skills, design and problem-solving, and engineering thinking skills scales by first analyzing the time spent in cooperative education or internship and all the control variables. The final model for each scale includes only the time spent in cooperative education or internship variable[4] and significant control variables. Only the variables in the final multivariate model are included when creating and analyzing the multinomial logistic regression models (proportional-odds cumulative logit and baseline-category logit) for the scales' items. Equation 3 is the general baseline-category logit model and Equation 4 is the general proportional-odds cumulative logit model for analyzing scale items.

Equation 3: General Baseline-category Logit Model for Analyzing Scale Items

$$\text{Log}\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right) = \beta_{10} + \beta_{11} * \text{Co-op} + \beta_{1x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right) = \beta_{20} + \beta_{21} * \text{Co-op} + \beta_{2x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{30} + \beta_{31} * \text{Co-op} + \beta_{3x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(More\ than\ Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{40} + \beta_{41} * \text{Co-op} + \beta_{4x} * \text{Control Variables}$$

Equation 4: General Proportional-odds Cumulative Logit Model for Analyzing Scale Items

$$\text{Log}\left(\frac{P(High\ Ability)}{P(More\ than\ Adequate\ Ability + Adequate\ Ability + Some\ Ability + No\ Ability)}\right) = \alpha_1 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability)}{P(Adequate\ Ability + Some\ Ability + No\ Ability)}\right) = \alpha_2 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability + Adequate\ Ability)}{P(Some\ Ability + No\ Ability)}\right) = \alpha_3 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability + Adequate\ Ability + Some\ Ability)}{P(No\ Ability)}\right) = \alpha_4 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

[4] The time spent in cooperative education or internship variable will be designated as "Co-op" in all the equations within this chapter.

For all the models, the significance of the time spent in cooperative education or internship variable answers the first research question: “Does experience in cooperative education or internship program influence students' self-perceptions of their engineering problem-solving skills?”

Basic Skills

The basic skills scale, which has a Cornbach’s alpha of .74, consisted of two items: 1) Apply knowledge of math and 2) Apply knowledge of physical sciences. The seniors of 2004 rated their ability on each item on a five-point Likert scale, where 1 = No Ability, 2 = Some Ability, 3 = Adequate Ability, 4 = More than Adequate Ability, and 5 = High Ability (See Appendix A for survey). Table 10 displays the distributions of 2004 seniors’ answers on the two items in the basic skills scale. The majority of the 2004 seniors reported that their abilities to apply knowledge of math and physical sciences were adequate or greater (98.59% and 97.17%).

Table 10: Distribution of 2004 Graduate Responses on the Items in the Basic Skills Scale

	No Ability	Some Ability	Adequate Ability	> Adequate Ability	High Ability
Apply knowledge of math	2 (.04%)	61 (1.37%)	802 (17.98%)	1932 (43.31%)	1664 (37.30%)
Apply knowledge of physical sciences	3 (.07%)	124 (2.78%)	1104 (24.75%)	2044 (45.82%)	1186 (26.59%)

Multivariate Regression Analysis on Basic Skills Scale

Equation 5 is the complete multivariate model for basic skills. All the independent variables in the model were entered into the model as categorical variables except SES variable which was entered as continuous. The reference group for the co-op/internship variable was seniors who had spent more than year in a co-op/internship. Table 11 shows that the urbanization and Carnegie Classification variables are not significant (p-values of .721 and .629) according to the Type III tests for fixed effects at an alpha of .05. All the majors except industrial engineering were not statistical different from mechanical engineering. Since industrial engineering was statistically significant, all the other engineering majors were included in the final model. Equation 6 presents the final model with these variables removed.

Equation 5: Complete Multivariate Regression Model for Basic Skills Scale

$$\text{Basic Skills} = \beta_0 + \text{Co-op/Internship} + \text{College GPA} + \text{SES} + \text{Design Competition} + \text{Major} + \text{Urbanization} + \text{Carnegie Classification}$$

Equation 6: Final Multivariate Regression Model for Basic Skills Scale

$$\text{Basic Skills} = \beta_0 + \text{Co-op/Internship} + \text{College GPA} + \text{SES} + \text{Design Competition} + \text{Major}$$

Table 12 provides the information criteria for both complete and final models. With smaller values for the Akaike's Information Criterion (AIC), Hurvich and Tsai's Criterion (AICC), Bozdogan's Criterion (CAIC), and Schwarz's Bayesian Criterion (BIC)[5], the final model is indeed better than the complete model. The final model explains about 8.19 percent of the variance in basic skills, which is slightly higher than the complete model, which explains 7.97 percent (Table 13).

Table 11: Type III Tests of Fixed Effects for Complete and Final Model for Basic Skills Scale

	Complete Model				Final Model			
	Num. df	**Denom. df**	**F**	**p-value**	**Num. df**	**Denom. df**	**F**	**p-value**
Intercept	1	4136	2058.20	.000	1	4146	2384.84	.000
Co-op/ Internship	4	4136	2.34	.053	4	4146	2.46	.044
College GPA	3	4136	86.07	.000	3	4146	86.81	.000
SES	1	4136	41.12	.000	1	4146	43.40	.000
Design Competition	4	4136	6.06	.000	4	4146	6.13	.000
Aerospace	1	4136	.966	.326	1	4146	1.23	.267
Chemical	1	4136	.640	.424	1	4146	.720	.396
Civil	1	4136	1.02	.313	1	4146	.906	.341
Computer	1	4136	.002	.965	1	4146	.003	.960
Electrical	1	4136	.089	.765	1	4146	.001	.972
Industrial	1	4136	15.23	.000	1	4146	13.81	.000
Urbanization	7	4136	.642	.721	--	--	--	--
Carnegie Classification	3	4136	.594	.619	--	--	--	--

[5] Akaike's Information Criterion (AIC), Hurvich and Tsai's Criterion (AICC), Bozdogan's Criterion (CAIC), and Schwarz's Bayesian Criterion (BIC) are measures to compare statistical models. When comparing between two models, the one with the smallest AIC, AICC, CAIC, and BIC is considered the better model.

Table 12: Information Criteria for Complete and Final Model for Basic Skills Scale

	Complete Model	Final Model
-2 Restricted Log Likelihood	8468.259	8434.633
Akaike's Information Criterion (AIC)	8470.259	8436.633
Hurvich and Tsai's Criterion (AICC)	8470.260	8436.634
Bozdogan's Criterion (CAIC)	8477.587	8443.963
Schwarz's Bayesian Criterion (BIC)	8476.587	8442.963

Table 13: Variance Explained for Complete and Final Model for Basic Skills Scale

	Residual Variance			Variance Explained
	Estimate	Standard Error	P-Value	
Unconditional Model[6]	.473150	.010399	.000	--
Complete Model	.435458	.009576	.000	.07966[7]
Final Model	.435207	.009559	.000	.08019[8]

Time Spent in a Co-op/Internship and Basic Skills Scale

In the final model, the cooperative education/internship variable (p-value of .044) is significant, suggesting that time spent has an influence on a seniors' basic skills (Table 11). Table 14 provides the final model estimates. The only significant parameter (alpha = .05) is between seniors who participated in a co-op or internship for 9 to 12 months (p-value of .016). With a negative estimate (-.0942), this indicates that on average, seniors who were in a co-op or internship for longer than a year reported better basic skills than seniors who participated in a co-op or internship for 9-12 months, after controlling for college GPA, SES, major, and time spent in a design competition. The non-significance of the other co-op parameter shows that seniors who did not participate, spent 1 to 4 months, or spent 5 to 8 months did not report significantly different basic skill levels than seniors who spent more than a year in a co-op or internship on basic skills after accounting for the control variables.

[6] The variance estimates for the unconditional model are found in Table 9.
[7] The variance explained for the complete model is calculated as the difference in the variance estimates of the unconditional model and the complete model divided by the variance estimate of the unconditional model ([.473150-.435458]/.473150).
[8] The variance explained for the final model is calculated as the difference in the variance estimates of the unconditional model and the final model divided by the variance estimate of the unconditional model ([.473150-.435207]/.473150).

Table 14: Final Model Estimates of Fixed Effects for Basic Skills

Parameter	Estimate	Std. Error	Df	t	p-value
Intercept	4.246	.167	4146	25.427	.000
Co-op/ Internship					
Did not participate	-.029	.032	4146	-.901	.368
1-4 months	-.003	.037	4146	-.087	.930
5-8 months	-.071	.037	4146	-1.903	.057
9-12 months	-.094	.039	4146	-2.418	.016
>12 months					
College GPA					
<2.50 (Below B-)	-.548	.046	4146	-11.838	.000
2.50-2.99 (B- to B)	-.386	.029	4146	-13.502	.000
3.00-3.49 (B to A-)	-.238	.024	4146	-9.750	.000
3.50-4.00 (A- to A)	-.548	.046	4146	-11.838	.000
SES	.031	.005	4146	6.588	.000
Major					
Aerospace Engineering	.114	.103	4146	1.109	.267
Chemical Engineering	.031	.037	4146	.848	.396
Civil Engineering	-.031	.033	4146	-.952	.341
Computer Engineering	-.002	.043	4146	-.050	.960
Electrical Engineering	-.001	.027	4146	-.035	.972
Industrial Engineering	-.158	.042	4146	-3.716	.000
Mechanical Engineering					
Time Spent in Design Competition					
Did not participate	-.161	.044	4146	-3.691	.000
1-4 months	-.111	.047	4146	-2.380	.017
5-8 months	-.097	.056	4146	-1.716	.086
9-12 months	.009	.064	4146	.146	.884
>12 months					

Multinomial Logistic Regression Analysis for Basic Skills' Items

Baseline-category logit models were utilized to analyze the basic skills items. The likelihood ratio is calculated to test whether a model is better than a horizontal-line approximation at the mean of the item. All models for the items examined in the basic skills scale are, to a statistically significantly degree, better than a means-estimate model at an alpha of .05 (see χ^2's and corresponding p-values in Table 15). This suggests that the variables examined in the models have an influence on the dependent variables (e.g., Apply knowledge of math and Apply knowledge of physical sciences).

Table 15: Testing the null hypothesis that the slope is equal to zero

	Proportional-Odds			Baseline Category		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Apply knowledge of math	19	348.40	<.0001	76	406.01	<.0001
Apply knowledge of physical sciences	19	423.26	<.0001	76	511.78	<.0001

The score test for the proportional odds (Table 16) tests the assumption that the variables' slopes in the model are equal across the different logit equations (Equation 1). The null hypothesis for this test is all slopes are equal, the alternative hypothesis is that at least one slope is different. At an alpha of .20, the null hypothesis is rejected and both items are modeled as baseline-category logit models (Equation 7).

Table 16: Score Test for the Proportional Odds

Item	df	χ^2	p-value	Model
Apply knowledge of math	57	73.08	.0742	Base-line Category
Apply knowledge of physical sciences	57	92.90	.0019	Base-line Category

Equation 7: Baseline-category Logit Model for Analyzing Apply Knowledge of Math and Apply Knowledge of Physical Sciences

$$\text{Log}\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right) = \beta_{10} + \beta_{11} * \text{Co-op} + \beta_{1x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right) = \beta_{20} + \beta_{21} * \text{Co-op} + \beta_{2x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{30} + \beta_{31} * \text{Co-op} + \beta_{3x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(More\ than\ Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{40} + \beta_{41} * \text{Co-op} + \beta_{4x} * \text{Control Variables}$$

The pseudo-R-square for the apply knowledge of math model is .0870; for the apply knowledge of physical science the pseudo-R-square is .1084 (Table 17), indicating that 8.7 percent and 10.8 percent of the variance respectively can be explained by the independent variables (i.e., co-op or internship, college GPA, SES, major, and time spent in a design competition).

Table 17: Pseudo-R-square for the Proportional-Odds and Baseline Category Model

	Proportional Odds	Baseline Category
Apply knowledge of math	.0752	.0870
Apply knowledge of physical sciences	.0906	.1084

Time Spent in a Co-op/Internship and Basic Skills' Items

The Wald chi-square tests the significance of the main effects of the baseline category logit model (Table 18). The co-op or internship variable for the baseline category logit model is not statistically significant at an alpha of .05 for any of the items in the basic skills.

Table 18: Likelihood Ratio Tests of the Main Effect for the Baseline Category

	Co-op/ Internship			College GPA			SES		
Item	df	χ^2	p-value	df	χ^2	p-value	df	χ^2	p-value
Apply knowledge of math	16	16.32	.4312	12	246.9	<.0001	4	23.56	<.0001
Apply knowledge of physical sciences	16	11.51	.7770	12	204.3	<.0001	4	37.93	<.0001

Table 18: Likelihood Ratio Tests of the Main Effect for the Baseline Category (con't)

	Major			Design Competition		
Item	df	χ^2	p-value	df	χ^2	p-value
Apply knowledge of math	28	40.85	.05554	16	8.55	.9307
Apply knowledge of physical sciences	28	135.25	<.0001	16	44.64	.0002

The baseline category model's parameters' estimates for the time spent in a cooperative education or internship variable (Table 19 and Table 20) provides an opportunity to examine any statistically significant differences between groups within the four ability levels (i.e., are seniors who have spent over a year in a co-op or internship more likely to rate themselves of having "high ability" than "no ability" in applying knowledge of mathematics as compared to seniors with no co-op or internship experience). Since all but one parameter estimates and all of the main effects are not significant (alpha of .05), this suggests time spent in a cooperative education or internship appears to have no influence on a graduate's ability to apply knowledge of math and apply knowledge of physical sciences.

Table 19: Co-op/Internship Parameter Estimates on Apply Knowledge of Math[9]

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P\ (>\ Adequate\ Ability)}{P(High\ Ability)}\right)$[10]			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	>1000	725.4	.00	.9883	.983	.443	.00	.9688	1.098	.141	.44	.5067	.886	.108	1.25	.2631
1-4 months	.310	984.8	.00	.9991	1.401	.490	.47	.4916	.823	.171	1.30	.2537	.993	.123	.00	.9555
5-8 months	.305	1018	.00	.9991	.997	.547	.00	.9960	1.173	.167	.92	.3376	1.047	.126	.14	.7122
9-12 months	.520	1046	.00	.9995	1.463	.533	.51	.4749	1.281	.174	2.04	.1530	1.097	.131	.50	.4784

Table 20: Co-op/Internship Parameter Estimates on Apply Knowledge of Physical Sciences[11]

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	>1000	623.7	.00	.9845	.948	.314	.03	.8662	1.052	.139	.13	.7156	.888	.116	1.03	.3092
1-4 months	>1000	623.7	.00	.9833	.834	.383	.22	.6356	1.054	.161	.11	.7445	.968	.134	.06	.8053
5-8 months	1.038	976.8	.00	1.000	1.07	.395	.03	.8647	1.395	.163	4.17	.0413	1.13	.137	.79	.3729
9-12 months	1.102	1042	.00	.9999	1.372	.386	.67	.4117	1.282	.17	2.14	.1431	1.067	.142	.21	.6456

9 Appendix E provides the parameter estimates for the control variables for the survey item, "Apply knowledge of math"
10 More than adequate ability for this table and subsequent tables with co-op/internship parameter estimates is denoted as "> than adequate."
11 Appendix E provides the parameter estimates for the control variables for the survey item, "Apply knowledge physical sciences"

Design and Problem-solving Skills

The design and problem-solving skills scale, which has a Cornbach's alpha of .92, consisted of six items: 1) Apply discipline-specific engineering knowledge, 2) Understand essential aspects of the engineering design process, 3) Apply systematic design procedures to open-ended problem, 4) Design solutions to meet desired needs, 5) Define key engineering problems and 6) Formulate a range of solutions to an engineering problem. Seniors rated their ability on each item on a five-point Likert-like scale, where 1 = No Ability, 2 = Some Ability, 3 = Adequate Ability, 4 = More than Adequate Ability, and 5 = High Ability (See Appendix A for survey). Table 21 displays the distributions of 2004 seniors' answers to the six items in the design and problem-solving skills scale. The majority of the seniors reported their ability to be adequate or greater on the items within the design and problem-solving scale (i.e., the sum of those responding that they had adequate ability, more than adequate ability, or high ability was greater than 90 percent for all six items).

Table 21: Distribution of 2004 Graduate Responses on the Items in the Design and Problem-solving Scale

	No Ability	Some Ability	Adequate Ability	> Adequate Ability	High Ability
Apply discipline-specific engineering knowledge	6 (.13%)	138 (3.09%)	973 (21.81%)	2022 (45.33%)	1322 (29.63%)
Understand essential aspects of the engineering design process	12 (.27%)	135 (3.03%)	978 (21.92%)	2022 (45.33%)	1314 (29.46%)
Apply systematic design procedures to open-ended problem	30 (.67%)	300 (6.72%)	1305 (29.25%)	1824 (40.89%)	1002 (22.46%)
Design solutions to meet desired needs	19 (.43%)	207 (4.64%)	1133 (25.40%)	1959 (43.91%)	1143 (25.62%)
Define key engineering problems	14 (.31%)	194 (4.35%)	1247 (27.96%)	1994 (44.71%)	1011 (22.67%)
Formulate a range of solutions to an engineering problem	16 (.36%)	233 (5.22%)	1297 (29.07%)	1932 (43.31%)	983 (22.04%)

Multivariate Regression Analysis on Design and Problem-solving Skills Scale

Equation 8 is the complete multivariate model for design and problem-solving skills. All the independent variables were entered into the model as categorical variables except for the SES variable which is modeled as continuous. The reference group for the co-op or internship variable contained seniors who had spent more than year in a co-op or internship. As shown in Table 22, the Carnegie Classification variable is not significant (p-value of .707) according to the Type III tests for fixed effects at an alpha of .05. Thus, Equation 9 is the final model with this variable removed.

Equation 8: Complete Multivariate Regression Model for Design and Problem-solving Skills Scale

Design and Problem-solving Skills = β_0 + Co-op/Internship + College GPA + SES + Design Competition + Major + Urbanization + Carnegie Classification

Equation 9: Final Multivariate Regression Model for Design and Problem-solving Skills Scale

Design and Problem-solving Skills = β_0 + Co-op/Internship + College GPA + SES + Design Competition + Major + Urbanization

Table 23 provides the information criteria for both complete and final models. With smaller values for the Akaike's Information Criterion (AIC), Hurvich and Tsai's Criterion (AICC), Bozdogan's Criterion (CAIC), and Schwarz's Bayesian Criterion (BIC), the final model an improvement over the complete model. The final model explains about 8.91 percent of the design and problem-solving skills' variance. This is slightly higher than the complete model which explains 8.89 percent (Table 24).

Time Spent in a Co-op/ Internship and Design and Problem-solving Skills Scale

In the final model, the cooperative education or internship variable (p-value = .004) is significant, suggesting that time spent in co-op or an internship has an influence on seniors' design and problem-solving skills (Table 22). Table 25 provides the final model estimates. At an alpha of .05, all the co-op or internship parameters are significant (p-values of .000, .002, .001,

.010) and negative (-.12, -.11, -.12, -.10), which suggests that seniors who spent more than one year in a co-op or internship report better design and problem-solving skills than those who either did not participate or participated for up to 12 months in a co-op or internships. These results hold true after accounting for the control variables.

Table 22: Type III Tests of Fixed Effects for Complete and Final Model for Design and Problem-solving Skills Scale

	Complete Model				Final Model			
	Num. df	Denom. df	F	p-value	Num. Df	Denom. df	F	p-value
Intercept	1	4136	2121.17	.000	1	4139	2228.30	.000
Co-op/ Internship	4	4136	3.82	.004	4	4139	3.87	.004
College GPA	3	4136	42.46	.000	3	4139	43.00	.000
SES	1	4136	59.87	.000	1	4139	64.50	.000
Design Competition	4	4136	41.54	.000	4	4139	41.50	.000
Aerospace	1	4136	1.32	.251	1	4139	1.47	.225
Chemical	1	4136	14.52	.000	1	4139	14.19	.000
Civil	1	4136	.18	.676	1	4139	.15	.696
Computer	1	4136	16.00	.000	1	4139	15.82	.000
Electrical	1	4136	3.47	.063	1	4139	3.41	.065
Industrial	1	4136	5.18	.023	1	4139	5.55	.019
Urbanization	7	4136	3.15	.003	7	4139	3.06	.003
Carnegie Classification	3	4136	.46	.707	--	--	--	--

Table 23: Information Criteria for Complete and Final Model for Design and Problem-solving Skills Scale

	Complete Model	Final Model
-2 Restricted Log Likelihood	8525.305	8514.665
Akaike's Information Criterion (AIC)	8527.305	8516.665
Hurvich and Tsai's Criterion (AICC)	8527.306	8516.666
Bozdogan's Criterion (CAIC)	8534.633	8523.993
Schwarz's Bayesian Criterion (BIC)	8533.633	8522.993

Table 24: Variance Explained for Complete and Final Model for Design and Problem-solving Skills Scale

	Residual Variance			Variance Explained
	Estimate	Standard Error	P-Value	
Unconditional Model[12]	.484506	.010654	.000	--
Complete Model	.441506	.009709	.000	.08875[13]
Final Model	.441335	.009701	.000	.08910[14]

[12] The variance estimates for the unconditional model are found in Table 9.

[13] The variance explained for the complete model is calculated as the difference in the variance estimates of the unconditional model and the complete model divided by the variance estimate of the unconditional model ([.484506-.441506]/.484506).

Table 25: Final Model Estimates of Fixed Effects for Design and Problem-solving Skills

Parameter	Estimate	Std. Error	df	t	p-value
Intercept	4.450	.172	4139	25.801	.000
Co-op/Internship					
Did not participate	-.121	.032	4139	-3.690	.000
1-4 months	-.114	.037	4139	-3.064	.002
5-8 months	-.121	.038	4139	-3.209	.001
9-12 months	-.101	.039	4139	-2.570	.010
>12 months					
College GPA					
<2.50 (Below B-)	-.401	.047	4139	-8.590	.000
2.50-2.99 (B- to B)	-.258	.029	4139	-8.944	.000
3.00-3.49 (B to A-)	-.189	.025	4139	-7.698	.000
3.50-4.00 (A- to A)					
SES	.039	.005	4139	8.031	.000
Major					
Aerospace Engineering	-.126	.104	4139	-1.213	.225
Chemical Engineering	.139	.037	4139	3.766	.000
Civil Engineering	-.013	.033	4139	-.391	.696
Computer Engineering	-.176	.044	4139	-3.978	.000
Electrical Engineering	.052	.028	4139	1.847	.065
Industrial Engineering	-.101	.043	4139	-2.356	.019
Mechanical Engineering					
Time Spent in Design Competition					
Did not participate	-.401	.044	4139	-9.077	.000
1-4 months	-.200	.047	4139	-4.248	.000
5-8 months	-.132	.057	4139	-2.324	.020
9-12 months	-.066	.065	4139	-1.021	.307
>12 months	-.401	.044	4139	-9.077	.000
Urbanization					
City: Large	-.002	.045	4139	-.055	.956
City: Midsize	.114	.048	4139	2.395	.017
City: Small	.040	.046	4139	.878	.380
Suburb: Large	.185	.091	4139	2.037	.042
Suburb: Midsize	.037	.061	4139	.601	.548
Town: Fringe	-.015	.071	4139	-.212	.832
Town: Distant	-.062	.122	4139	-.510	.610
Rural: Fringe					

[14] The variance explained for the final model is calculated as the difference in the variance estimates of the unconditional model and the complete model divided by the variance estimate of the unconditional model ([.484506-.441335]/.484506).

Multinomial Logistic Regression Analysis on Design and Problem-solving Skills Items

According to the likelihood ratio test, all proportional-odds cumulative and baseline-category logit models for the items examined in the design and problem-solving skills scale are better to a statistically significant degree than a means-estimate model at an alpha of .05 (Table 26).

Table 26: Testing the null hypothesis that the slope is equal to zero

	Proportional-Odds			Baseline Category		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Apply discipline-specific engineering knowledge	26	482.27	<.0001	104	583.41	<.0001
Understand essential aspects of the engineering design process	26	347.49	<.0001	104	418.82	<.0001
Apply systematic design procedures to open-ended problem	26	403.21	<.0001	104	483.16	<.0001
Design Solutions to meet desired needs	26	389.80	<.0001	104	480.31	<.0001
Define key engineering problems	26	357.71	<.0001	104	450.18	<.0001
Formulate a range of solutions to an engineering problem	26	359.63	<.0001	104	447.09	<.0001

At an alpha of .20, the null hypothesis for the score test is rejected for four of the six items in the design and problem-solving scale: 1) Apply discipline-specific engineering knowledge, 2) Design solutions to meet desired needs, 3) Define key engineering problems, 4) Formulate a range of solutions to an engineering problem (Table 27). These items are best modeled with a base-line category logit model. Understanding essential aspects of the engineering design process and applying systematic design procedures to open-ended problems had p-values of .3195 and .4628 respectively, which suggests that the proportional-odds cumulative model is best for these items. Equation 10 and Equation 11 are logit models for the design and problem-solving skills items. The appropriate equation for each item is labeled in Table 27.

Table 27: Score Test for the Proportional Odds

Item	df	χ^2	p-value	Model
Apply discipline-specific engineering knowledge	78	98.35	.0595	Base-line category
Understand essential aspects of the engineering design process	78	83.31	.3195	Proportional-odds cumulative
Apply systematic design procedures to open-ended problem	78	78.50	.4628	Proportional-odds cumulative
Design Solutions to meet desired needs	78	93.18	.1157	Base-line category
Define key engineering problems	78	91.19	.1458	Base-line category
Formulate a range of solutions to an engineering problem	78	92.26	.1289	Base-line category

Equation 10: Baseline-category Logit Model for Apply Discipline-specific Engineering Knowledge, Design Solutions to Meet Desired Needs, Define Key Engineering Problems, and Formulate a Range of Solutions to an Engineering Problem

$$\text{Log}\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right) = \beta_{10} + \beta_{11} * \text{Co-op} + \beta_{1x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right) = \beta_{20} + \beta_{21} * \text{Co-op} + \beta_{2x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{30} + \beta_{31} * \text{Co-op} + \beta_{3x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(More\ than\ Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{40} + \beta_{41} * \text{Co-op} + \beta_{4x} * \text{Control Variables}$$

Equation 11: Proportional-odds Cumulative Logit Model for Understand Essential Aspects of the Engineering Design and Apply Systematic Design Procedures to Open-ended Design

$$\text{Log}\left(\frac{P(High\ Ability)}{P(More\ than\ Adequate\ Ability + Adequate\ Ability + Some\ Ability + No\ Ability)}\right)$$
$$= \alpha_1 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability)}{P(Adequate\ Ability + Some\ Ability + No\ Ability)}\right)$$
$$= \alpha_2 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability + Adequate\ Ability)}{P(Some\ Ability + No\ Ability)}\right)$$
$$= \alpha_3 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability + Adequate\ Ability + Some\ Ability)}{P(No\ Ability)}\right)$$
$$= \alpha_4 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

The pseudo-R-square for the items in the design and problem-solving skills scale ranges from .0750 to .1226 (Table 28). This suggests that the independent variables in the model (i.e., co-op or internship, college GPA, SES, major, time spent in a design competition, and urbanization) explain between 7.5 and 12.26 percent of the variance in these measures.

Table 28: Pseudo-R-square for the Proportional-Odds and Baseline Category Model

	Proportional Odds	**Baseline Category**
Apply discipline-specific engineering knowledge	.1025	.1226
Understand essential aspects of the engineering design process	.0750	.0896
Apply systematic design procedures to open-ended problem	.0865	.1027
Design Solutions to meet desired needs	.0837	.1021
Define key engineering problems	.0771	.0961
Formulate a range of solutions to an engineering problem	.0775	.0954

Time Spent in a Co-op/ Internship and Design and Problem-solving Skills' Items

Table 29 and Table 30 provide the Wald chi-square tests for the baseline category logit models and the proportional-odds cumulative logit models. A significant Wald chi square suggests that the variable is significant in explaining some of the variance in the dependent variable. At an alpha of .05, the co-op or internship variable is significant for Understanding essential aspects of the engineering design solution (p-value = .0008), Applying systematic design procedures to open-ended problem (p-value = .0009), and Designing solutions to meet desired needs (p-value = .0036). Applying discipline-specific engineering knowledge (p-value = .0751) and Defining key engineering problems (p-value = .0654) are significant when alpha is set to .10. Time spent in a co-op or internship has no significant influence on an engineering senior's perception of their ability to formulate a range of solutions to an engineering problem (p-value = .1909).

Table 29: Likelihood Ratio Tests of the Main Effect for the Baseline Category

	Co-op/ Internship			College GPA			SES		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Apply discipline-specific engineering knowledge	16	24.71	.0751	12	212.6	<.0001	4	51.17	<.0001
Design solutions to meet desired needs	16	35.33	.0036	12	73.34	<.0001	4	48.75	<.0001
Define key engineering problems	16	25.24	.0656	12	63.46	<.0001	4	66.68	<.0001
Formulate a range of solutions to an engineering problem	16	20.69	.1909	12	80.03	<.0001	4	64.76	<.0001

Table 29: Likelihood Ratio Tests of the Main Effect for the Baseline Category (con't)

	Major			Design Competition			Urbanization		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Apply discipline-specific engineering knowledge	28	84.79	<.0001	16	100.74	<.0001	28	27.86	.4721
Design solutions to meet desired needs	28	82.01	<.0001	16	131.07	<.0001	28	39.87	.0679
Define key engineering problems	28	44.80	.0231	16	130.19	<.0001	28	36.77	.1241
Formulate a range of solutions to an engineering problem	28	52.40	.0034	16	125.04	<.0001	28	39.56	.0724

Table 30: Likelihood Ratio Tests of the Main Effect for the Proportional Odds Model

	Co-op/ Internship			College GPA			SES		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Understand essential aspects of the engineering design process	4	19.04	.0008	3	66.10	<.0001	1	44.09	<.0001
Apply systematic design procedures to open-ended problem	4	18.67	.0009	3	73.98	<.0001	1	62.23	<.0001

Table 30: Likelihood Ratio Tests of the Main Effect for the Proportional Odds Model (con't)

	Major			**Design Competition**			**Urbanization**		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Understand essential aspects of the engineering design process	7	45.98	<.0001	4	101.36	<.0001	7	20.58	.0045
Apply systematic design procedures to open-ended problem	7	57.24	<.0001	4	126.4	<.0001	7	24.08	.0011

The baseline category and proportional odds models parameters' estimates for the time spent in a cooperative education or internship variable (Table 31, Table 32, Table 33, Table 34, Table 35, and Table 36) show the statistically significant differences between groups within abilities. Appendix E provides the parameter estimates for the control variables for each survey item in the design and problem-solving skill scale.

Apply discipline-specific engineering knowledge. Table 31 provides the parameter estimates for the baseline category model for the item Apply discipline-specific engineering knowledge. Even though the main effect is not significant at an alpha of .05, significant parameter estimates suggest time spent in a cooperative education or internship has an influence on a senior's perception of his ability to apply discipline-specific engineering knowledge. Seniors with one to four months of co-op or internship experiences were almost twice (1.92) as likely to rate themselves as having some ability than seniors with more than a year experience who rated themselves as having high ability on this item. The odds ratio estimates decrease as time spent in a co-op or internship increases; however, seniors who spent five to eight months report higher levels of ability than seniors who spent nine to twelve months (1.850 versus 2.324).

Examining the parameter estimates for seniors with adequate ability and more than adequate ability versus those with high ability, we see that seniors with no experience, seniors one to four months of co-op or internship experience, seniors with five to eight months experience, and seniors with nine to twelve months experience are more likely to assess their ability as either adequate or more than adequate than high (odds ratio greater than one) compared to seniors with more than twelve months experience. All of these odds ratios are significant at an alpha of .05, except for seniors with nine to twelve of work experience who assess their ability adequate compared to high ability (p-value = .0860).

When examining the parameter estimate for the four equations (Table 31), the odds ratio estimates does not appear to follow a linear trend. For example, when examining the odds ratio estimate for the adequate ability to the high ability equation, there is an n-shape trend (odds ratio estimate of 1.367 for zero months; odds ratio estimate of 1.474 for one to four months; odds ratio estimate of 1.725 for five to eight months; and odds ratio estimate of 1.352 for nine to twelve months). This is not the case when comparing seniors with more than adequate ability to seniors with high ability, as the parameter estimates suggests no discernable trend (odds ratio estimate of 1.392 for students who did not participate; odds ratio estimate of 1.378 for one to four months; odds ratio estimate of 1.460 for five to eight months; and odds ratio estimate of 1.424 for nine to twelve months).

Understand essential aspects of the engineering design process. Table 32 provides the parameter estimates for the proportional odds model for the item, Understand essential aspects of the engineering design. All the odds ratio estimates in the proportional odds model for this item are less than one (1.0), which implies that seniors with less than 12 months are less likely to rate themselves as having high ability compared to seniors who have spent more than twelve months in a co-op or internship. On this item, seniors with more than twelve months of experience are significantly better in reported abilities than the other seniors (alpha = .05). The parameter estimates suggests no discernable trend with respect to time spent in a co-op or internship (odds ratio estimate of .685 for students who did not participate; odds ratio estimate of .728 for one to four months; odds ratio estimate of .705 for five to eight months; and odds ratio estimate of .790 for nine to twelve months).

Apply systematic design procedures to open-ended problem. I provide the parameter estimates for the proportional odds model for Apply systematic design procedures to open-ended problems in Table 33. The overall trend of these estimates suggest that as time spent in co-op or internship increases, students rate their abilities higher (odds ratio estimates are .723, .754, .680, and .851). The estimate for seniors with nine to twelve months experience is not significant (p-value = .1344), which provides evidence that there is no significant difference between these seniors and seniors with more than twelve months of co-op or internship experience.

Design solutions to meet desired needs. Table 34 provides the parameter estimates for the baseline category model for the item, Design solutions to meet desired needs. Seniors with less than 12 months are less likely to rate themselves at high ability than adequate or more than adequate ability as compared to a seniors who have spent more than twelve months in a co-op or internship (all odds ratio estimates in this model are greater than one). As time spent in co-op or internship increases, the overall trend for both the odds ratio of adequate versus high ability and more than adequate versus high ability is decreasing (odds ratio estimates are 1.558, 1,538, 1,861, and 1,453 for adequate ability and 1.575, 1.389, 1.605, and 1.373 for more than adequate ability).

Define key engineering problems. Table 35 provides the parameter estimates for the baseline category model for the item, Define key engineering problems. The odds ratio estimates for seniors who do not participate in a co-op or internship suggest that they are significantly different in their perceptions of having either some ability or adequate ability to define key engineering problems when compared to seniors who spent more than a year in a co-op or internship. Seniors who spent nine to twelve months in co-op or internship are equally likely to say they have either no ability or some ability as compared to those seniors who have more than twelve months of experience (using an alpha of .05). However, those who spent nine to twelve months in a co-op or internship are more likely to assess their ability in defining key engineering problems as adequate or more than adequate than high when compared to seniors who spent more than twelve months in a co-op or internship (odds ratio estimates of 1.418 and 1.425; and p-values of .0404 and .0149 respectively).

Except for the more than adequate ability versus high ability, the significant parameter estimates (alpha = .05) show a decreasing trend (for some ability versus high ability, odds ratio are 2.223 and 2.056; for adequate ability versus high ability odds ratio estimates are 1.592, 1.494, 1.561, and 1.418), which implies that as time increases in a co-op or internship, the 2004 seniors are more likely to give themselves a high rating on ability to define key engineering problems.

Formulate a range of solutions to an engineering problem. The parameter estimates for the baseline category model for the item, Formulate a range of solutions to an engineering problem are found in Table 36. Seniors who do not participate in a co-op or internship are significantly different in their perception of their abilities from seniors who participated in a co-op or internship for more than twelve months on this item (odds ratios are significant for some ability, adequate ability, and more than adequate ability). Seniors who spent nine to twelve months are more likely to self-assess their ability in formulating a range of solutions to an engineering problem as adequate or more than adequate than high compared to seniors with more than twelve months (odds ratio estimate s= 1.464 and 1.530 with p-values = .0234 and .0043). The odds ratio for adequate ability is less than that for seniors who spent five to eight months in a co-op or internship (1.511, p-value = .0089).

The only significant parameter when examining the some ability seniors versus the higher ability seniors equation is the people who did not participate in a co-op nor an internship (odds ratio are 1.918 with p-values of .0105). Seniors with one to four months of experience are equally likely to rate their ability as the same regardless of time spent in a co-op or internship.

Table 31: Co-op/Internship Parameter Estimates on Apply Discipline-specific Engineering Knowledge

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	>1000	508	.00	.9826	1.923	. 325	4.05	.0441	1.367	. 142	4.86	.0274	1.392	. 113	8.53	.0035
1-4 months	>1000	508	.00	.9788	1.905	. 373	2.99	.0839	1.474	. 164	5.58	.0182	1.378	. 131	6.03	.0141
5-8 months	>1000	508	.00	.9804	1.850	. 384	2.57	.1090	1.725	. 165	10.9	.0010	1.460	. 133	8.13	.0044
9-12 months	.604	834	.00	.9995	2.324	. 378	4.98	.0256	1.352	. 176	2.95	.0860	1.424	. 136	6.72	.0095

Table 32: Co-op/Internship Parameter Estimates on Understand Essential Aspects of the Engineering Design Process

	Odds Est.	**Std. Error**	χ^2	**p-value**
Did not participate	.685	.090	17.61	<.0001
1-4 months	.728	.104	9.36	.0022
5-8 months	.705	.105	11.09	.0009
9-12 months	.790	.109	4.66	.0309

Table 33: Co-op/Internship Parameter Estimates on Apply Systematic Design Procedures to Open-ended Problem

	Odds Est.	**Std. Error**	χ^2	**p-value**
Did not participate	.723	.089	13.34	.0003
1-4 months	.754	.102	7.60	.0058
5-8 months	.680	.103	13.94	.0002
9-12 months	.851	.107	2.24	.1344

Table 34: Co-op/Internship Parameter Estimates on Design Solutions to Meet Desired Needs

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	>1000	270.1	.00	.9632	2.324	.263	10.3	.0014	1.558	.136	10.57	.0011	1.575	.117	15.1	.0001
1-4 months	>1000	270.1	.00	.9626	1.750	.309	3.28	.0700	1.538	.157	7.54	.0060	1.389	.135	5.93	.0149
5-8 months	>1000	270.1	.00	.9630	1.589	.327	2.00	.1573	1.861	.159	15.3	<.001	1.605	.138	11.7	.0006
9-12 months	>1000	270.1	.00	.9662	1.042	.362	.01	.9100	1.453	.165	5.14	.0234	1.373	.14	5.12	.0237

Table 35: Co-op/Internship Parameter Estimates on Define Key Engineering Problems

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	2.050	1.096	.43	.5126	2.223	.289	7.67	.0056	1.592	.138	11.30	.0008	1.207	.121	2.43	.1191
1-4 months	1.799	1.241	.22	.6363	2.056	.328	4.82	.0281	1.494	.159	6.35	.0117	1.194	.139	1.63	.2020
5-8 months	3.025	1.177	.88	.3470	1.617	.349	1.89	.1691	1.561	.161	7.68	.0056	1.240	.141	2.35	.1253
9-12 months	1.424	1.432	.06	.8049	1.531	.37	1.32	.2498	1.418	.17	4.20	.0404	1.425	.145	5.93	.0149

Table 36: Co-op/Internship Parameter Estimates on Formulate a Range of Solutions to an Engineering Problem

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	3.064	1.084	1.07	.3017	1.918	.255	6.55	.0105	1.457	.137	7.55	.0060	1.305	.123	4.67	.0307
1-4 months	1.899	1.245	.27	.6067	1.703	.295	3.25	.0713	1.377	.157	4.15	.0417	1.220	.141	1.98	.1592
5-8 months	2.198	1.243	.40	.5265	1.564	.307	2.13	.1444	1.511	.158	6.84	.0089	1.229	.143	2.07	.1498
9-12 months	1.556	1.432	.10	.7574	1.371	.334	.89	.3453	1.464	.168	5.14	.0234	1.530	.149	8.15	.0043

Engineering Thinking Skills

The following nine items form the engineering thinking skills scale with a Cornbach's alpha of .94: 1) Break down complex problems to simpler ones; 2) Apply fundamentals to problems that I haven't seen before; 3) Know when to use a formula, algorithm, or other rule; 4) Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems; 5) Draw conclusions from evidence or premises; 6) Develop a course of action based on my understanding of a whole system; 7) Ensure that a process or product meets a variety of technical and practical criteria; 8) Compare and judge alternative outcomes; and 9) Develop learning strategies that I can apply in my professional life. Seniors rated their ability on each item on a five-point Likert scale, where 1 = No Ability, 2 = Some Ability, 3 = Adequate Ability, 4 = More than Adequate Ability, and 5 = High Ability (See Appendix A for survey). Table 37 displays the distributions of participants' answers to each of the nine items in the engineering thinking skills scale. The majority (more than 90%) of the seniors reported their ability to be adequate or greater for each of the nine items in the engineering thinking skills scale.

Table 37: Distribution of 2004 Graduate Responses on the Items in the Engineering Thinking Skills Scale

	No Ability	**Some Ability**	**Adequate Ability**	**> Adequate Ability**	**High Ability**
Break down complex problems to simpler ones*	5 (.11%)	138 (3.09%)	1069 (23.97%)	1989 (44.60%)	1259 (28.23%)
Apply fundamentals to problems that I haven't seen before	19 (.43%)	299 (6.70%)	1428 (32.01%)	1783 (39.97%)	932 (20.89%)
Identify critical variables, information, and/or relationship involved in a problem	4 (.09%)	159 (3.56%)	1205 (27.01%)	1987 (44.54%)	1106 (24.79%)
Know when to use a formula, algorithm, or other rule	14 (.31%)	286 (6.41%)	1342 (30.07%)	1800 (40.35%)	1019 (22.84%)
Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems.	9 (.20%)	271 (6.07%)	1364 (30.58%)	1922 (43.08%)	895 (20.06%)

Table 37: Distribution of 2004 Graduate Responses on the Items in the Engineering Thinking Skills Scale (con't)

	No Ability	Some Ability	Adequate Ability	> Adequate Ability	High Ability
Draw conclusions from evidence or premises*	5 (.11%)	160 (3.59%)	1139 (25.54%)	2066 (46.32%)	1090 (24.44%)
Develop a course of action based on my understanding of a whole system	10 (.22%)	169 (3.79%)	1122 (25.15%)	2085 (46.74%)	1075 (24.10%)
Ensure that a process or product meets a variety of technical and practical criteria	24 (.54%)	181 (4.06%)	1262 (28.29%)	2025 (45.39%)	969 (21.72%)
Compare and judge alternative outcomes	7 (.16%)	157 (3.52%)	1124 (25.20%)	2114 (47.39%)	1059 (23.74%)
Develop learning strategies that I can apply in my professional life	23 (.52%)	165 (3.70%)	1106 (24.80%)	1980 (44.40%)	1185 (26.58%)

Multivariate Regression Analysis on Engineering Thinking Skills Scale

The complete multivariate regression model for engineering thinking skills is shown in Equation 12. As for the other multivariate regression models for the other two focal outcomes, the independent variables were entered into the model as categorical except for the SES variable which was entered as a continuous variable. The reference group for the co-op or internship variable was seniors who had spent more than year in a co-op or internship. As show in Table 38, the Carnegie Classification variable is not significant (p-values of .133) according to the Type III tests for fixed effects at an alpha of .05. Equation 13 is the final model with the non-significant variable removed.

Table 38: Type III Tests of Fixed Effects for Complete and Final Model for Engineering Thinking Skills Scale

	Complete Model				Final Model			
	Num. df	**Denom. df**	**F**	**p-value**	**Num. df**	**Denom. df**	**F**	**p-value**
Intercept	1	4136	2352.12	.000	1	4139	2487.31	.000
Co-op/ Internship	4	4136	1.80	.126	4	4139	1.88	.111
College GPA	3	4136	55.16	.000	3	4139	55.34	.000
SES	1	4136	67.71	.000	1	4139	73.17	.000
Design Competition	4	4136	25.79	.000	4	4139	25.62	.000
Aerospace	1	4136	.948	.330	1	4139	1.18	.278
Chemical	1	4136	.940	.332	1	4139	1.13	.287
Civil	1	4136	1.40	.238	1	4139	1.31	.253
Computer	1	4136	24.15	.000	1	4139	23.65	.000
Electrical	1	4136	8.20	.004	1	4139	9.06	.003
Industrial	1	4136	13.69	.000	1	4139	15.07	.000
Urbanization	7	4136	3.19	.002	7	4139	3.06	.003
Carnegie Classification	3	4136	1.87	.133	--	--	--	--

Equation 12: Complete Multivariate Regression Model for Engineering Thinking Skills Scale

Engineering Thinking Skills = β_0 + Co-op/Internship + College GPA + SES + Design Competition + Major + Urbanization + Carnegie Classification

Equation 13: Final Multivariate Regression Model for Engineering Thinking Skills Scale

Engineering Thinking Skills = β_0 + Co-op/Internship + College GPA + SES + Design Competition + Major + Urbanization

Table 39 provides the information criteria for both complete and final models. The smaller values for the Akaike's Information Criterion (AIC), Hurvich and Tsai's Criterion (AICC), Bozdogan's Criterion (CAIC), and Schwarz's Bayesian Criterion (BIC) reveal that the final model is indeed better than the complete model. The final model explains about 7.55 percent of the variance, which is slightly lower than the complete model which explains 7.61 percent (Table 40).

Table 39: Information Criteria for Complete and Final Model for Engineering Thinking Skills Scale

	Complete Model	Final Model
-2 Restricted Log Likelihood	8144.701	8137.999
Akaike's Information Criterion (AIC)	8146.701	8139.999
Hurvich and Tsai's Criterion (AICC)	8146.702	8140.000
Bozdogan's Criterion (CAIC)	8154.029	8147.327
Schwarz's Bayesian Criterion (BIC)	8153.029	8146.327

Table 40: Variance Explained for Complete and Final Model for Design and Engineering Thinking Skills Scale

	Residual Variance			Variance Explained
	Estimate	Standard Error	P-Value	
Unconditional Model[15]	.435874	.009588	.000	--
Complete Model	.402691	.008855	.000	.07613[16]
Final Model	.402945	.008858	.000	.07555[17]

Time Spent in a Co-op/ Internship and Engineering Thinking Skills Scale

In the final model, the cooperative education or internship variable (p-value of .111) is not significant, implying that the amount of time spent has no influence on a student's perception of their engineering thinking skills (Table 38). Table 41 provides the final model estimates. The p-values are significant at an alpha of .05 for seniors who did not participate (-.074), seniors who were in a co-op or internship for 5 to 8 months (-.078) and seniors who were in a co-op or internship for 9 to 12 months parameters (-.091). The parameter estimates are negative, suggesting that seniors who spent more than one year in a co-op or internship rated their engineering thinking skills higher after controlling for college GPA, SES, major, time spent in a design competition, and the nature of the institution.

[15] The variance estimates for the unconditional model are found in Table 9.
[16] The variance explained for the complete model is calculated as the difference in the variance estimates of the unconditional model and the complete model divided by the variance estimate of the unconditional model ([.435874-.402691]/.435874).
[17] The variance explained for the final model is calculated as the difference in the variance estimates of the unconditional model and the final model divided by the variance estimate of the unconditional model ([.435874-.402945]/. 435874).

Table 41: Final Model Estimates of Fixed Effects for Engineering Thinking Skills

Parameter	Estimate	Std. Error	df	t	P-value
Intercept	4.720	.165	4139	28.637	.000
Co-op/ Internship					
Did not participate	-.074	.031	4139	-2.353	.019
1-4 months	-.063	.036	4139	-1.775	.076
5-8 months	-.078	.036	4139	-2.165	.030
9-12 months	-.091	.038	4139	-2.405	.016
>12 months					
College GPA					
<2.50	-.398	.045	4139	-8.912	.000
2.50-2.99 (B- to B)	-.300	.028	4139	-10.895	.000
3.00-3.49 (B to A-)	-.205	.023	4139	-8.715	.000
3.50-4.00 (A- to A)					
SES	.039	.005	4139	8.554	.000
Major					
Aerospace Engineering	.107	.099	4139	1.084	.278
Chemical Engineering	.038	.035	4139	1.065	.287
Civil Engineering	.036	.032	4139	1.144	.253
Computer Engineering	.205	.042	4139	4.863	.000
Electrical Engineering	.080	.027	4139	3.009	.003
Industrial Engineering	.159	.041	4139	3.882	.000
Mechanical Engineering					
Time Spent in Design Competition					
Did not participate	-.302	.042	4139	-7.160	.000
1-4 months	-.143	.045	4139	-3.169	.002
5-8 months	-.161	.054	4139	-2.963	.003
9-12 months	-.023	.062	4139	-.365	.715
>12 months					
Urbanization					
City: Large	-.022	.043	4139	-.524	.600
City: Midsize	.028	.045	4139	.607	.544
City: Small	-.035	.044	4139	-.806	.420
Suburb: Large	.138	.087	4139	1.590	.112
Suburb: Midsize	-.123	.058	4139	-2.111	.035
Town: Fringe	-.058	.068	4139	-.856	.392
Town: Distant	-.288	.116	4139	-2.475	.013
Rural: Fringe					

Multinomial Logistic Regression Analysis on Engineering Thinking Skills Items

All proportional-odds cumulative and baseline-category logit models for the items examined in the design and problem-solving skills scale are statistically significantly better than a means-estimate model at an alpha of .05 according to the likelihood ratio test (Table 42).

Table 42: Testing the null hypothesis that the slope is equal to zero

	Proportional-Odds			Baseline Category		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Break down complex problems to simpler ones	26	371.21	<.0001	104	459.25	<.0001
Apply fundamentals to problems that I haven't seen before	26	394.06	<.0001	104	490.80	<.0001
Identify critical variables, information, and/or relationship involved in a problem	26	349.76	<.0001	104	438.95	<.0001
Know when to use a formula, algorithm, or other rule	26	382.68	<.0001	104	452.98	<.0001
Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems.	26	339.85	<.0001	104	426.44	<.0001
Draw conclusions from evidence or premises	26	286.66	<.0001	104	391.87	<.0001
Develop a course of action based on my understanding of a whole system	26	280.44	<.0001	104	362.25	<.0001
Ensure that a process or product meets a variety of technical and practical criteria	26	250.66	<.0001	104	355.52	<.0001
Compare and judge alternative outcomes	26	285.19	<.0001	104	388.41	<.0001
Develop learning strategies that I can apply in my professional life	26	289.57	<.0001	104	377.61	<.0001

At an alpha of .20, the null hypothesis for the score test is rejected for six of the ten items in the scale: Breaking down complex problems to simpler ones, Applying fundamentals to problems that I haven't seen before; Drawing conclusions from evidence or premises; Ensuring that a process or product meets a variety of technical and practical criteria; Comparing and judging alternative outcomes; and Developing learning strategies that I can apply in my professional life (Table 43). These items are best modeled with a base-line category logit model. The p-values for the remaining items are not significant, suggesting that the proportional-odds cumulative model is best for these items: Identifying critical variables, information, and/or relationship involved in a problem; Knowing when to use a formula, algorithm, or other rule; Recognizing and understanding organizing principles (laws, methods, rules, etc.) that underlie problems; and Developing a course of action based on my understanding of a whole system.

Equation 14 and Equation 15 are logit models for the scale items.

Table 43: Score Test for the Proportional Odds

Item	df	χ^2	p-value	Model
Break down complex problems to simpler ones	78	88.35	.1983	Base-line category
Apply fundamentals to problems that I haven't seen before	78	88.40	.1973	Base-line category
Identify critical variables, information, and/or relationship involved in a problem	78	87.48	.2168	Proportional -odds cumulative
Know when to use a formula, algorithm, or other rule	78	68.76	.7633	Proportional -odds cumulative
Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems.	78	80.58	.3983	Proportional -odds cumulative
Draw conclusions from evidence or premises	78	110.03	.0099	Base-line category
Develop a course of action based on my understanding of a whole system	78	78.74	.4551	Proportional -odds cumulative
Ensure that a process or product meets a variety of technical and practical criteria	78	102.10	0349	Base-line category
Compare and judge alternative outcomes	78	123.90	<.0001	Base-line category
Develop learning strategies that I can apply in my professional life	78	102.47	.0331	Base-line category

Equation 14: Proportional-odds Cumulative Logit Model for the following: Identify Critical Variables, Information, and/or Relationship Involved in a Problem; Know When to Use a Formula, Algorithm, or Other Rule; Recognize and Understand Organizing Principles (laws, methods, rules, etc.) that Underlie Problems; and Develop a Course of Action Based on My Understanding of a Whole System;

$$\text{Log}\left(\frac{P(High\ Ability)}{P(More\ than\ Adequate\ Ability + Adequate\ Ability + Some\ Ability + No\ Ability)}\right)$$
$$= \alpha_1 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability)}{P(Adequate\ Ability + Some\ Ability + No\ Ability)}\right)$$
$$= \alpha_2 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability + Adequate\ Ability)}{P(Some\ Ability + No\ Ability)}\right)$$
$$= \alpha_3 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(High\ Ability + More\ than\ Adequate\ Ability + Adequate\ Ability + Some\ Ability)}{P(No\ Ability)}\right)$$
$$= \alpha_4 + \beta_1 * \text{Co-op} + \beta_x * \text{Control Variables}$$

Equation 15: Baseline-category Logit Model for Break Down Complex Problems to Simpler Ones; Apply Fundamentals to Problem's that I haven't Seen Before; Draw Conclusions from Evidence or Premises; Ensure that a Process or Product Meets a Variety of Technical and Practical Criteria; Compare and Judge Alternative Outcomes; and Develop Learning Strategies that I can Apply in My Professional Life

$$\text{Log}\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right) = \beta_{10} + \beta_{11} * \text{Co-op} + \beta_{1x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right) = \beta_{20} + \beta_{21} * \text{Co-op} + \beta_{2x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{30} + \beta_{31} * \text{Co-op} + \beta_{3x} * \text{Control Variables}$$

$$\text{Log}\left(\frac{P(More\ than\ Adequate\ Ability)}{P(High\ Ability)}\right) = \beta_{40} + \beta_{41} * \text{Co-op} + \beta_{4x} * \text{Control Variables}$$

The pseudo-R-square for the items in engineering thinking skills scale range from .0547 to .1042 (Table 44). This suggests that the independent variables in the model (i.e., co-op or internship, college GPA, SES, major, time spent in a design competition, and urbanization) explain between 5.47 to 10.42 percent of the variance.

Table 44: Pseudo-R-square for the Proportional-Odds and Baseline Category Model

	Proportional Odds	Baseline Category
Break down complex problems to simpler ones	.0799	.0979
Apply fundamentals to problems that I haven't seen before	.0846	.1042
Identify critical variables, information, and/or relationship involved in a problem	.0754	.0938
Know when to use a formula, algorithm, or other rule	.0822	.0966
Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems.	.0734	.0912
Draw conclusions from evidence or premises	.0623	.0841
Develop a course of action based on my understanding of a whole system	.0610	.0780
Ensure that a process or product meets a variety of technical and practical criteria	.0547	.0766
Compare and judge alternative outcomes	.0620	.0834
Develop learning strategies that I can apply in my professional life	.0629	.0812

Time Spent in a Co-op/Internship and Engineering Thinking Skills' Items

Table 45 and Table 46 provide the Wald chi-square tests for the baseline category logit models and the proportional-odds cumulative logit models. As indicated in Table 45, the co-op or internship variable is significant at an alpha of .05 for two items: Ensuring that a process or product meets a variety of technical and practical criteria and Comparing and judging alternative outcomes. Time spent in a co-op or internship is also significant at an alpha of .10 for Developing a course of action based on my understanding of a whole system (Table 46). Time spent in a co-op or internship has no significant influence on an engineering senior's ability to Break down complex problems to simpler ones; Apply fundamentals to problems that I haven't seen before; Identify critical variables, information, and/or relationship involved in a problem; Know when to use a formula, algorithm, or other rule; Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems; Draw conclusions from evidence or premises; and Develop learning strategies that I can apply in my professional life.

Table 45: Likelihood Ratio Tests of the Main Effect for the Baseline Category

	Co-op/ Internship			College GPA			SES		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Break down complex problems to simpler ones	16	14.56	.5571	12	133.38	<.0001	4	54.90	<.0001
Apply fundamentals to problems that I haven't seen before	16	11.59	.7715	12	149.48	<.0001	4	70.28	<.0001
Draw conclusions from evidence or premises	16	17.54	.3513	12	101.65	<.0001	4	49.94	.0007
Ensure that a process or product meets a variety of technical and practical criteria	16	28.33	.0288	12	64.23	<.0001	4	45.71	<.0001
Compare and judge alternative outcomes	16	35.76	.0031	12	64.94	<.0001	4	59.83	<.0001
Develop learning strategies that I can apply in my professional life	16	21.26	.1688	12	70.21	<.0001	4	53.16	<.0001

Table 45: Likelihood Ratio Tests of the Main Effect for the Baseline Category (con't)

	Major			Design Competition			Urbanization		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Break down complex problems to simpler ones	28	94.41	<.0001	16	74.96	<.0001	28	28.54	.4363
Apply fundamentals to problems that I haven't seen before	28	53.70	.0024	16	95.31	<.0001	28	51.41	.0045
Draw conclusions from evidence or premises	28	50.82	.0052	16	73.97	<.0001	28	28.40	.4435
Ensure that a process or product meets a variety of technical and practical criteria	28	53.59	.0025	16	71.38	<.0001	28	44.15	.0269
Compare and judge alternative outcomes	28	65.54	<.0001	16	75.41	<.0001	28	20.38	.8501
Develop learning strategies that I can apply in my professional life	28	49.08	.0082	16	86.40	<.0001	28	35.53	.1549

Table 46: Likelihood Ratio Tests of the Main Effect for the Proportional Odds Model

	Co-op/ Internship			College GPA			SES		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Identify critical variables, information, and/or relationship involved in a problem	4	4.24	.3745	3	132.16	<.0001	1	80.00	<.0001
Know when to use a formula, algorithm, or other rule	4	2.99	.5598	3	200.39	<.0001	1	19.23	<.0001
Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems.	4	2.33	.6756	3	144.59	<.0001	1	30.05	<.0001
Develop a course of action based on my understanding of a whole system	4	9.26	.0550	3	56.63	<.0001	1	60.62	<.0001

Table 46: Likelihood Ratio Tests of the Main Effect for the Proportional Odds Model (con't)

	Major			Design Competition			Urbanization		
Item	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**	**df**	χ^2	**p-value**
Identify critical variables, information, and/or relationship involved in a problem	7	27.62	.0003	4	45.52	<.0001	7	24.32	.0010
Know when to use a formula, algorithm, or other rule	7	42.03	<.0001	4	54.94	<.0001	7	20.79	.0041
Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems.	7	29.13	.0001	4	69.23	<.0001	7	26.69	.0004
Develop a course of action based on my understanding of a whole system	7	29.48	<.0001	4	79.65	<.0001	7	11.18	.1311

The baseline category and proportional odds models parameters' estimates for the time spent in a cooperative education or internship variable for each of the items within the engineering thinking skills scale are shown in Table 47 to Table 56. Appendix E provides the parameter estimates for the control variables for each survey item in the engineering thinking skills scale.

Break Down Complex Problems to Simpler Ones. Table 47 provides the parameter estimates for the proportional odds model for the item, Break down complex problems to simpler ones. All the odds ratio estimates in the proportional odds model for this item are greater than one (1.0), which implies the seniors are less likely to rate themselves at a higher ability compared to seniors who have spent more than twelve months in a co-op or internship. Seniors who spent one to four months and seniors who spent nine to twelve months are more likely to rate their ability to break down complex problems as more than adequate than high compared to seniors who spent more than twelve months in a co-op or internship (odds ratios = 1.301 and 1.387 with p-values of .0494).

Apply Fundamentals to Problems that I have not seen before. See Table 48 for the parameter estimates in the proportional odds model for the item Apply fundamentals to problems that I haven't seen before. All the odds ratio estimates less than one, suggesting that seniors with less than twelve months of co-op or internship experience are more likely to rate themselves lower than seniors who spend more than twelve months in a co-op or internship on their ability to apply fundamentals to problems that I haven't seen before. However, the only significant parameter is for seniors who did not participate in a co-op on this item (odds ratio is 1.704 with a p-value of .0207).

Identify Critical Variables, Information, and/or Relationship Involved in a Problem. In examining the parameter estimates for the proportional odds model for the item Identify critical variables, information, and/or relationship involved in a problem, all the odds ratio estimates are not significant (Table 49). This suggests that time spent in a co-op or internship does not influence seniors' perception on their ability to identify critical variables, information, and/or relationship involved in a problem.

Know When to use a Formula, Algorithm, or Other Rule. All the odds ratio estimates in the proportional odds model for this item are non-significant, which suggest that time spent in a co-op or internship does not influence seniors' perception on their ability in knowing when to use a formula, algorithm, or other rule (see Table 50).

Recognize and Understand Organizing Principles that Underlie Problems. Table 51 provides the parameter estimates for the proportional odds for the item, Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems. Once gain all the parameters for this model are not significant. Time spent in a co-op or internship does not appear to influence seniors' perception of their abilities to recognize and understand organizing principles that underlie problems.

Draw Conclusions from Evidence or Premises. Seniors who spent nine to twelve months in co-op or internship are equally likely to say they have no ability, some ability, or adequate ability as those who have more than twelve months of experience (Table 52). Seniors with five to eight months of co-op or internship experience are more likely to rate themselves as having adequate ability than high ability when compared with seniors who spent more than twelve in a co-op/internship (odds ratio is 1.512 with a p-value of .0107). Those who do not participate in a co-op/internship are more likely to assess themselves as adequate or more than adequate than high ability (odds ratios are 1.509 and 1.262 with p-values of .0489).

Develop a Course of Action Based on My Understanding of a Whole System. Table 53 provides the parameter estimates for the proportional odds model for the item "Develop a course of action based on my understanding of a whole system." All the odds ratio estimates in the proportional odds model for this item are less than one, which implies that seniors with less than twelve months in a co-op/internship are less likely to rate themselves as having higher ability than seniors who spent more than twelve months in a co-op/internship. The overall trend of these estimates is increasing, which suggests that as more time is spent in a co-op/internship the more likely the student is to rate his ability as higher when compared to a graduate with more than twelve months in a co-op or internship (odds ratio estimates are .779, .804, .808, and .906). The estimate for seniors with nine to twelve months experience is not significant, providing evidence that there is no significant difference between these seniors and seniors with more than twelve months of co-op or internship experience.

Ensure that a Process or Product Meets a Variety of Technical and Practical Criteria. Seniors who do not participate in a co-op or internship are significantly different in their self-assessment of abilities from seniors who participated in a co-op or internship for more than twelve months on the item Ensure that a process or product meets a variety of technical and practical criteria (Table 54). The significant parameters (alpha = .05) for adequate and versus high ability has an overall decreasing trend as time spent in a co-op or internship increases (odds ratios are 1.715, 1.596, 1.477, and 1.572). For more than adequate ability versus high ability the significant parameter estimates form a positive linear trend (odds ratio estimates are 1.293 and 1.358).

Compare and Judge Alternative Outcomes. Table 55 provides the parameter estimates for the baseline category model for the item Compare and judge alternative outcomes. Seniors who do not participate in a co-op or internship or spend only one to four months in a co-op or internship are more likely to assess their abilities as either adequate or more than adequate the high compared to seniors who participated in a co-op or internship for more than twelve months. The significant parameters (alpha = .05) for adequate ability versus high ability decrease as time spent in a co-op or internship increases (odds ratio estimates are 1.626, 1.485, and 1.450); whereas this trend is reversed for more than adequate ability versus high ability (odds ratio estimates are 1.331, 1.472, and 1.610).

Develop Learning Strategies that I can apply in my Professional Life. Table 56 presents the parameter estimates for the baseline category model for the item Develop learning strategies that I can apply in my professional life. The only significant parameter estimate is seniors who do not participate in a co-op or internship who are more likely to rate themselves as having adequate ability than high ability compared to seniors with more than twelve months experience (odds ratio = 1.458 and p-value = .0061). Since the majority of the estimates are not significant, time spent in a co-op/internship does not appear to have an influence on seniors' perception of their ability to develop learning strategies that they can apply in their professional life.

Table 47: Co-op/Internship Parameter Estimates on Break Down Complex Problems to Simpler Ones

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	.991	1.266	.00	.9941	1.368	.292	1.15	.2835	1.298	.137	3.61	.0573	1.116	.116	.89	.3457
1-4 months	<0.001	477.9	.00	.9795	1.396	.34	.96	.3264	1.243	.161	1.83	.1759	1.301	.134	3.86	.0494
5-8 months	<0.001	485.8	.00	.9799	.905	.372	.07	.7895	1.287	.16	2.47	.1158	1.180	.135	1.51	.2195
9-12 months	1.882	1.524	.17	.6782	1.011	.396	.00	.9775	1.369	.17	3.44	.0638	1.387	.141	5.42	.0199

Table 48: Co-op/Internship Parameter Estimates on Apply Fundamentals to Problems that I haven't Seen Before

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	2.884	1.085	.95	.3289	1.704	.23	5.35	.0207	1.109	.137	.57	.4516	1.120	.129	.78	.3787
1-4 months	3.998	1.142	1.47	.2248	1.373	.273	1.35	.2454	1.204	.158	1.37	.2415	1.171	.148	1.13	.2873
5-8 months	2.287	1.249	.44	.5077	1.638	.269	3.36	.0669	1.202	.161	1.31	.2518	1.202	.15	1.49	.2217
9-12 months	3.711	1.252	1.10	.2950	1.589	.288	2.60	.1072	1.369	.167	3.52	.0606	1.283	.157	2.53	.1118

Table 49: Co-op/Internship Parameter Estimates on Identify Critical Variables, Information, and/or Relationship Involved In a Problem

	Odds Est.	**Std. Error**	χ^2	**p-value**
Did not participate	.839	.089	3.83	.0502
1-4 months	.856	.103	2.26	.1324
5-8 months	.840	.104	2.80	.0940
9-12 months	.858	.108	1.99	.1585

Table 50: Co-op/Internship Parameter Estimates on Know when to use a Formula, Algorithm, or Other Rule

	Odds Est.	**Std. Error**	χ^2	**p-value**
Did not participate	1.055	.088	.37	.5452
1-4 months	.985	.102	.02	.8795
5-8 months	.933	.103	.46	.4989
9-12 months	.938	.107	.36	.5487

Table 51: Co-op/Internship Parameter Estimates on Recognize and Understand Organizing Principles (laws, methods, rules, etc.) that Underlie Problems.

	Odds Est.	Std. Error	χ^2	p-value
Did not participate	.989	.089	.02	.8967
1-4 months	.995	.103	.00	.9584
5-8 months	.888	.104	1.33	.2492
9-12 months	.927	.108	.50	.4810

Table 52: Co-op/Internship Parameter Estimates on Draw Conclusions from Evidence or Premises

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	Std. Error	χ^2	p-value	Odds Est.	Std. Error	χ^2	p-value	Odds Est.	Std. Error	χ^2	p-value	Odds Est.	Std. Error	χ^2	p-value
Did not participate	>1000	602.6	.00	.9838	1.542	.287	2.27	.1320	1.509	.139	8.80	.0030	1.262	.118	3.88	.0489
1-4 months	.840	858.1	.00	.9998	1.521	.33	1.62	.2037	1.398	.159	4.42	.0356	1.155	.136	1.13	.2881
5-8 months	>1000	602.6	.00	.9819	1.126	.362	.11	.7434	1.512	.162	6.52	.0107	1.262	.138	2.84	.0917
9-12 months	1.247	934.8	.00	.9998	1.282	.368	.45	.5001	1.283	.172	2.12	.1457	1.349	.142	4.46	.0348

Table 53: Co-op/Internship Parameter Estimates on Develop a Course of Action Based on My Understanding of a Whole system

	Odds Est.	Std. Error	χ^2	p-value
Did not participate	.779	.09	7.72	.0055
1-4 months	.804	.104	4.42	.0355
5-8 months	.808	.105	4.18	.0409
9-12 months	.906	.109	.83	.3615

Table 54: Co-op/Internship Parameter Estimates on Ensure that a Process or Product Meets a Variety of Technical and Practical Criteria

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p -value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	1.399	.672	.25	.6173	1.709	.264	4.11	.0425	1.715	.138	15.2	<.001	1.293	.122	4.47	.0345
1-4 months	.327	1.171	.91	.3393	1.660	.302	2.82	.0930	1.596	.16	8.51	.0035	1.293	.14	3.34	.0676
5-8 months	1.834	.755	.65	.4218	1.197	.322	.31	.5762	1.477	.162	5.77	.0163	1.312	.141	3.71	.0541
9-12 months	.440	1.174	.49	.4848	.821	.373	.28	.5964	1.572	.168	7.23	.0072	1.358	.147	4.36	.0368

Table 55: Co-op/Internship Parameter Estimates on Compare and Judge Alternative Outcomes

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	.477	1.228	.36	.5463	1.367	.27	1.34	.2478	1.626	.139	12.32	.0004	1.331	.118	5.84	.0157
1-4 months	<.001	385.7	.00	.9743	1.622	.305	2.51	.1134	1.340	.161	3.30	.0691	1.271	.135	3.14	.0763
5-8 months	1.759	1.311	.19	.6669	.942	.353	.03	.8648	1.485	.164	5.83	.0158	1.472	.138	7.89	.0050
9-12 months	1.613	1.491	.10	.7487	.566	.435	1.71	.1908	1.450	.172	4.65	.0311	1.610	.143	11.1	.0009

Table 56: Co-op/Internship Parameter Estimates on Develop Learning Strategies that I can Apply in my Professional Life

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Did not participate	1.184	.702	.06	.8098	1.557	.274	2.62	.1054	1.458	.137	7.53	.0061	1.183	.118	2.06	.1515
1-4 months	2.189	.719	1.19	.2757	1.368	.317	.98	.3225	1.225	.159	1.64	.2001	1.078	.134	.31	.5767
5-8 months	.334	1.17	.88	.3483	.867	.356	.16	.6895	1.318	.161	2.94	.0863	1.229	.136	2.31	.1288
9-12 months	1.012	.936	.00	.9901	.855	.37	.18	.6724	1.187	.168	1.04	.3081	1.172	.139	1.29	.2555

CHAPTER 5:

PRACTICING TO BECOME CONFIDENT

"I was thinking 'No wonder he wants to study internships', because I really do feel like it definitely changed my confidence."

-Vanessa

Upon graduation, new engineers are expected to "apply the principles of science and mathematics to develop economic solutions to technical problems (U.S. Department of Labor, 2008)." If new graduates cannot solve problems, they will not succeed as engineers when they enter the workforce. Data collected from students' interviews responds to the second research question: "How do students with cooperative education or internship differ in their perception and understanding of their engineering problem-solving skills as compared to students with no experience?" I assumed that qualitative differences in these skills between the groups (cooperative education students, internship students, and students with neither co-op nor internship experience) would be distinguishable and thus that the groups could be compared. The results of the quantitative analysis (Chapter 4), which suggests that students who have work experience (either through cooperative education or internships) are better at certain problem-solving skills, support this assumption. The statistical models (multiple regression, proportional-odds logistic, and baseline category logistic models) presented in Chapter 4, however, explained only six to ten percent of the variance in students' perception of their problem-solving skills. This suggests over ninety percent of the variance in students' perception of their problem-solving skills are attributed to factors that are not related to time spent in an internship or co-op or the control variables (college grade point average, socioeconomic status, engineering major, time spent in design projects and competitions, Carnegie classification and urbanization).

When I analyzed the interview data, I came to a similar conclusion: students' approaches to problem-solving appeared to be similar and thus any differences could not be attributed to group membership. The differences in problem-solving skills between the groups seem to be as great as the differences within the groups. My analysis of the interview data, however resulted in findings that aligned with Alexander's (1997, 2003) Model of Domain Learning (MDL). This model explains how an individual's knowledge, strategic processes, and interest changes as he or she progresses towards expertise in a particular domain of knowledge, such as engineering. The study did not seek to assess students' expertise in engineering, but rather to examine how co-op and internship experience influenced students' perceptions of their problem-solving skills. The analysis presented in this chapter suggests that the components of MDL (i.e., knowledge, strategic processes, and interest) are influenced by curricular, co-curricular, and work experiences like co-op and internships. This chapter explores how these classroom and work experiences influenced students' knowledge, learning strategies, and interest in developing engineering problem-solving skills. When salient, I will contrast the differences between students with work experience (i.e., students with co-op versus those with internship experience).

Participant Characteristics

To explore the influences of work experiences such as cooperative education and internships on engineering problem-solving skills, I interviewed seventeen electrical engineering (EE) seniors from a Research I University: four who completed at least three cooperative education rotations, eight who completed at least one internship, and five who did neither co-op nor internship. I initially attempted to limit variation in participants' academic ability by requiring a grade point average (GPA) of 3.0 or greater. This selection criterion was met for all students in the internship group and the group which had neither cooperative education nor internship experiences; however, due to the limited number of students who completed three co-op rotations, this requirement was relaxed. Two out of the four cooperative education students had GPAs less than a 3.0 (2.89 and 2.70).

The sample yielded participants with various characteristics and experiences (Table 57). Fourteen of the participants were male, which is a lower percentage than enrolled in the selected engineering program (91%) and nationally (88%) (American Society for Engineering Education, 2008)[18]. The sample included four transfer students (Andrew, Carl, William, and Kevin[19]), four Honors College students (Carl, Christina, Jill, and Isaac), two international students (Jim and Kevin), and an intercollegiate athlete (Keith). The majority of the students participated in some form of co-curricular activity (e.g., clubs, fraternities, or undergraduate research). Only Larry and William had not participated in extracurricular or co-curricular activities; however, relevant to the topic under study, Larry spent his first three-years in college working part-time in construction.

The four cooperative education students completed their co-op rotations in four different ways. Andrew completed his rotations during the summers and also worked part-time at the same company during his sophomore year. Matt spent a year working at his co-op company after his sophomore year and completed an additional rotation between the summer of his junior and senior years. Two of the eight internship students (David and Jill) completed two internships, while the other six students completed one internship each. David and Jill completed their internships during the summers between their sophomore and junior years and junior and senior years. Carl was the only student who completed his single internship between his freshmen and

---

[18] With respect to gender, a chi-square test demonstrated that the sample was representative of the program's (χ^2 = .56, p-value = .45) and national's (χ^2 = .56, p-value = .45) population.
[19] All names are pseudonyms

sophomore years; the other single-internship students finished their internships between their junior and senior years.

Table 57: Participant's Characteristics

Participant	Gender	GPA
Cooperative Education Students		
Andrew	Male	2.89
Bob	Male	2.70
Matt	Male	3.50
Spencer	Male	3.19
Internship Students		
Carl	Male	4.00
Christina	Female	3.74
David	Male	3.23
Jill	Female	3.70
Jim	Male	3.63
Steven	Male	3.66
Vanessa	Female	3.37
William	Male	3.67
Neither Co-op nor Internship Students		
Brian	Male	3.27
Issac	Male	3.91
Keith	Male	3.12
Kevin	Male	3.01
Larry	Male	3.35

As suggested by the quantitative analysis, the differences in problem-solving skills between participants could not be attributed solely to work experiences gained through co-op or internship or classroom experiences. Students with undergraduate research experience felt it was influential in their problem-solving skill development. Carl, for example, learned how to "focus on alternatives. … once I find a solution that works, don't just pick that solution and forget everything else." Other students found co-curricular activities such as intramural sports or student clubs helpful in their problem-solving development. Jill said:

> I would say [intramural sports] would be more of solving problems within social groups. I have been the captain … so it is my job to see who is performing the

best, who is going to play in the actual games, who is going to actually pull through and allow us to win.

While not all the students shared the same opinion of their co-curricular experiences, the interview data suggests that some of these activities were influential in the development of problem-solving skill. In the sections that follow, I refer to these variations in students' academic experience when they are relevant to the questions at hand.

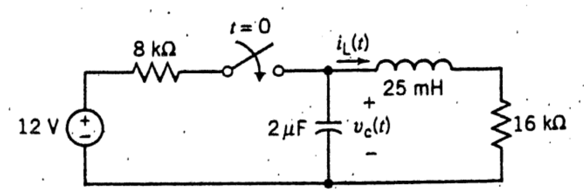
Solving Well- and Ill-Structured Problems

As part of the interview, students completed two think-aloud problems. One problem was a well-structured problem from an introductory textbook on electric circuits (Figure 6) and the other problem was an ill-structured problem asking students to design an automated pill inspection system for a company's quality assurance department (Figure 7). I told the students not to worry about providing correct solutions and to instead focus on their thought process as they solved the problems. The majority of the students could not articulate their problem-solving process during the think-aloud without solving the problem. Instead of saying that, for example, they would identify important information for the well-structured think-aloud problem, the participants talked about the properties of the capacitors and inductor, which are important information for solving the problem.

Students' responses to both problems were coded using a priori codes based on the component items of applying basic skills, design and-solving skills, and engineering thinking skills scales used in the quantitative analysis. Recall that these scale items are based on the learning outcomes specified on the accreditation criteria for engineering programs and the literature on problem-solving (see Chapter 2). In addition, I also used open codes to capture responses not covered by the aforementioned codes.

Figure 8: Well-Structured Problem*

P 7.9-3 The switch in Figure 7.9-3 has been open for a long time before closing at time $t = 0$. Find $v_C(0+)$ and $i_L(0+)$, the values of the capacitor voltage and inductor current immediately after the switch closes. Let $v_C(\infty)$ and $i_L(\infty)$ denote the values of the capacitor voltage and inductor current after the switch has been closed for a long time. Find $v_C(\infty)$ and $i_L(\infty)$.



***Source:** Dorf and Svoboda (1998) Introduction to Electric Circuits 4th Edition, p. 318

Figure 9: Ill-structured Problem

An integrated biopharmaceutical company manually inspects all incoming materials and final product which pass through their manufacturing site. The first goal of this project is to design an automated pill inspection system for company's quality assurance department using image processing techniques to deliver a software-based rules engine that will detect, classify and quantify defects.

*Source: Harvey Mudd (2008) *2008 Projects Day Program*

There were no noticeable trends when examining the skills in problem-solving between students with or with internship or co-op experience; however, variations in students' approaches to the well- and ill-structured problems were evident (see Table 58 for a comparison). Fourteen students utilized a greater number of skills when solving the well-structured problem (Appendix F). Three students utilized the same number of skills when solving either type of problem.

When solving the well-structured problem, the majority of the students talked about:

- Applying discipline-specific engineering knowledge (17 of 17 or 100%);
- Applying fundamentals to problems that they hadn't seen before (59%);
- Breaking down complex problems into simpler ones (65%);
- Defining key engineering problems (53%);

- Identifying critical variables, information, and/or relationship involved in a problem (88%);
- Knowing when to use a formula (59%).

When solving the ill-structured problem, students discussed

- Applying discipline-specific engineering knowledge (65%);
- Breaking down complex problems to simpler ones (53%);
- Defining key engineering problems (82%);
- Identifying critical variables, information, and/or relationship involved in a problem (94%).

Table 58: Problem-Solving Skills Utilized in Think-Aloud Problems

Problem-Solving Skill	Skills mentioned for Well-Structured Problem n (%)	Skills mentioned for Ill-Structured Problem n (%)
a) Apply discipline-specific engineering knowledge	17 (100%)	11 (65%)
b) Apply fundamentals to problems that I haven't seen before	10 (59%)	0 (0%)
c) Apply systematic design procedure to open-ended problem	0 (0%)	4 (24%)
d) Break down complex problems to simpler ones	11 (65%)	9 (53%)
e) Compare and judge alternative outcomes	0 (0%)	5 (29%)
f) Define key engineering problems	9 (53%)	14 (82%)
g) Develop a course of action based on my understanding of a whole system	3 (18 %)	3 (18%)
h) Ensure that a process or product meets a variety of technical and practical criteria	3 (18%)	7 (41%)
i) Identify critical variables, information, and/or relationship involved in a problem	15 (88%)	16 (94%)
j) Know when to use a formula	10 (59%)	0 (0%)
k) Understand essential aspects of the engineering design process	0 (0%)	2 (12%)
l) Research information to solve problem	14 (82%)	2 (12%)

When examining the open codes for the think-aloud, a problem-solving skill not captured by the component items of applying basic skills, design and-solving skills, and engineering thinking skills scales was "researching the problem." If unsure of their knowledge-base when solving the problem, students mentioned researching the problem (82% for the well-structured problem and 12% for the ill-structured problem). This included asking others for help, utilizing textbooks, referencing journals, and conducting searches on the Internet.

All 17 students talked about "applying discipline-specific knowledge" for the well-structured problem as the problem required knowledge learned in their introductory electrical engineering course. Not surprisingly, the number of students who discussed utilizing discipline-specific knowledge decreased for the ill-structured problem, since it required knowledge from multiple specializations within electrical engineering that they might not have encountered in their coursework. Yet, fourteen students said they would research information to help them solve a well-structured problem if they were unsure of their knowledge base (i.e., do they have the correct equation for a capacitor). Surprisingly, only two students mentioned this as a strategy for solving ill-structured problems even though they are more likely not to have all the knowledge to solve these types of problems.

Regardless of whether they were solving the ill-structured or well-structured problem, the majority of the participants i) "identified critical variables, information and/or relationships involved in a problem" and said that they would d) "break down complex problems to simpler ones." Fewer students, however, talked about defining the key engineering problem when solving the well-structured problem than when solving the ill-structured problem. For the think-aloud circuit problem many of the students properly identified the components and properties that would allow them to solve the well-structured problem; they knew how to solve this type of problem without explicitly defining the problem. A possible explanation for the difference is that students were more familiar with well-structured problems regarding circuits and did not feel the need to define the key engineering problem in order to solve the problem offered; whereas their lack of exposure to solving ill-structured problems necessitated the need to define the problem.

The differences in knowing how to use a formula and comparing and judging alternative outcomes between the well-structured and ill-structured problems (ten versus zero for each) are most likely explained by the nature of the problems. The well-structured think-aloud problem required the utilization of a formula for the solution while the ill-structured think-aloud did not. By definition, a well-structured problem only has one solution; thus there is no need for students to compare and judge alternative solutions for these types of problems. This may explain why none of the students talked about comparing and judging alternative solutions for the well-structured think-aloud problem, but five students did for the ill-structured think-aloud problems, which by definition has multiple solutions.

In sum, there were differences in students' approaches to solving well- and ill-structured problems; namely more students talked about a) "Applying discipline-specific knowledge engineering knowledge", b) "Applying fundamentals to problems that I haven't seen before", j) "Knowing when to use a formula," and l) "Researching information to solve the problem" when solving a well-structured problem than an ill-structured problem. A possible explanation for some of these differences such as "Applying discipline specific knowledge" and "Knowing when to use a formula" maybe explained by the nature of the problem (i.e., whether it is well-structured or ill-structured problem). In analyzing the interview data, I explore possible explanations for differences in "Applying fundamentals to problems that I haven't seen before" and "Researching information to solve the problem" in this chapter.

The Role of Knowledge in Domain Learning

According to Alexander's model, an individual's knowledge within a specific domain (e.g., electrical engineering) increases in breadth and depth as she becomes an expert in the field. The field of electrical engineering requires the application of one's knowledge of mathematics, physics, electricity, and electromagnetism to problems. Accordingly, a deep understanding of these topics is important to an electrical engineer's problem-solving ability. Without the domain knowledge needed to solve problems, a student will not become a competent engineer.

A comparison of the responses of students with co-op or internship experiences and students without these experiences revealed some differences in the types of knowledge gained during college. In this section, I examine how these work experiences influence the types of knowledge gained. Although many of the interview questions framed problems as either well- or ill-structured, many participants appeared to interpret these problems as either ideal or real-world problems. To students, ideal problems provide the opportunity to enhance or test one's theoretical knowledge while real-world problems are those encountered in the workforce. For example, Christina described exams in the electrical engineering department that included circuit problems with ten resistors in parallel and this tests students' knowledge of parallel resistors. In the real-world, she argued, these circuits would only have one resistor. Thus, the knowledge gained in well-structured problem seemed to students to provide theoretical knowledge that was sometimes, but not always directly applicable in work settings.

Theoretical Knowledge

I define theoretical knowledge as the theories, laws, principals, and properties of devices that engineers need to understand to solve problems. My analysis of the think-aloud problems indicated that when possible, students relied on their knowledge of theories used in electrical engineering in explaining their problem-solving process. One way to improve students' problem-solving ability is to expand their electrical engineering knowledge base so that they are prepared to solve all types of problems within the discipline. Andrew suggested this when he said, "The more knowledge you have the easier it gets to solve a problem." The majority of the non-co-op or internship students shared this sentiment. In responding to whether his problem-solving skills improved since the start of college, Keith replied, "My electrical engineering knowledge has gone from zero to where it is now. … If I'd seen [the think-aloud] problem then, I probably wouldn't have known what the inductor is." Without knowing the properties of an inductor, Keith would not have been able to solve the think-aloud problem because he would not have used the proper equation[20]. Isaac answered in the same fashion, "Well, my knowledge improved a lot. When I was [age] ten, I could solve problems too, but I didn't have the knowledge to tackle so many problems."

Through their coursework and solving textbook problems, students gained or enhanced their knowledge of electrical engineering concepts and principles. William referred to his experiences solving textbook problems in classes.

> You're always kind of figuring out new ways to look at something. And in particular, like with that problem [the think-aloud textbook problem], you could, if you're a novice at electrical engineering, just coming in your junior year, you would probably solve that problem the long way. You would just go through it entirely. You would write out all the differential equations basically and try and solve back and figure out how it would work. But since you kind of do those problems a lot, you can just kind of look at it and the

[20] An inductor and a capacitor are energy storing devices, but have different functions and properties. For an inductor, the voltage equation involves a differential equation while the current equation involves an integral. This is different for a capacitor, where the voltage equation involves an integral and the current equation is a differential equation.

> professors -- I think they do this on purpose -- they don't tell you the short cuts that you can take. So, you do it the long way. And then, you know, after you do it a little bit you figure out the short cuts and then later on they kind of tell you that "well you can just do this."

William is describing how his theoretical knowledge increased through practice. He became more efficient in solving problems because he learned how to reduce differential equations to linear equations. Likewise, in explaining whether his problem-solving skills improved during his collegiate career, Steven focused on gains in his knowledge of electrical engineering:

> I'm not sure that the electrical engineering course work that I've taken has necessarily improved my ability to solve problems in general as much as it's allowed me to extend the problem-solving skills, maybe that I already had, to problems that required that electrical engineering knowledge.

Larry, who had neither co-op nor internship experience, felt that problem-solving skills "are better developed in major-specific classes, because electrical engineers don't think the same as agricultural engineers." Both fundamentals and advanced coursework contributed to the knowledge-base he needed to succeed in his field.

> How it changed, when I got into the EE [electrical engineering] coursework, is I guess you learn to think like an electrical engineer would think in terms of real and imaginary pieces of things. … We consider stuff with imaginary numbers and sinusoids, but you do get that from math and physics. That is important, but I guess you learn … what stuff from those classes is going to be important. … And there is going to be stuff that you never see again that you have in math class, and there is going to be stuff that you see

every day, so when you start your major course work, you get more familiar with these aspects and how to solve problems that involve these things.

In reflecting on their classroom experiences, the majority of the students found the coursework helpful because it enhanced their theoretical knowledge in electrical engineering. A few talked about how, at the time they took a course, they thought the knowledge taught was useless, but also how they eventually found it useful. Problem-solving was one way to ascertain the value of the knowledge learned in the classroom. As David replied when asked whether solving well-structured problems helped him with ill-structured problems: “You’re not going to solve a circuit for the customer or get any of your work done if you don’t understand the basic concepts.”

Practical Knowledge

Since all the participants in this study shared a similar curriculum at the Research I University, we can examine differences in knowledge between co-op or internship students and those who did neither co-op nor internships to explore how co-curricular experiences – namely, cooperative education and internship opportunities – influenced problem-solving. The interview data suggests that because of their work experiences, internship and co-op students had more opportunities to apply the domain (theoretical) knowledge to problems encountered in a “non-ideal” setting. As one student explained, “Theoretical [knowledge] is ‘this is how this works, this is how it will work if you actually do this in real life.’ Practical [knowledge] is taking that theoretical knowledge and putting it to real-world uses.”

The non-co-op/internship students often felt they did not have enough opportunities to learn how to apply or apply the discipline knowledge to real-world problems in their coursework.

Brian, who had neither co-op nor internship experience, felt he understood, for example, how antennas worked, but did not know how to apply this knowledge.

> I understand how antennas work. I just don't know how to build them. I think it's going to be more useful to know how to build them. … For instance, if I get a job designing cell phones… I need to know how to build an antenna into these cell phones to get it to function properly because if you can't build an antenna in there, the cell phone won't work. I think it's just understanding the full process, I think is very important. And I just think we were pretty limited on that kind of experience, or my experience through the courses I've taken.

Brain also thought that his courses sometimes covered theoretical knowledge in more depth than necessary to understand how to utilize the material.

> I didn't think that [learning how MOSFETs[21] work] was very useful. Like just knowing how the atoms line up, I didn't think that was very useful or practical or it's going to help me. I know how MOSFETs work, but I don't think we needed to go into the detailed physics of how it worked, for me, to be able to use it.

Non-co-op/internship students often wanted their professors to spend more time teaching the application of the material. While co-op or internship students did not learn the application of knowledge in the classroom either, they had the opportunity to learn it at their work. A quote from William, an internship student, illustrates how his internship complemented his classroom experience by allowing him to learn how the knowledge gained in the classroom applies to the real-world.

[21] MOSFETs are metal-oxide-semiconductor field-effect transistors used to amplify or switch electronic signals in circuits.

> There's this concept called skin depth and basically it's how electromagnetic waves propagate into a medium. How far they go down is classified as the skin depth. We spent maybe a day going over it [in class] and I just thought, this is kind of stupid, I don't know where you'd ever use this. Then when I went to my internship, of course, it was all about that. It was all about how far the EM [Electromagnetic] waves propagate into the material that is below what they call micro strip line, which is based in the wires. So it was a big problem, but I just thought at the time that this is kind of useless. I don't see how you would ever use it because I had no understanding of communications circuits at the time.

William wished that his professor in his electromagnetic course had made the connection between this theoretical knowledge and real-world application:

> It would have been awesome if the professor would have mentioned, at least briefly mentioned, what a micro strip was. And that's really where skin-depth comes in. In particular, I mean I don't, I don't know of any other applications really of skin depth other than micro strip and there is nothing in our electromagnetic book about it.

Without his internship experience, William would have continued to believe the knowledge learned in class was useless because he would not have understood its applications.

To many of the students I interviewed, hands-on experiences provided opportunities to apply theoretical knowledge. These hands-on experiences not only allowed students to apply what they learned about electrical engineering, but enabled them to understand the limitations of these theories. Steven's experience building circuits for his internship allowed him to contrast school learning with the practical knowledge gained on the job. Speaking of his internship experience he explained,

> I would blow out some chips every once in a while, and it was because the, well the first thing I noticed were that massive amounts of current was being drawn from the supply. And then, though you know, you could deduce from that since all of that current was being drawn you could look at the circuit and try to figure out what would cause that problem. And then the answer was, the circuit involved a switch, switching things on and off, and there was a problem with shorting, when both switches were on at the same time, shorting the supply and ground. And that problem was solved through seeing that there was this current draw problem and looking at the schematic, and saying, why would that be a problem? And going from there, and that is something you get from experience of actually building a circuit. That is not something you are going to see in a textbook.

In determining why the chips "blow out" once in a while, Steven applied his disciplinary knowledge to a specific problem in chip design. Through his hands-on experiences in building circuit, he could see the negative effects of a poor design that he may not have noticed by just examining the circuit's schematic.

Jill and others acknowledged that many practical applications would be too costly or difficult to incorporate into courses. To succeed in her internships, however, Jill realized she needed to build upon that knowledge based gained through coursework.

> For my power company, I designed a relay system for a distribution on a power grid. I had to look back on all my design classes and be like, OK this is how I would do this, and this is why I would do it this way. I was obviously critiqued in different methods [by people at my internship], and saying this works in theory, but this isn't practical because you know this part, they don't make this part anymore, we have to move on to try something different. A lot of the systems were going from analog to digital, we focused a

> lot at least sophomore year on analog systems. I mean I had seen the basics before, but I had never actually applied them to a real-world problem.

Through her internship, Jill was able to apply the knowledge learned in her classes and also see its limitations. Through these experiences, she learned first-hand that contextual factors are important to consider when solving problems. Practical knowledge was not viewed as a replacement for of theoretical knowledge; rather they defined it as the application of theoretical knowledge. They also understood that through hands-on experiences, like co-op programs and internships, revealed some of the practical limitations that might hinder them from solving assigned problems on the job.

Determining the Scope of the Problem. Jill and Steven, and other students with work experiences had the opportunity to practice solving real-world problems that allowed them to apply their disciplinary knowledge. From these experiences, these students began to realize that the application of disciplinary knowledge may not be sufficient for solving most real-world problems; they needed to consider how contextual factors such as budget and time constraints, shaped engineering solutions. Cooperative education and internships encourage students to expand the problem scope that is, to move beyond the ideal, and to consider both technical and nontechnical factors that may influence the solution to a given problem. David, an internship student, noted,

> At school you don't even [consider] some things. For instance, at school you see the circuit and the voltage is there and it's perfect every single time, it's all theoretical. And then in the workforce almost 90 percent of your problems are noise. Why is there noise in my circuit? Everywhere you go there's noise. Well maybe you should wrap the wires around each other so there's less noise, maybe you should twist them so there's less noise.

> And then, at school it's like, "Oh yeah, just assume the noise is zero, and then here is your final result" … So at one point you feel like they're teaching you wrong at school, and then the other side of it is well, "now I've got all this experience at my job," I come back to school like the hotshot and then at my classroom I'm going to be the man and just do it well because I see the big picture.

Because of his work experience, David understood that in order to solve real-world problems, he needed to go beyond the theoretical to consider a variety of factors that the well-structured problems encountered in the typical engineering classroom do not include. Andrew, a co-op student, mentioned the same issues when discussing whether the textbook-type problems were useful. He commented that textbook-type problems helped him understand the properties of inductors and capacitors, but that on the job, he needed to know how these were connected and what types of wire was being used to connect them. In general the cooperative education and internship students understood the limitations of theoretical knowledge and the need to enhance their practical knowledge. As Andrew suggested, it's not only knowing about voltage but also dealing with noise that allows one to see the "big picture" issues that go beyond discipline-specific knowledge.

When talking about their classroom experiences in solving problems, non-co-op/internship students often limited the problem scope to issues related to electrical engineering. In the following quote, Issac talked about the practical knowledge gained through building circuits for his class assignments.

> Building circuits, sometimes it is hard because there are so many things. That is maybe why I say it [building circuits] is more practical, because you need a lot of practice figuring out what is wrong because there are so many things. You might have something

> not powered correctly, you might not see what you are supposed to see because there is not a big enough load and you are not drawing enough current. There are so many different things.

Isaac gained some practical knowledge that taught him to examine the "load" when a circuit is not functioning properly, but the scope of his practical knowledge is limited to technical issues related to circuit design. Even though the examples provided by David, Andrew, and Steven (co-op or internship students) are also limited to electrical engineering issues, the co-op or internship students often considered other contextual issues when explaining the knowledge gained from solving problems at work. Vanessa, who spent her internship designing helicopters, stressed that school problems only consider the ideal situation; whereas, real problems required one to consider electrical engineering issues but and other contextual considerations.

> Like in school you don't spend a lot of time learning about cables and real uses of them. There's so much stress on the ideal. In college, you don't have to think about putting circuit breakers and protecting your wires from overheating and you don't have to think about corrosion and you don't think about flying over an ocean versus flying over a lake. You don't have to think about how cold's going to affect it. You're in a lab and you're just putting together a circuit. You don't have to think about that.

Students with co-op or internship experiences were often able to enlarge the scope of the problem and consider aspects that went beyond the technical issues. When considering possible solutions to problems from his co-op experience, Spencer researched whether projects were technologically "feasible," economically "doable," and could be completed in a timely fashion.

After completing her internship, Jill realized how her first-year student design project succeeded technically, but failed to consider contextual factors such as costs, and manpower.

> The [Unmanned Aerial Vehicle] system that we came up with, that we thought would be the best to use, realistically, it looked good on paper. It would have done exactly what it needed to be done, and we ended up getting an A on the project. However, realistically, it would have been very difficult to implement. With the price of materials always going up and down, it would have been very expensive. It would have taken a lot of manpower to get the entire system as a whole up and running. We weren't really graded on the practicality of it. We were just can you get an answer; not does this answer actually make sense and is it useful.

Some students in this Research I university (and others) encounter real-world problems in first-year design or introductory electrical engineering courses that purposefully ask students to address contextual issues. However, these types of problems often are not assigned again until students' senior year capstone course (Devon, Bilen, McKay, Pennington, Serrafero, & Sierra, 2004; Sheppard, Macatangay, Colby, Sullivan, 2008). Students with neither co-op nor internship experiences may not realize the importance of contextual issues in solving engineering problems. Brian, a non-co-op/internship student, focused only on the technical aspects as he described a sound card project he completed in his introductory EE course:

> We had to build a sound card. That was pretty cool. And I know we had to have certain outputs at certain locations at certain notes to do certain functions. And that's kind of what I imagine just designing circuits, because you need voltages or currents at certain locations.

Matt described the same sound card project as a "simulation of the real-world," where he had to consider some contextual constraints such as budgets. He believed it was the combination of his co-op and class work that he helped him understand the importance of broadening the problem scope.

In colleges and universities that do not stress hands-on learning and the application of theory to engineering practice, students with neither co-op nor internship experience are likely to have fewer opportunities to work with real-world problems than students with co-op or internship experience. Although classroom experiences may provide them with the hands-on experiences, the assigned problems (such as those given in labs) often only highlight the technical and not the contextual issues of problems.

Procedural Knowledge

MDL views knowledge as a critical component to the development of expertise in a domain. As a person progresses towards expertise, having both breadth and depth of knowledge in a specific domain allows her to organize concepts in such a fashion that allows her to evaluate the merits and validity of new ideas. Procedural knowledge, or “formulaic techniques” (Alexander, Graham, & Harris, 1998) are part of the knowledge component in the MDL. If an engineer does not have the procedural knowledge or problem-solving skills, he is unlikely to become an expert in the profession. The following section examines students’ procedural knowledge and how they developed it to become better problem solvers.

Important Problem-Solving Components. When asked to identify the two most important components[22] of problem-solving and how they developed those skills (Table 59), three students (Jim, Isaac, and Kevin) identified knowledge as important. To these students, knowledge was needed to solve problems. Even though a few students (Vanessa, Keith and Larry) mentioned behaviors characteristics (such as diligence or “don’t freak out”) as important components, all

---

[22] I utilized the term “component” during the interview, so that I would not bias the participant to think only about problem-solving steps or problem-solving skills.

the students mentioned at least one problem-solving skill (e.g., understanding the problem, breaking the problem down, checking the solution). Thus, students often recognized that solving problems went beyond content knowledge to the utilization of problem-solving skills. Isaac, who had neither co-op nor internship experience said:

> Just looking at a problem trying to solve it, working on it, but also I think it is really helpful and I think maybe it is not done enough [in the classroom], but learning how to solve problems instead of learning about problems.

For some students, classroom experiences were an opportunity to gain subject-matter knowledge, as well as to learn how to approach a problem. David said,

> I think school teaches you that not necessarily "here's a circuit, how to solve it," but in the broader aspect it teaches you "here's a problem, how do I attack it"? And, you know it may not be this little circuit where you solve for this little voltage on some capacitor, but it is how do I take this problem that I've been given and hack it apart until I get the solution I want.

For David, the purpose of his engineering education was not only to develop his knowledge-base so that he could problems such as the think-aloud, well-structured problem, but also to develop his problem-solving skills so that he could solve any type of problem (whether it be ill-structured or well-structured). Because of his internship experience, Steven realized that the knowledge gained in his coursework was not something he was going to use on an everyday basis to solve problems, but he "pick[ed] up problem-solving skills by working with material like [electromagnetic]." He thought solving ill-structured problems is "more of how you look at it and how you're personally inclined to solve problems rather than [materials] you've learned in courses."

Many of the students did not have all the domain knowledge needed (i.e., programming, image processing, and electronics) to solve the ill-structured think-aloud problem. Instead of refraining from the task because they lacked the knowledge, however, they proceeded with the exercise by relying on their problem-solving skills to solve the problem (i.e., defining the engineering problems; identifying critical variables, information and/or relationship involved in a problem, breaking down complex ones to simpler ones). To compensate for their lack of subject-matter knowledge, students utilized their procedural knowledge to develop a process to solve the ill-structured think-aloud problem.

Common Problem-solving Skills. When examining the students' responses to my question about the most important problem-solving components, I did not find any noticeable differences between those students who had co-op or internship experience and those who did not. In fact, the majority of the students (ten of seventeen), regardless of group membership, identified 'defining the problem" or "understanding the problem" as either the most or second most important component in solving problems (Table 59). The consistent focus on "defining the problem" suggests that most students understood this to be a critical step in the problem-solving process. David, an internship student, explained, "you can't really go about drafting up a solution until you really understand your problem." Jim, another internship student, reiterated this thought, saying "you have to define the problem to solve the problem. You can't start if you don't know what the problem is." Problem definitions, Matt explained, determined the next steps to be taken in solving an engineering problem:

> If you don't understand what the problem is asking for, you are going out somewhere else. That actually happens to a lot of people, probably me in some classes. I think that is

> the first key [component] I try to focus on, what it is exactly asking me to do. So right away, you know where to start.

Misunderstanding the problem, Spencer contended, can lead to a faulty final solution. He thus stressed the importance of understanding the client's needs before considering solutions:

> if you don't really understand the problem then you probably are solving the wrong problem. So you probably do all kinds of work for nothing. Maybe you just can see if you are wrong from the beginning, you are wrong all the way to the end, So I just want to make sure I am on the right path and looking at the right problem first, if I even do research or anything. I need to understand what people want.

"Breaking down the problem" or "Divvying everything up" was second most common theme among all the participants mentioned by five of 17 students. Some students thought this was an important component of problem-solving because it often made the problem more manageable. Matt suggested that "you achieve the goal [i.e., solving the problem] faster and plus you might be more focused when you break it down. You might, be able to focus on one small aspect and take it one step at a time … that might help you in the overall goal." Bob talked about simplifying the problem: "take this little piece of a problem and you can solve that problem, and then you can insert this back into it and you can take this next piece, and insert that back in." Although other students did not explicitly mention breaking down the problem as an important component, many of them employed or described this skill during the think-aloud for the well-structured problem (65%) and ill-structured problem (53%).

Table 59: Important Problem-Solving Components

Participant	Problem-solving Components
Cooperative Education Students	
Andrew	1. Communicating with team members 2. Understand the problem
Bob	1. Breaking it down into lots and lots of components 2. Verification – knowing that what you did is correct
Matt	1. Understand what the problem is asking for 2. Breaking down the problem
Spencer	1. Understand the problem 2. Information gathering
Internship Students	
Carl	1. Defining the problem 2. Check your work
Christina	1. Knowing the problem and knowing the solution 2. Breaking things down
David	1. Understanding the problem 2. Figuring out the first step toward the solution
Jill	1. Understand the problem 2. Research to see if others have done something similar.
Jim	1. Defining the problem 2. Knowledge
Steven	1. Coming up with unique solution 2. Coming up with a solution in a timely fashion
Vanessa	1. Thinking about the different angels that can be involved 2. Working until you solved the problem 3. Getting a second opinion, because sometimes you really do need help when you can't figure things out
William	1. Be able to lay [the problem] out and divvy everything up 2. Knowing what to do with those parts, because it keeps you organized
Neither Co-op nor Internship	
Brian	1. Vision – visualize a final product 2. An idea on how to do it
Issac	1. Having a good plan of how you want to go about solving the problem 2. Being able to categorize and identify the problem. 3. Knowledge to solve the problem
Keith	1. Don't freak out 2. Break problem down into smaller components
Kevin	1. Theoretical and practical (implementation of theory) knowledge 2. How you think… go back and process everything to pick out, this is similar to what I did before and try to utilize it.
Larry	1. Recognizing what problem is and what needs to be done to solve it 2. Diligence. Not just giving up because you hit a roadblock

Even though, the participants shared similar academic curricular experiences there was little consensus on the most important problem-solving skills, beyond "understand the problem" and "breaking down the problem." A great variety of other components were mentioned in the interviews. These components ranged from "communicating with team members" to "don't freak out," suggesting there was little overt curricular focus on problem-solving as procedural knowledge at this Research University. The following section examines where engineering students develop their problem-solving skills.

Development of Problem-Solving Skills. For the students in this study, the critical skill of problem-solving seemed to develop without much explicit focus in courses in their academic program. In his comments Steven, who had internship experience, suggested courses develop content knowledge, but not problem-solving skills.

> It's almost like, you know, the problem-solving skills are something you've learned elsewhere, and then you learn the electrical engineering material that just allows you to apply that to electrical problems, not necessarily that learning the electrical engineering material teaches you problem-solving.

Given the importance of problem-solving in engineering, it was surprising that only one student reported being explicitly taught a problem-solving process (or heuristic) in the electrical engineering program. Instead, students learned problem-solving techniques elsewhere. Carl reported that he learned a process from a physics teacher in high school, while Jim learned a process during his internship. Christina said she learned the importance of breaking down problems in her high school computer science course. Keith was the only student who mentioned that an electrical engineering professor explicitly taught students problem-solving skills.

Jill claimed she was never formally taught problem-solving skills but had developed skills such as understanding the problem and researching through her own attempts to solve engineering problems. William shared similar sentiments:

> I just figured it out on my own; no one really told me that, … after I did so many problems and then I realized that if you just try and jump into these problems, you're never going to figure it out.

The majority of the students, regardless of group membership said they developed their problem-solving skills through their experiences in solving problems. Spencer claimed:

> Redoing problem over again, then you start to build the list I mentioned, like the order how to solve problem, and you don't really just get that order from one problem. You have to like redo all kinds of different problems.

Spencer also mentioned that he learned about information gathering through his experience working on a project at his co-op job. Matt talked about how the problems he encountered in high school, college, and work taught him the importance of breaking down a problem. Larry also attributed his skill development to practicing solving problems through his classroom experiences. Vanessa learned to approach problems from multiple angles from doing homework problems.

Bob and David credited their experiences solving problems in the classroom and at work with developing their problem-solving skills. However, both mentioned the urgency to complete the task in a job setting provide an incentive to improve their problem-solving skills ("It was my job and I needed to get it done," "You have a deadline to meet"). The common theme in all these interviews is that no matter the problem-solving skill, the majority of students developed their ability through practice in solving either well-structured, ill-structured, or both types of problems.

Several students mentioned that observing and modeling others enhanced their problem-solving skills. Isaac caught glimpses of the problem-solving process in classes.

> So like looking at the problem-solving method, it is done, but always within the context of the class. And it is never, kind of like taught to you, that everything is a problem and there are certain ways to go about doing [it]. It is kind of understood, though …. I really enjoy it when my professors look at problems in class, and kind of explain those steps to you of how to solve problems. I think that is a sign of a good teacher, and I think it is may be the students job to pull those things out from class and see how they could work within other classes and other problems.

Christina reported that her problem-solving improved by listening to other students' problem-solving processes.

> I just know that there are times when I have done a problem and I have seen the way someone else has done and I realize the way they went about doing it was so much simpler than the way I did or made so much more sense, or [was] just overall better. Like their ideas were more concrete than mine; some of mine might be a little vague. I would see the way they did it and I would remember that. And if I ever got other problems that were similar to that or even not so similar, I knew that kind of viewpoint, like how they went from point A to point B and I meshed that with how I would went from point A to point B.

For Christina though, this modeling behavior was not limited to her classroom experiences. At her internship, she was able to observe her co-workers' problem-solving processes through her weekly work meetings.

> I just watched them [her engineering co-workers], we would have meetings every week, saying this is what I did this week, and people would elaborate if necessarily, other people would ask them questions, how did you come about this idea, and they would

> explain it was like, wow, that was really interesting. And I would remember things like that, using that hopefully in the future.

Steven also learned to solve problems by observing his co-workers.

> We had all these different people on the team that specialized in different things and it was just really good experience working with them, because we all brought something different to the table and could look at the material, what we were trying to do with the material from different angles and talk about it.

Students appreciated the role of a variety of perception in problem-solving as a result of these work experiences.

The great variety of second steps/components that students named seemed to support their contention that their academic program did not explicitly teach a problem-solving process. Since the primary responsibility of any engineer is to solve problems, the absence of repeated opportunities to explicitly learn the procedural knowledge of the discipline and can hinder the development of competent engineers. As the majority of the participants explained, theoretical and practical knowledge are important element of problem-solving, but just as important is the procedural knowledge to solve problems.

Theoretical, Practical, and Procedural Knowledge

In her Model of Domain Learning, Alexander separates the knowledge component into two categories: breadth (person's declarative, procedural, and conditional knowledge of the field) and topic (person's depth of knowledge in a specific area within the field). In the literature review (Chapter 2), I wrote about "breadth of knowledge" in terms of a student's knowledge of electrical engineering. Depth, I suggested, came from knowledge of the subfields within it (e.g., systems and control, digital signal processing, circuits and power). The interview data though suggests, however, that my conceptualization of the breadth and depth may need to be revised.

A more reasonable conceptualization may be that engineering, understood broadly, constitutes breadth. Engineering knowledge then is the procedural knowledge of how to solve problems. Depth in this domain comes from knowledge of the subfields of engineering, such as electrical engineering, which include both theoretical knowledge and practical knowledge. Developing both the breadth and depth of knowledge within the field allows students to apply their theoretical and practical knowledge in a systematic fashion. For example, when solving the well-structured problems, students did not just apply their theoretical knowledge to solve the problem. Instead, the majority of them talked about applying their theoretical knowledge in a systematic fashion that allowed them to break down the problem into simpler components. This resulted in solving the think-aloud problem using algebraic equations as opposed to differential equations.

This revised conceptualization of the engineering domains places equal importance on theoretical knowledge and procedural knowledge, whereas my previous conceptualization appeared to minimize the importance of procedural knowledge and placed greater emphasis on theoretical knowledge. As the next section will show, engineering students, especially those with work experience, appear to develop a metacognitive awareness of their knowledge-base limitations. Yet, instead of developing strategies to enhance their theoretical and practical knowledge, these students developed strategies to enhance their procedural knowledge, adding breath in addition to depth, in moving towards competency in their field.

Strategic Processes in Domain Learning

Strategic processing, another component of MDL, refers to how an individual gains knowledge. As a person progresses towards expertise he is more likely to employ deep-level processes (i.e., strategies focused on understanding concepts) as opposed to surface-level processes (e.g., memorizing the definition of a concept). The transition from deep-level to surface level processing is important to understand because advanced learning strategies improve a person's acquisition of knowledge.

Students mentioned several learning strategies in the interviews: "reading the books constantly;" taking notes in class ("Every single thing, I write it down"); keeping a journal from "personal issues to stuff I did in class I thought as interesting," modeling behavior (either their peers, professors, or co-workers), and focusing on the main concepts ("it wasn't really important for me to remember all of the little things that built off of this main thing that I have never seen before. Just know what the main thing is and [its] properties"). Almost all the participants, though, talked about learning through problem-solving exercises.

Practice in Problem-solving

Problem-solving exercises, either paper and pencil problems or hands-on-activities, can be viewed as learning strategies because they ask students to apply knowledge and develop or enhance their understanding of concepts and principles. Most of the students, no matter what group they were in, claimed that they gained or enhanced their knowledge through their experiences in solving problems. Bob recognized that he gained knowledge through solving problems, which would help him solve future problems.

> Experience gives you the knowledge you need to go out and solve maybe similar, but not identical, problems and to carry your knowledge base into a different problem and to use

> those skills that you learned from that previous problem to solve the new problem that is different.

Matt, a co-op student, expressed similar feelings:

> Maybe for example if you are doing a project, in my case a communication project, and if you have experienced a similar problem you might think realize oh I have seen this in a different project or a different course. I think we should do this a certain way, so that might speed up your process in that sense. But if you are doing it for the first time, you don't really know which of the choices might be better for achieving that goal.

In explaining his communication project, Matt talked about how his experiences solving similar problem helped him become a more efficient problem-solver. For Steven, solving circuit problems developed his knowledge base, which he argued would help him avoid future mistakes.

> With circuit designs, certain problems will come up and since you're reusing a lot of ideas, once you encounter those problems the first time you're hopefully not going to make the same mistake again. So it's just a matter of building on experience.

In explaining how his problem-solving ability improved, William, quoted earlier, learned to apply his mathematical knowledge to a problem ("write out all the differential equations"), but also increased his discipline-specific knowledge. As he came to understand the properties of a capacitor and inductor, he was able to simplify the process in solving circuit problems involving those devices (i.e., reducing the differential equations to algebra equations), which in turned improved his problem-solving skills. Increased theoretical knowledge within electrical engineering improved his problem-solving skills.

The development and enhancement of knowledge is evident when examining student responses to how textbook problems may help them solve ill-structured problems. A few students claimed the practice of solving well-structured problems developed their knowledge-base which in turn helped them solve ill-structured problems. Carl talked about how the fundamentals learned from the textbook problems were useful in carrying out the tasks assigned to him at his internship.

> The textbook problems provide me confidence and understanding of the fundamentals of whatever it is they [instructors] are trying to get across. For example, in computer science class when we learned C++, you know, it was very rigid. You need to write a code to do this and there's generally one or two, you know, straightforward ways to do it. So it's not, it's not fully open-ended, you know I consider it mostly a closed problem. Because you know where it is and you've learned something in task so you just apply in one step. I have been able to apply it for my internship. So I was able to take the basic understanding of computer programming whether it be declaring variables and setting up loops and identifying and using branch statements. Then I could apply that to an internship, but that was only because I had known it from the textbook problems.

The textbook problems helped Carl understand basic concepts he needed to solve problems encountered during his internship.

Jessica, a student with internship experience, agreed that solving textbook problems were helpful in solving ill-structured problems and explained:

> You can't start running until you learn how to walk. You have to get a background in what you are learning about, no matter how tedious or time consuming. You have to learn how to do it, or else you are not going to be able to look at an open-ended problem and know you can do it this way, this way, or that way.

Jessica recognized that the basics learned from solving textbook problems are important to solving ill-structured problems. Other students also talked about how the textbook problems provided them with the "basic concepts" that they needed to address more complex problems.

The Role of Hands-on Experiences

Even though classroom instruction and textbook problems are important to development of "basic concepts" or theoretical knowledge, the students with neither co-op nor internship experience realized that the lack of instruction on applications of domain knowledge in their coursework and lack of hands-on activities hindered their learning. Kevin, a student who had neither co-op nor internship experience, said the lack of hands-on activities prevented him from rating himself as a higher problem-solver.

> I don't have that much practical skill, therefore, I feel that I don't know as much. Maybe if it is from the book, I can manage [the problem]. I can do something and solve it. But until I actually do a real job, I don't think, or if I go into the labs a lot, I don't think I really have that high problem-solving skills.

Classroom experiences in which professors demonstrate experiments rather than asking students to do them, Kevin argued, are less useful than hands-on experiences.

> Suppose we are working on chips and stuff, and in one of our classes, so until I am actually into that chip, I am actually able to see it and actually see it on a computer and see from point A to point B what's happening, what's not. … I can solve the problem better. But if … we are mostly looking at the book, and even if we are in the lab, it mostly the teacher who is doing it because he doesn't want us to screw it up, or something else. So we are just kind of looking, and we are learning a bit, but I don't think it is as good as if we were actually doing it ourselves.

Kevin realized that with more hands-on experience, his problem-solving ability could improve. Recall, too, that Issac, another non-co-op/internship student, suggested his lack of hands-on experience in building circuits prevented him from rating himself higher on ill-structured problems. In general, the students with neither co-op nor internship experience acknowledged a deficiency in practical knowledge due to their lack of hands-on experiences.

"Engineering … you can't know everything"

As noted, Alexander (1997, 2003) considers metacognition a learning strategy. Through their work experiences, many of the co-op or internship students came to the realization that the knowledge they possessed was not always sufficient to complete their assigned tasks. As one internship student said, "Today's problems, they're so complex. The best expert in the world isn't going to be able to solve it, because you need someone who's an expert on something else and no one can work alone on a huge project."

Spencer, through his co-op experience, realizes the knowledge learned in school is not always necessary to solve problems encountered in the real-world.

> Well I would say the working experience definitely changed the attitude a lot. I remember specifically after first, because I did my first co-op and internship straight it was like spring into summer. When I came back in fall a lot of stuff changed, because after you work in real company, you figure out that the knowledge you learn in school, even though you are good at them, doesn't necessarily help you in the future. You start to know what really will help you in the future and maybe that is a point I started to change, putting less effort in the knowledge or technology I am learning right now compared to more effort gathering information that maybe I need in the future or more like reality information. Just nobody really talks about Ohms law or anything like that in real life, so

> you have to know, also a lot of information we learn in school is all basic information, and technology changes really fast so you have to like keep yourself updating and that takes a lot of time, too.

At his co-op, Spencer learned that a single-minded focus on understanding the material taught in class would be insufficient and he changed his learning strategy to focus not only on developing his theoretical knowledge but also his procedural knowledge. Spencer felt that he was better at solving problems in his freshmen year, when problems were simpler and all the needed information was provided. Currently though, he argued that he doesn't "necessarily need to know a lot of information to solve problems." Through classroom, co-op, and co-curricular activities, he developed strategies for searching out the knowledge needed to solve problems, mainly by incorporating "research" into his problem-solving process.

> In high school or middle school, I [would] see a problem. I probably [would] just wait for the answer if I don't know it. And probably look, I want to say I won't look that hard, if I can solve the problem. If I cannot then I cannot. But after college, maybe right now, I don't think there is any problem I cannot solve. … [I]f I see a problem [for which] I have no idea, I don't know how to solve, I will go ahead and do more research and look for the right people to talk to and that way I will eventually solve it, compared to in high school I probably won't do anything at all.

Similar to Spencer, other co-op and internship students realized that when they did not have the content knowledge to solve a problem, then they needed to be active in finding resources to accomplish their goals. After her internship, Vanessa described this more active approach: "if you don't know it, just look it up, just finding something that's gonna work. You can find it. It's out there somewhere." Jill talked about how her problem-solving process became more efficient through her classroom and work experience. She realized the limitations in her knowledge-base and learned to seek resources to help her solve problems.

> A lot of people, they don’t want to express that they don’t know something about something. I have come to the realization that just because I don’t know something doesn’t mean nobody else will, and people aren’t going to judge you if you don’t know it. You just come out, you ask them straight up what’s going on, and they will be happy to answer you because they have a question they need you to answer as well.

For Jill, asking for help from other engineers became easier when she realized that others may need to do the same. She understood that all engineers would at some point lack knowledge to solve problems. Matt had similar experiences at his co-op, where he recognized the importance of asking other engineers for help when he lacked knowledge to solve a particular problem: “Now, I am trying to look at other resources rather than just relying on myself, so that would be my first step [in completing an assigned tasked at work], looking at other engineers.” For Spencer, Jill, and Matt, the lack of knowledge does not become a hindrance because they developed strategies (i.e., research a problem, asking questions) to overcome their deficiencies.

Bob explained how seeking resources is important to being successful in solving work problems.

> [Co-op] definitely developed [my problem-solving skills] because you know it was my job and I needed to get it done. The kind of thing where my boss doesn’t really care how I get it done as long as it is on his desk by the end of the week, or whatever it may be. So that's just really finding different resources, different people within the company, and different knowledge resources within the company. And you know, getting in touch with

> the right people really is a huge factor to be successful, I think, because no one is a one man show, everybody needs help, and it is just all about finding the right resources.

In talking about how his co-op developed his problem-solving skills, Bob learned from his work experiences that “no one is a one man show” and, like Jill, realized everybody needs help. Working at a company may have aided him to this conclusion, because his company was not concerned with how or who completed the task, but instead whether the task was correctly completed. Seeking outside resources to help solve problems, these students realized, is not a characteristic of a poor problem solver, an important part of the problem-solving process.

Unlike the non-co-op/internship students, many co-op or internship students became more proactive in seeking the necessary knowledge to solve problems (e.g., searching the internet, researching journals, asking co-workers) and incorporating that skill into their problem-solving process. Thus, students with cooperative education and internship experience not only began to understand the limitations of engineering as domain knowledge, but also the limitations of their personal knowledge-base. Some co-op or internship students developed active strategies to overcome these challenges, whereas, the non-co-op/internship students did not actively seek other ways to overcome their lack of practical knowledge.

Interest

According to Alexander (1997, 2003), interest transforms from situational to personal as an individual progresses towards expertise in a domain. Situational interest is the result of external factors (e.g, learning for a grade), whereas personal interest is internally motivated (e.g., learning to satisfy one’s own interest) (Alexander, 1997, 2003). If a student does not develop interest in a field, he is more likely to leave it. Those who develop an interest are more likely to stay.

Short-term and Long-term Plans

During the interview, I asked participants about their short-term and long-term plans to gauge their interest within the field of engineering. I was interested in their goals and whether their work experiences influenced their interest. Table 60 provides participants' responses regarding their short- and long-term plans.

When asked about their short-term plans, 12 students indicated that they planned to work in engineering. Three planned to attend graduate school or law school. One student said he planned to leave the field of engineering. With respect to their long-term plans, nine students expressed interest in graduate school, planning to pursue a master's degree in engineering or business. Another planned to earn his professional engineer license. One wanted to become a patent attorney and another one planned to move into management. Three expressed a desire to work within engineering as either an audio engineer or an environmental engineer.

All the cooperative education students' short-term plans focused on employment in engineering. There was also additional differences between the internship or co-op students and students with neither co-op nor internship experience. Two of the eight internship students planned to pursue a graduate degree in engineering; another planned to leave the field; but the majority planned to pursue employment in the field. The students with neither co-op nor internship experience also had various plans. One student planned to pursue a law degree, another a graduate degree within the field. The remaining three planned to seek employment within engineering.

Co-op students' long-term and short-term plans suggested that they were more focused on engineering work compared to students in the other two groups. This seems logical but it is not clear whether their co-op rotation were the cause or effect of these plans. In this same group of

EE majors, internship students appeared to be more interested in research than work, but internship students appeared to be the most undecided group with respect to their long term plans. Three of the eight students wanted to see how their short-term plans would affect their interest before they settled on a career. Two wanted to work first to explore their interest before pursuing graduate school; while one wanted to see if she liked graduate school before she pursued a PhD (See Table 60 for a complete list).

Table 60: Participant's Short-term and Long-term Plans

Participant	Short-term Plans	Long-term Plans
Cooperative Education Students		
Andrew	Get a job	After I graduate, I want to go for my PE [professional engineering].
Bob	I have a job currently.	I think I would like to get my masters in systems engineering, but I also am debating on getting my MBA.
Matt	I am probably going to work in probably DSP or communications.	Probably think about if I want to go back to grad school after that … either in engineering or business. I haven't decided yet.
Spencer	I am going to start working after I graduate, and probably stay with engineer, I won't say within electrical engineer.	Stay with the engineer field, I am thinking like four or five year. After that maybe get my MBA degree or move up to like management positions.
Internship Students		
Carl	I considered graduate school, but I've been interviewing with companies, so I think I'm going to enter the workforce if everything is on track.	Possibly returning to graduate school. Graduate school will then mean more to me because I've had the work experience on the job. And then seeing what happens there. Either senior researcher role or senior manager role within the company.
Christina	I am applying to graduate school [in EE].	I am not sure, I don't know if I want to get my PhD yet. It is kind of just; I am going to see how I feel in my graduate studies to see how much further I want to go with it.
David	Definitely right out of school getting a job, not looking to go to grad school anytime soon.	Keep my options open for managerial side, but I think I want to [get] a lot of experience in technical first, so I'm a good manager.
Jill	I am looking for a job.	Eventually, I think I'd like to probably go to grad school, but I want to get out, out in the working field first.

Table 60: Participant's Short-term and Long-term Plans

Participant	Short-term Plans	Long-term Plans
Internship Students		
Jim	I am going to stop here and move to like consulting jobs not EE … even though, I get a good GPA, I didn't really like it. I didn't feel like this is my thing that I want to do for my entire life.	
Steven	I am planning on going to grad school… and they're both actually music related	I'm looking to continue down this path with audio engineering kind of stuff
Vanessa	I'm going to be working for the same company that I interned.	I plan on working there [company that hired her], but I really am more interested in the environment and working on stuff like that so, hopefully within then years, I'll be more in that type of field.
William	Originally, I kind of wanted to go to grad school and then I kind of backed off because I wasn't too sure what I wanted to specialize in. … I figured if I go out and work in another [EE sub]field, if I like it, I'll go to school somewhere. … I do want to go back to school and specialize in something, get more knowledge on a particular specialization.	
Neither Co-op nor Internship Students		
Brian	I actually want to go to law school [and become a patent attorney]	
Issac	I'd would like to go to PhD program [in EE], but I haven't applied to any graduate schools yet, so I am just thinking about maybe I will get a job for a little bit and apply to grad school, but I would definitely like to get my PhD	
Keith	I'm really hoping to get a job with the [Government] that I've more or less been offered … I'll be working as a security engineering officer	I'd always love to go into audio engineering. The more practical application of being a sound engineer for bands that travel.
Kevin	I want to get into grad school [in EE] … If I don't get into PhD here [in US], another option that I have is I want to go Sweden and study masters there and then apply here [US] for PhD again	
Larry	I took a job with a defense contractor.	Potentially, [Company Name deleted] offer a good program to put you through grad school, so I intend to pursue that if I can. And at least get a feel for what it is like with my specialty for the next year or so, and if I think I can do this for thirty, forty years ; stick with it or if not there is always time to change.

The Influences of Interest on Engineering Choices

Even though patterns appear to emerge with respect to students' plans, the influences of these goals varied from person to person. For example, Bob and Matt were still unsure of whether they wanted to pursue a master's degree in business or engineering, and planned to decide after working in the field for a number of years. Alternatively, Spencer said he always wanted to "start a business" or work in management, and thus pursued an engineering degree because it would provide him the technical background to achieve his dream. Andrew, after observing many professional engineers (PE) at his internships, said:

> I wanted to go for my master's, but then I changed my mind, because I have seen a lot of PE engineers at work and I think it is better for me to go for my PE than my masters.

Occasionally, a student's co-op or internship experiences directly influenced his plans. For example, two students (Bob and Vanessa) received and accepted job offers from the companies they worked with during their co-op or internship. In contrast, Jim decided as a result of his internship experience that he did not want to work as an electrical engineer.

> So I did my internship in the R&D department as like assistant engineer. It was great experience to work with those real engineers who like build and design TV's displays, cell phones. I worked there for two months, but the interesting thing is, they didn't really like it. There are like ten people designing TV's … and there were not many people who really liked their job. … I was frustrated to see them always come to work and [they told me], "If you don't like it very much, don't try to come here, don't try to work here, do something else, go do the doctorate and go to medical school," and they were like that, and they said it to me in different ways.

Originally, Jim planned to pursue a PhD in engineering. After his internship, he decided that electrical engineering was not for him and planned to work as a consultant. William also attributed his change in career plans to his internship experience.

> It's not that I didn't like [Electromagnetic] it's just that it's something that I wouldn't want to do for the rest of my life. So when I was [at internship company], I realized that

> maybe this isn't for me. And there's totally different specialization's in electrical engineering other than you know just communications and E&M, so I took courses in DSP [digital signal processing] last semester, computer vision course, an image processing. … Right now I find the stuff really interesting, but I don't want to just go out to grad school and be left in the dark.

At his internship, William learned he did not like the type of work involving electromagnetics, which he thought was "mostly experimental." After his internship, he decided to pursue some of the other subfields within electrical engineering (e.g. digital signal processing) and decided it would be wise for him to "find something I like" and then go to grad school.

The influence of interest was evident in students' course choices. For example, the majority of the students interviewed (14 of 17) based their course selections on their interest in the course topic. Some co-op and internship students' work experiences positively influenced their interest in certain topics within engineering and subsequently their choice of specialty within electrical engineering. Matt, a co-op student, said:

> My co-op was more in communications engineering, so it liked kind of tied in to what courses I took and plus developed my interest if I want to take [more] courses in DSP [Digital Signal Processing] and communications.

In contrast, William's internship experience helped him decide that pursuing electromagnetic was not a career interest for him. He explained, "I did have an intern[ship] experience at a communication firm, …, that kind of turned me off in a sense to electromagnetic itself."

Situational and Personal Interest

Few students commented directly on their level of interest in engineering, and when they did it usually arose in the discussion of learning. These students more often expressed interest in understanding the material (personal interest) as opposed to achieving a certain grade (situational interest). Bob, who made an effort to "really understand how [he] got the right answer," said, "It is the kind of thing where would you rather go through college with a 4.0 and know nothing or would you rather go through with a 2.0 and know everything."

Christina explained how her internship helped her realize the importance of understanding as opposed to memorizing concepts.

> In my internship I saw that there were things I just learned and forgot and that was important to know. And I realized, before it was all about the grade, I just wanted get good grade so I could get a job, but then I ended up getting a job, and I realized that I needed to actually, it sounds stupid that I didn't know it before, but I needed to know the stuff that I was learning, so which I think is a major problem in our department. And it seems like the only goal for most people is to graduate, and not really to kind of come out of this major feeling like you actually know everything that you learned and are comfortable.

Christina learned that earning good grades was not enough to succeed in the workforce. She had come to this conclusion after sitting in a meeting at her internship:

> We were in a meeting and we were talking about zero hold filters, and I had learned what they were, I just couldn't remember them then, and I had to go and look it up, and that is something I should have known off the top of my head.

Isaac also talked about this shift in his focus.

> Coming into college, I wanted to get my undergraduate degree and then, as I went through I really wanted to go on and get my PhD and you need to be serious about learning. You can't just want to get your PhD, you have to work hard and you have to

> become like a legitimate PhD candidate, and you have to be someone who would be valuable as someone with a doctorate degree, so you need those kinds of tools and you need an understanding of the subject, and I think that changed a little bit as I went through. Maybe in the beginning of college as well, I was like, I will get A's it is not going to be a big problem. But then I realized, just getting A's is not enough. You have to try.

Issac's interactions with his professors helped him make a transition.

> I don't know. I think it is from dealing with professors, because they know a lot of stuff, and if you think, I am an undergrad, and I feel like they know so much, right? And could I ever possibly know so much and remember so much and be able to recall so much? Maybe in dealing with them that has made me get more serious about education, possibly.

Larry made the transition because he found the coursework interesting and was committed to making electrical engineering his career.

> I'd say now I'm probably more [eager] to learn, as opposed to when I first started. Now, I feel like I really want to. Maybe when I started, I was thinking that the grades were more important. But it really doesn't matter, in my opinion, now the grades. I feel like what you are learning is by far the most important. … Maybe some of that is you are young, you are scared, you are in a new environment, you are hesitant to raise your hand and speak out, but definitely my approach to learning is more interactive now, especially with the professors.

Two participants were notable for their lack of personal interest in the field. Both planned to leave the field after graduation. Brian, a non-co-op/internship student who planned to become a patent attorney, determined the usefulness of material taught in class based on whether he was tested on it in the course's exams. He also explained how he allocated his time to studying, "Like on a homework assignment that's worth well, if homework is worth ten percent of your final grade, I won't invest as much time on a weekly homework assignment as I would studying for an exam." Jim also discussed how grades were influential in his learning of the material.

> I have to sit down here, like do a bunch of work and like for engineering stuff you have to understand materials first and then you can solve the problem. Everything is like that, but I have to like highlight all those important stuff in the book. My type of study habit is going through page by page, so I was like in the library for like 12 hours for five days. I didn't want to get bad grades or fall behind, so I was putting myself so much effort. And I felt like I didn't like that life.

Unlike Christina's internship, which motivated her to understand the material, Jim's internship solidified his choice to leave the field despite his 3.6 GPA. Brian's classroom experience, which did not allow him to connect with the engineering material beyond tests and exams, never influenced him to change his interest from becoming a lawyer to an electrical engineer.

Confidence in Problem-Solving Ability

Ideally, engineering students will develop their problem-solving skills during college so that they are confident in their ability to solve a variety of engineering problems by the time they earn their bachelor's degree and enter the workforce. Research has shown that an individual's confidence rises when she has mastered a skill (Bandura, 1997), suggesting that an engineering student's confidence in solving problems is related to her mastery of these skills. From the previous sections, students' experiences (either classroom or work) influenced their knowledge that is, the development of theoretical, practical, procedural knowledge. These course and work experiences also shaped strategic processes and students' self-awareness of limitations in knowledge as well as their interest sometimes transforming situational interest to personal interest. As suggested by the conceptual framework, during the experiential learning cycle, the perception of self-ability may alter due to possible changes in knowledge, strategic processes, or interests. The data from the interviews suggests such a relationship between students' levels of experience with problem-solving and their confidence as a problem solver.

Students' Self-Ratings

In the interviews, students were asked to rate their 1) overall problem-solving ability, 2) ability to solve well-structured problems (such as textbook problems), and 3) ability to solve ill-structured problems (defined as problems with no single correct answer). The 1-10 scale (with one being low ability and ten being high ability) allowed for greater variability between student ratings than a smaller scale. The disadvantage of such scales, however, is that raters may differently interpret the points on the scale. It is thus, impossible to know that one person's seven is qualitatively different from another person's nine. Conceivably, students' GPA could be utilized to assess the reliability of the self-rated scores with regard to problem-solving ability, where a high reliability value would justify comparisons between students. In examining these, however, I did not see any trends with respect to GPA and perceived problem-solving ability (See Table 61). Since an individual student uses the same scale to rate herself on the ill- and well-structured problems; comparisons between these ratings for an individual are more easily interpretable than differences between students. The following analysis thus primarily focuses on the differences in students' confidence in solving well- and ill-structured problems.

Table 61: Students' Self Assessment of their Problem-solving Ability and Overall GPA

Participant	Overall GPA	Overall Ability to Solve Problem	Ability to solve Well-structured Problems	Ability to Solve Ill-structured Problems
Cooperative Education Students				
Andrew	2.89	7-8	8	>8
Bob	2.70	7-8	7-8	8
Matt	3.50	7-8	> 8	< 7
Spencer	3.19	8-9	8	9
Internship Students				
Carl	4.00	5	9-10	5
Christina	3.74	7.5	9	5-6
David	3.23	7	6	7-8
Jill	3.70	8	6	8
Jim	3.63	5	8-9	5
Steven	3.66	7-8	8	8
Vanessa	3.37	6	7.5	7
William	3.67	7	8.5-9	7
Neither Co-op nor Internship				
Brian	3.27	9	8-9	3-4
Issac	3.91		10	6-7
Larry	3.35	7	8	6
Kevin	3.01	6-7	8	8
Keith	3.12	8-9	5-6	8-9

When examining the differences in confidence, nine students (Matt, Carl, Jim, William, Christina, Vanessa, Brian, Issac, and Larry) rated their ability to solve well-structured problem higher than their ability to solve ill-structured ones; six students (Bob, Spencer, Andrew, David, Jill, and Keith) rated their ability to solve ill-structured problems higher than well-structured; and two students (Steven and Kevin) rated their ability both types of problems relatively the same. The differences in confidence were often larger in magnitude in students who felt they were better at well-structured than ill-structured problems. For students who felt that they were better at well-structured than ill-structured, five of eight students had differences greater than two compared to two of the six students who had more confidence in solving ill-structured than well-structured. In general, the differences in confidence in solving different types of problems were smallest among the cooperative education students who had the most work experience.

Confidence and Experience

As a follow-up question to the self-rating questions, each student was asked about factors that influenced her confidence/comfort in solving problems. An examination of students' responses suggests that the most influential factor is experience in problem-solving. The more practice students have in solving problems, the more confident they become as problem solvers. This theme was common regardless of the type of problem discussed in the interview (ill- or well- structured) or group membership: 16 of the 17 students interviewed mentioned experience, or the lack of it, as an influence on their confidence in solving problems. The link between confidence and experience is common throughout the three groups of students (co-op, internship, and neither).

For example, Vanessa, an internship student, explained that she was once hesitant in solving problems but became more comfortable through practice.

> When I was a freshman I wasn't as good at problem-solving. I wasn't as quick at learning. I was a lot more hesitant, I hadn't seen as many things. The more problems that you solve the better you are at solving other problems, even if they're not related. Just knowing that you have done it before and you can find a solution is comforting.

In talking about her classroom experience, Christina, an internship student said, "doing problems like that [referring to textbook-type problems], for as long as I remember" was the reason she rated herself a nine in solving well-structured problems. David, another internship student, said, "You do more and more [problems], and you solve more and more, and you get the right answer more often, then you start to feel kind of confident."

Repeated practice appears to enhance confidence. This is best illustrated by contrasting Brian's reasoning for his high self-rating on well-structured problems versus his low self-rating on ill-structured problems. Brian, who had completed neither a co-op or internship, rated himself as an eight or nine in solving well-structured problems because “if you do it over and over again, different examples that are similar, I guess you get more confident in yourself and your ability to solve problems.” In contrast, he expressed concerned about solving ill-structured problems because of his lack of experience.

> I don’t think [Research I University]’s done a good job of preparing me for those [ill-structured problems]. I think it’s very textbook-oriented, personally. For example, my senior design project, I have to build a rail gun. And to be honest, I’m a little scared about doing that because I don’t think I’ve really had too much experience, it’s kind of sink or swim, that’s how I feel. … I don’t know what to expect personally. You know, if they told me what to do I could do it. But doing it on my own -- It’s just understanding how to do it on your own is a little more difficult.

Similarly to Brian, Carl, an internship student who rated himself a ten on his ability to solve well-structured problems, attributed his high rating to “extreme practice. Just straight-out practice.” He reported that he solved well-structured problems throughout high school and college. Carl attributed his low self-rating (five) on ill-structured problems to his lack of exposure to them in classes.

> The biggest difference is lack of experience. … It’s not as much exposure to the open-ended problems. There was maybe one or two, one class, maybe, each year where I’ve actually had an open-ended project. This semester we’re doing the senior project. It’s really probably the first major open-ended project that I’ve had since a freshman and doing the robotics competition. So I didn’t expect that coming into [Research I

> University]. I thought there would be more open-ended projects. So that's why. It's just purely lack of experience.

In explaining his self-assessments, Carl said:

> The reason why I have a nine or ten on the textbook problems, [it is] because I've solved many more textbook problems in the last four years. The reason why I'm a five in open-ended problems is because I haven't had experience, or chances to do that.

Brian and Carl had more opportunities to solve well-structured, textbook-type problems through their course work and both felt more confident in solving those types of problems than ill-structured problems. Hypothetically, as Carl's and Brian's comments suggested, students could gain experience in solving ill-structured problems if they had more opportunities to solve them in their coursework, similar to the opportunities they had to practice solving well-structured problems.

Yet, gains in confidence were not limited to just well-structured problems. In discussing his co-op experiences, Spencer said, "Confidence itself, you can only get that from doing that problem [assigned tasks given by his company], probably more than one time." These comments suggest that the more experiences students have in solving a certain type of problems, the more confident they become in their ability to tackle those kinds of problems. Thus, it appears that the experience of working out problems is related to confidence in problem-solving, and repeated exposure to problems (of both types) is important to developing students' self confidence in solving problems.

Authenticity of an Experience

All experiences are not the same, which may explain why some students found some experiences more influential in the development of problem-solving skills than other students.

According to Carver (1996), experiential learning involves tasks that are authentic or activities that have real consequences. The consequences, such as enhanced knowledge-base or monetary award, from such authentic tasks appeared to motivate students more to complete those tasks than textbook problems assigned in class. Matt, a co-op student, compared and contrasted his work and classroom experiences, saying:

> I described doing a project in the class. The only thing would be a grade that matters, but in the real-world you might cost the company lots of dollars, like millions of dollars in some cases, so I think there is a lot more pressure, and I think it is a different situation versus actual situation in class, where instead of an A you might get a B or a C+.

Matt was aware of the consequences of flubbing a work assignment and thus felt it was more meaningful than earning a grade for a course.

> At least to me, and most people, pressure might make you a little bit more focused and might even make you take the project and go more seriously in that sense, plus you have a feeling you are actually doing something important that is going to matter a lot than just getting like a good grade, so I think that is another feeling, like you might have a better sense of accomplishment, I guess, after doing like a successful project in the real-world versus like you know doing a project in class.

Although it was not a common theme among the participants, there may be a linkage between the authenticity of an experience and the motivation to complete it. When solving problems, two students (one internship and one co-op) explicitly discussed how the type of problem influenced their motivation to solve it. Jill, an internship student, said she might not put as much effort (or energy) in answering textbook-type problems, even though she had the ability to solve them.

> Solving problems out of a book, first of all that doesn't really interest me all that much, because they have no practical application besides learning the material at hand, so I would say that I don't necessarily care as much about those as I do like a design project. Therefore, I don't put quite as much energy into them, … even though I feel that the information is very necessary to learn, I am not going to kill myself trying to figure out their one solution and go from there.

Spencer shared a similar viewpoint:

> I like solving problems, but I don't like solving problems with no purpose or solving problems just for the math. I like solving practical problem more and through all my internship, … I didn't see any problem that I cannot solve yet. It is just a matter of if I want to solve it or not.

To Spencer, the goal of solving these types of problems is to prepare for tests.

> And usually every semester I just study really hard before the test and try to get used to those problems, but once after the test I don't remember anything. So if I just learn the stuff, and if I just review and if I really put effort in there, I probably have like a nine, because I am not really interested in those questions, so probably an eight.

Spencer did not find solving textbook problems worthwhile and did not expend as much energy to learn the material.

Neither Jill nor Spencer appeared interested in textbook-type problems, believing the knowledge gained from solving these problems is limited to understanding the fundamentals of engineering. Larry, with neither co-op nor internship experience, shared a similar opinion. He also enjoyed solving open-ended problems more than textbook-type problem because there was potential to learn more from solving those types of problems.

> I would say I think [open-ended problems] are more applicable to the real-world, so that helps motivate you, as opposed to just solving every odd numbered math problem in a textbook or something. You are posed a question and it is pretty much up to you. You get out of it what you put into it. If you want to go the whole nine yards and like research everything extensively, make sure that you take care of all potential variables, I feel like you are working a lot harder, but at the same time you are definitely taking a lot more out of it.

These three comments suggest that the authenticity of the problem can influence students' experience in whether they develop or enhance their problem-solving skills.

Summary

The conceptual framework proposed for this study is the amalgamation of Alexander's Model of Domain Learning and Kolb and Frye's Experiential Learning Cycle. The framework hypothesizes that through experiences, a person's knowledge, strategic processes and interest may change within an academic domain, which in turn influence's his/her confidence in that domain. Key findings from the interview data suggests that students' experiences (both classroom and work) in solving problems and confidence problem-solving ability are related. For all the participants in the study, the more experiences in solving problems, regardless of whether these were well-structured or ill-structured, the more confident they became in problem-solving. Additionally, a lack of confidence is attributed to a lack of experience in solving problems.

As hypothesized via the conceptual framework and supported by the interview data, the relationship between experiences and confidence can be explained by changes in a person's knowledge, learning strategies, and interest. The interview data revealed salient differences between students with work experiences (co-op and internships) and students without work experience.

All participants appeared to gain theoretical knowledge (i.e., theories, laws and principles of the field) through their classroom experiences and solving textbook-type problems. In addition to their classroom experiences, co-op and internship students also appeared to gain practical knowledge that allowed them not only to understand the limitations of the theoretical knowledge but also to expand the problem scope to consider contextual factors (e.g. budgets, time, environmental) as well as the technical factors.

Some co-op and internship students also began to not only understand the limitations of theoretical knowledge in their field, but also to develop metacognitive awareness of their knowledge-base within the field. This metacognition influenced them to focus their learning strategies on understanding theoretical and practical knowledge, and also to develop procedural knowledge (or for these students, problem-solving skills). Developing metacognition may be particularly important for these students because the majority were not explicitly taught problem-solving skills in their coursework, where the emphasis was learning theoretical knowledge associated with the field.

Work experience appeared to have both positive and negative influences on participants' interest in the field. For some students, the experiences helped them choose what subfields within electrical engineering to pursue, while for one student an internship dissuaded him from pursing a career in the field. More importantly, through their work experiences, co-op and internship students' interest appeared to transform from situational to personal as they become more focused on understanding the concepts of the field as opposed to just achieving good grades in courses.

Even though Alexander's MDL component appeared to be more salient, the interview data does support elements of Kolb and Fry's Experiential Learning Cycle. For these participants, experience is the repeated practice of solving problems, regardless of the type of problem. Through these repeated practices of solving problems, students' knowledge, learning strategies, and interests changed. The effect of repeated practice, then, suggests that the cycle component of the framework exists. The cycle may not be perfectly periodic in that students' experience did not always immediately modify their knowledge, learning strategies, or interests, but instead each experience may have a short-term and long-term effect. For example, when Jill talked about her first-year design project, she learned how to build an Unmanned Aerial Vehicle (short-term effect) but did not learn the practical limitations of the projects until after she completed her internship (long-term effect).

Although, not strongly supported by the interview data, some students seemed to suggest that the authenticity of the problem is important; otherwise they may not be as interested in solving it. These students perceive authentic problems as experiences with important consequences such as monetary gains or the knowledge gained from completing such tasks.

CHAPTER 6:

LEARNING ON THE JOB: THEORY AND PRACTICE IN PROBLEM-SOLVING

In today's world, the contributions by engineers surround us. From the cars we drive to work, to the televisions we watch for entertainment, to the cell phones we use to communicate with one another all are products developed by engineers. From one perspective, these products are answers to a problem; cars allow us to travel from point A to point B in a timely fashion, televisions bring entertainment to our homes, and cell phones make us easily accessible to our friends and family. Yet, even after these products are available to the general population, engineers still search for ways to enhance them to produce a better product. The solution to the problem is never perfect, and thus problem-solving is continuous. The nation's desire for environmentally friendly cars has engineers searching for solutions to improve fuel economy and develop alternative fuels. Televisions are not only larger than they were 20 years ago but flatter and producing life-like images in an energy efficient fashion. People now communicate not only by talking through cell phones, but also through texting and sending pictures. Technology develops through engineers solving problems.

As the United States evolved from an industrialized to a knowledge-based economy, the development of new technologies has become vital to its economic welfare. Accordingly our government is concerned not only with the pipeline for engineers but also, with ensuring those engineers have the skills to develop the technologies needed to improve the quality of life for citizens of the United States and the global community (NAE, 2004, 2005). If engineering is, as I have suggested, a process of problem-solving, then understanding how undergraduate engineers develop problem-solving skills is important for engineering education. Educational research can contribute to the capacity of understanding how undergraduate programs develop curricula that facilitate students' growth as problem-solvers.

Cooperative Education

Cooperative education (co-op) and internships are similar types of experiential learning programs in which companies or government agencies employ students who want to complement their academic experiences with practical work experiences (Kerka, 1999). The main difference between the two types of experiences is the time requirement. A single internship usually lasts three to four months (although students may have multiple internship experiences). Co-op programs differ from internship programs in that co-op students are required to complete at least a year of supervised work experience during their undergraduate program (NCCE, 2002). The typical engineering co-op model entails alternating semesters/quarters of classes and full-time work. Similarly, a single co-op rotation usually lasts three to four months. Students usually stay with the same employer throughout their co-op experiences, but have the option of working for different companies or agencies. Unlike some other professional fields, such as teaching and nursing, an internship or cooperative education, even though recommended, is not a graduation requirement for most institutions, and is not necessary to enter the profession.

Cooperative education has been in existence since 1906 and approximately 100 engineering schools in the United States currently have a co-op program (Mathias-Regal, 2006). Much of the engineering education research on cooperative education focuses on benefits such as higher salaries (Blair & Millea, 2004; Blair, Millea, & Hammer, 2004; Friel, 1995; Schuurman, Pangborn & McClintic, 2005), the number of job interviews obtained (Schuurman, Pangborn & McClintic, 2005), and academic achievement (grade-point-average) (Blair & Millea, 2004; Blair, Millea, & Hammer, 2004) among students who do and do not participate. Other studies of cooperative education have shown that employers perceive students with co-op experiences as having better problem-solving skills than those who do not (Friel, 1995), and that students perceive their cooperative education experience in aiding their development of problem-solving skills (Pierrakos, Borrego, & Lo, 2008).

Still, little is known about how these experiences influence the development of problem-solving skills. The current study moves beyond previous research by examining how co-op or internship programs influence learning by considering the similarities and differences in problem-solving skills between students with engineering work experience (co-op or internships), and students with no engineering work experience.

Research Questions

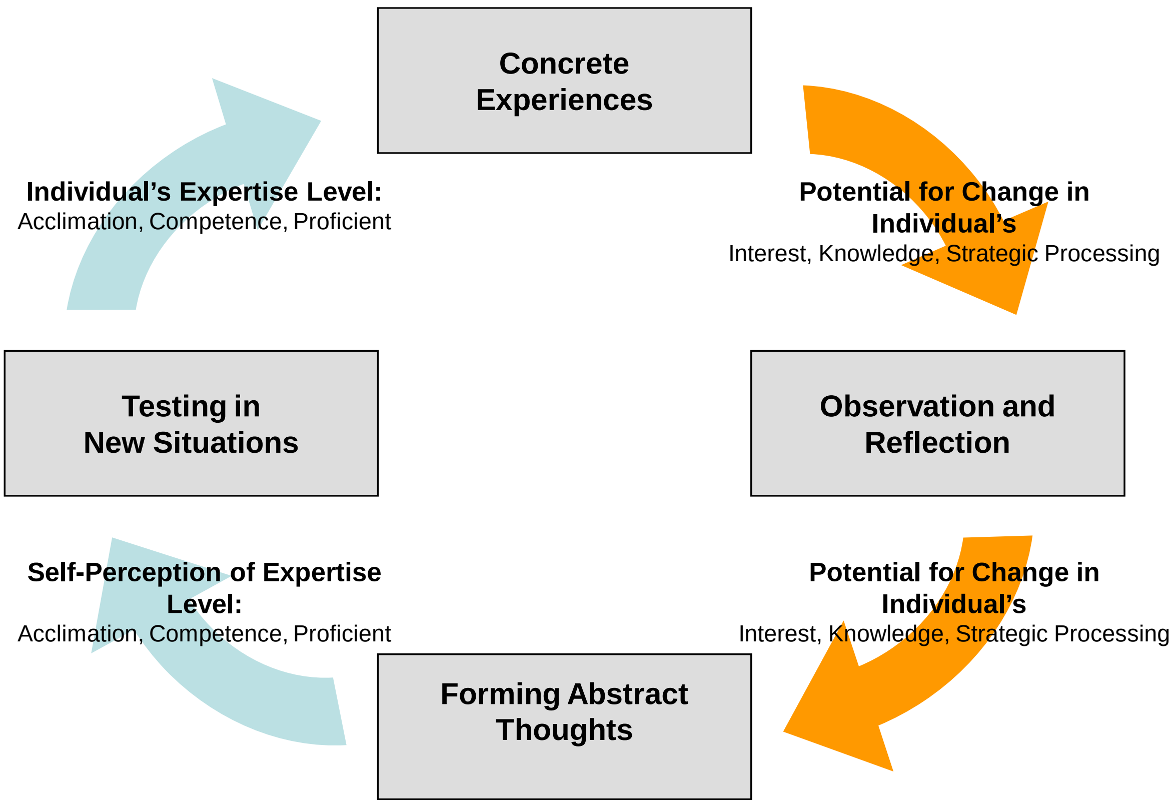
The main purpose of this research was to understand if and how co-op and internship experiences in engineering influence the development of students' problem-solving skills in engineering. Utilizing a mixed-method approach, this study addressed two questions:

1. Does experience in cooperative education or internship programs influence students' self-perception of their engineering problem-solving skills?
2. How do students with cooperative education or internship experience differ in their perceptions and understanding of their engineering problem-solving skills as compared to students with no experience?

Conceptual Framework

The conceptual framework for this study synthesizes Alexander's Model of Domain Learning (1997, 2003) and Kolb and Frye's Experiential Learning Cycle (1975) to explain a person's progression toward expertise in an academic domain (Figure 10). The basis for the conceptual framework is the experiential learning cycle, which posits that learning occurs in four phases in a spiral fashion: Concrete Experience, Observation and Reflection, Forming Abstract Thoughts, and Testing in New Situations. An iteration of the cycle usually begins with a person engaging in an activity. Once he completes the activity, the individual reflects and learns from the experience. He may then test the knowledge gained from the experience in a new situation, thus leading to a new concrete experience.

Figure 10: The Role of Experience in Domain Learning and Expertise: A Conceptual Framework



The proposed framework extends the original experiential learning cycle by suggesting that components of the MDL model (interest, knowledge, and strategic processing) and expertise levels (acclimation, competence, and proficiency) are potential influences on the transitions between the phases. The framework hypothesizes that through a single iteration of the experiential learning cycle in a given domain of knowledge, a person's knowledge, strategic processes and interest change. This in turn influences the person's confidence in his domain.

These changes in self-perception and ability then influence future experiences. The spiral nature of this framework provides one possible explanation of how individuals progress towards expertise in a domain: expertise develops gradually through experiences, such as solving assigned classroom problems or competing work tasks in a cooperative education job that contribute to one's knowledge, strategic processing repertoire, and interest in the domain.

Methodology

The design of this study included a quantitative and a qualitative component. This mixed-method approach allowed for a detailed understanding of how cooperative education and internship programs influence engineering students' problem-solving skills by answering the research questions posed in this study.

I conducted a quantitative analysis to answer the first research question, "Does experiences in cooperative education or internship programs influence students' self-perception of their engineering problem-solving skills?" The quantitative component utilized multivariate regression and multi-nominal logit models to examine whether significant differences existed between students with engineering work experience and students with no engineering work experience with regard to their assessment of 1) basic skills, 2) design and problem-solving skills, and 3) engineering thinking skills. The key variables came from a set of three scales and their respective items from the nationally representative *Engineering Change* (EC2000) dataset, which contains survey responses from 4,461 senior engineering students from the class of 2004 in seven engineering disciplines (aerospace, chemical, computer, electrical, industrial, and mechanical) from 39 accredited institutions. The analysis controlled for students' college grade point average, socioeconomic status, major, and time spent in engineering design projects and design competitions beyond class requirements. With respect to institutional characteristics, Carnegie classification and the urbanization of the institutions were included as control variables in the models.

The second research question, “How do students with cooperative education or internship experience differ in their perception and understanding of their engineering problem-solving skills as compared to students with no experience,” was addressed through qualitative data collection and analysis. I interviewed three groups of senior electrical engineering students at a single Research I university: 1) students who completed three rotations in the co-op program, 2) students who completed at least one internship, and 3) students who did neither co-op program nor internship. For this portion of the study, problem-solving was defined broadly so that it included skills such as those represented in design and problem-solving skills scale used in the quantitative analysis, as well as the more general thinking skills common in engineering courses, represented by items in the basic skills and engineering thinking-skills scales used in the first phase of the study (Donald, 2002).

In total, I interviewed 17 undergraduate engineering students, including 1) four students who completed at least three cooperative education rotations, 2) eight students who completed at least one internship and, 3) five students who did neither cooperative education nor internship. Initially I tried to develop an academically homogenous sample by selecting students who had a cumulative grade point average greater than 3.0. When sufficient participants could not be found, this requirement was relaxed to ensure an adequate number of participants. This was true for the cooperative education group, because only six electrical engineering students at the participating institution had completed at least three co-op rotations. The co-op group was comprised of two students with a cumulative GPA greater than 3.0 and two students with a cumulative GPA less than 3.0.

The interview protocol (see Appendix D) asked students about their short- and long-term career and educational plans, confidence in solving ill-structured and well-structured problems, problem-solving experience, learning experience, and their development of problem-solving skills. As part of the protocol, students were asked to describe how they would solve two think-aloud problems (a well-structured and ill-structured problem) as well as their approaches to problems solving. I analyzed the interview data utilizing the conceptual framework as the basis for my coding schematic, but also used open coding to capture themes not anticipated by the conceptual framework.

Results

Does Work Experience Matter?

In answering the first research question, the national analysis involving the EC2000 dataset provided evidence that time spent in a cooperative education (co-op) or internship increases students' self-perceptions of ability on certain problem-solving skills. For this analysis, I operationalized engineering problem-solving through three scales: 1) basic skills, 2) problem-solving and design skills, and 3) engineering thinking skills. The multiple regression models revealed that time spent in a co-op or internship was significant for only the problem-solving and design skills' scale (p-value = .004) after controlling for students' college grade point average, socioeconomic status, major, their time spent in design projects and competitions beyond class requirements, institution's urbanization, and Carnegie classification.

Students rated their ability on a 5-point scale for each of the items within the three scales (where 1 = No Ability, 2 = Some Ability, 3 = Adequate Ability, 4 = More than Adequate Ability, and 5 = High Ability). When the dependent variable is ordinal with a non-normal distribution, multi-nominal logistic regression models are more appropriate statistical methods than regression models. I analyzed items utilizing either a baseline-category logit model or a proportional-odd cumulative logit model. When the equal-slopes assumption was met, the item was analyzed with a proportional-odd cumulative logit model; otherwise, a baseline-category logit model was developed.

The multi-nominal logit models examined whether time spent in a co-op or internship influenced students' perceptions of their abilities for each item within the three scales. In total, 18 multi-nominal logit models were developed for this study. Time spent in a co-op or internship variable was significant at an alpha of .05 for the following items:

- Understand essential aspects of the engineering design process (p-value = .0008)
- Apply systematic design procedures to open-ended problems (p-value = .0009)
- Design solutions to meet desired needs (p-value = .0036)
- Ensure that a process or product meets a variety of technical and practical criteria (p-value = .0288)
- Compare and judge alternative outcomes (p-value = .0031)

Significance at a less stringent alpha suggests that time spent in a co-op or internship variable had a moderate influence on students' ability. For the following items, time spent in a co-op or internship variable was not significant at an alpha of .05 but was significant at an alpha of .10.

- Apply discipline-specific engineering knowledge (p-value = .0751)
- Define key engineering problems (p-value = .0656)
- Develop a course of action based on my understanding of a whole system (p-value = .0550)

The majority of the odds ratios were greater than one for the multi-nominal logit models, providing evidence that as time spent in a co-op or internship increased, students' perceptions of their abilities also increased. For example, the more time spent in a co-op or internship, the more likely a student was to rate his ability to understand essential aspects of the engineering design process higher than a student who spent less time in a co-op or internship.

The main effects for the following skills were not significant, but some of the odds ratios estimates were significant and greater than one when examining the probability of a student rating himself adequate ability to high ability and the more than adequate ability to high ability models.

- Formulate a range of solutions to an engineering problem (p-value = .1909)
- Draw conclusions from evidence or premises (p-value =.3513)

These odds ratios show that as time spent in co-op or internship increased, the more likely a student was to rate himself as having high ability compared to adequate ability or more than adequate ability.

The time spent in co-op or internship variable for the following items was not significant, suggesting that time spent in a co-op or internship has no influence on a student's perception of her ability to:

- Apply knowledge of math (.4312)
- Apply knowledge of physical sciences (.7770)
- Break down complex problems to simpler ones (p-value =.5571)
- Apply fundamentals to problems that I haven't seen before (p-value = .7715)
- Develop learning strategies I can apply in my professional life (p-value = .1688)
- Identify critical variables, information, and or relationship involved in a problem (p-value = .3745)
- Know when to use a formula algorithm or other rule (p-value = .5598)

- Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems (p-value = .6756)

The relative homogeneity in students' self ratings in this sample (which is representative of the national population) suggests that engineering programs are preparing students to be fairly competent problem-solvers even without co-op or internships. Spending time in a co-op or internship, however, while not a necessary curricular component in producing competent engineers, enhances certain problem-solving skills. Thus, students with co-op or internship experiences perceive themselves to be more competent problem-solvers than students with no co-op or internship experiences.

The impact of co-op or internship experience on these items should not be overstated because the models developed had pseudo r-square values between .06 and .10. These results were not unexpected as the majority of the engineering seniors in 2004 rated their ability as either more than adequate ability or high ability on the items.

How Does Work Experience Matter?

The main objective of the qualitative analysis was to answer the second research question, "How do students with cooperative education or internship experience differ in their perceptions and understanding of their engineering problem-solving skills as compared to students with no experience?," by comparing and contrasting academic experiences of students who completed the co-op program, students with at least one internship experience, and students with neither co-op nor internship experience. Although my initial assumption was that these three groups would report distinctive experiences, I found that the co-op and internship students, who all had relevant work experiences, tended to have similar experiences.

My analysis suggested three types of knowledge were differentially influenced by students' classroom and work (co-op or internship) experiences: theoretical, practical, and procedural knowledge. "Theoretical knowledge" refers to the theories, laws and principles of the field. The majority of the students reported that classroom experiences in solving textbook problems helped them develop this type of knowledge.

Participants reported that they learned that there were limitations to the theories, laws, and principles they learned in the courses through the application of theoretical knowledge. "Practical knowledge" encouraged them to consider factors besides technical issues when solving problems. Some of the students without work experience commented that a lack of hands-on learning opportunities in the engineering curriculum prevented them from gaining practical knowledge in the field. In contrast, students with work experience described how their work assignments often required them to consider contextual factors beyond technical issues. These contextual factors were not always prominent in classroom assignments or homework problems.

Participants also reported that they developed problem-solving skills, such as "defining a problem" or "breaking down problems to simpler components" as they solved problems. When comparing the groups, students with co-op and internship experiences were more likely to understand the importance of this kind of procedural knowledge than students without work experience. Thus, some co-op or internship students believed it was equally important to develop their procedural knowledge as they developed theoretical and practical knowledge.

The interview data provided reasonable evidence as to why these qualitative differences exist between the groups. Students with work experience appeared to develop a metacognitive awareness of their knowledge-base limitations. Through their work experiences and work with more advanced engineers, they learned that one person could not know everything about the field. Thus, instead of focusing exclusively on gaining more theoretical knowledge, co-op or internship students talked about developing their procedural knowledge to overcome their limitations. This involved learning that researching possible solutions into their process or asking for help were legitimate parts of the problem-solving process.

Work experiences also could strengthen or diminish interest in the field. The type of work completed at the co-op or internship convinced some students that they enjoyed engineering, while for others, the co-op or internship experience persuaded them to pursue another career. Solidifying interest in the field focused student's learning for personal reasons (i.e., learning to become a competent engineer) as opposed to learning for situational reasons (i.e., learning for a grade).

One of the key findings from the interviews was that students' confidence grew as they gained experience in problem-solving. When asked to define what they meant by "experience," many students defined it as practice in solving problems. Since the engineering curriculum at the research site provided fewer opportunities to solve ill-structured problems (real-world) than well-structured problems (textbook), students with little or no work experience often felt less confident in solving ill-structured problems. In contrast, students with work experience had opportunities to solve ill-structured problems at their co-op or internship and were thus more confident of their skills. In summary, students' knowledge of the field, their learning strategies, and their interest were affected by the experience of solving both well-structured and ill-structured problems. The changes were more apparent when examining students' knowledge where solving well-structured problems seemed to develop students' theoretical knowledge of the field, while solving ill-structured problems develop students' procedural knowledge.

Engineering Knowledge

In this section, I integrate the findings highlighted in the previous two sections. First I discuss how the types of knowledge that emerged from the interview data may be utilized to interpret the quantitative findings. Next, I suggest how the results from the quantitative analyses support the "knowledge themes" that emerged from the qualitative analysis.

My analyses of the interview data focused on students' discussion of three types of knowledge: theoretical, practical, and procedural knowledge. These types of knowledge align with those examined in the quantitative study component. In fact, all but one of the survey items used in the quantitative analyses can be grouped into one of these three types of knowledge. The item that does not fit is "Develop learning strategies I can apply in my professional life." This item, which represents an interest in life-long learning, however, can be considered a general learning strategy, and thus a component of Alexander's MDL.

Theoretical knowledge includes theories, laws, principles and concepts of the discipline. Several survey items represent theoretical knowledge:

- Applying knowledge of math and physical sciences
- Applying fundamentals to problems that I haven't seen before
- Identifying critical variables
- Knowing when to use a formula algorithm, or other rule
- Recognizing and understanding principles or other rules

Each of these survey items focuses on students' ability to understand and use theories, laws, principles, and concepts of the discipline. The same argument might be made for the item, "Apply discipline-specific engineering knowledge." The interview data, however, suggest that the application of discipline-specific engineering knowledge requires both theoretical and practical knowledge. Participants in the study described practical knowledge as the knowledge needed to understand the non-technical issues that arise when solving problems. For example, in building circuits, electrical engineering students must apply their knowledge about Ohm's Law but they must also consider practical issues like the size and thickness of the wires or soldering techniques. Thus, I argue that this item combines as theoretical and practical knowledge.

Finally, procedural knowledge can be defined as knowledge of how to solve problems. I have grouped the following survey items into this category:

- Applying systematic design procedures to open-ended problems
- Breaking down complex problems to simpler ones
- Comparing and judging alternative outcomes
- Defining key engineering problems
- Designing solutions to meet desired needs
- Developing a course of action based on my understanding of a whole systems
- Drawing conclusions from evidence or premises
- Ensuring that a process or product meets a variety of technical and practical criteria
- Formulating a range of solutions to an engineering design process
- Understanding essential aspects of the engineering design process

These items stress what Sheppard, Macatangay, Colby and Sullivan (2008) call the "know how," which they contrast with the "know what" (theoretical) knowledge needed to in solve problems.

The majority of the participants in the study explained how practicing problem-solving through assigned problem-sets increased their level of confidence in solving well-structured problems. Students in all three groups explained how such practice also developed their theoretical knowledge of electrical engineering (i.e., the laws, theories, principals of the field). Engineering programs appeared to be clearly focused on the development of students' theoretical knowledge; over 90 percent of the 2004 engineering seniors rated themselves as either adequate or above for the aforementioned problem-solving skills. The quantitative analysis supports the interview data. Co-op or internship students do not appear to have an advantage over non-co-op/internship students with regards to theoretical knowledge. The variable, time spent in a co-op or internship, was not significant (alpha= .05) for the following problem-solving skills that emphasize understanding theoretical knowledge (see Table 62):

- Apply knowledge of math
- Apply knowledge of physical sciences
- Apply fundamentals to problems that I haven't seen before
- Identify critical variables, information, and or relationships involved in a problem
- Know when to use a formula algorithm or other rule
- Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems

The interview data does, however, suggest that one of the advantages of supervised work experience is that the students have more opportunities to use and test their theoretical knowledge in authentic problem-solving. Through these work experience, co-op or internship students began to understand the limitations of theoretical knowledge in addressing real-world (ill-structured) problems. Understanding these limitations helped these students develop practical knowledge, such as determining the scope of a problem by considering non-technical, contextual factors that are not part of the engineering domain. For example, one internship student talked about how the design of helicopters required her to consider not only technical issues, but also contextual factors such as operating temperature and types of geological terrains. Students without work experiences mentioned how the lack of ill-structured problems in the curriculum often prevented them from gaining practical knowledge.

Table 62: *EC2000* Items Arranged into Theoretical, Practical, Procedural Knowledge

	Item	**p-value***
Theoretical Knowledge	Apply knowledge of math	.4312
	Apply knowledge of physical sciences	.7770
	Apply fundamentals to problems that I haven't seen before	.7715
	Identify critical variables, information, and or relationship involved in a problem	.3745
	Know when to use a formula, algorithm, or other rule	.5598
	Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems	.6756
Theoretical + Practical Knowledge	Apply discipline-specific engineering knowledge	.0751
Procedural Knowledge	Apply systematic design procedures to open-ended problem	.0009
	Break down complex problems to simpler ones	.5571
	Compare and judge alternative outcomes	.0031
	Define key engineering problems	.0656
	Design solutions to meet desired needs	.0036
	Develop a course of action based on my understanding of a whole system	.0550
	Draw conclusions from evidence or premises	.3513
	Ensure that a process or product meets a variety of technical and practical criteria	.0288
	Formulate a range of solutions to an engineering problem	.1909
	Understand essential aspects of the engineering design process	.0008
Learning Strategies	Develop learning strategies I can apply in my professional life	.1688

* The p-value for time spent in a co-op or internship's main effect.

The distinction between theoretical and practical knowledge found in the interview data suggests that disciplinary knowledge of electrical engineering (or any subfield within engineering) is comprised of these two components. The quantitative analysis supports this conclusion. If engineering discipline knowledge were only comprised of theoretical knowledge, the variable “time spent in a co-op/internship” would have no influence on the criterion variable, “Apply engineering discipline-specific knowledge.” This variable, although, non-significant at an alpha of .05, has a p-value of .0751, suggesting that it had a moderate effect on the item. On the flip side, if discipline knowledge were confined to practical knowledge, then the time spent in a co-op or internship should have been significant at a more rigorous alpha. The moderate influence on students’ rating of their ability to apply discipline-specific knowledge by time spent in a co-op/internship suggests that confidence in ones’ ability to apply discipline knowledge is influenced by ones’ sense of competence in understanding and using both theoretical knowledge and practical knowledge. Also, as suggested by the interview data, co-op or internship students gained confidence in applying engineering knowledge because they have had more opportunities to solve ill-structured problems. Solving these ill-structured problems, they reported, in turn developed their practical knowledge.

The qualitative analyses suggested that another kind of knowledge was important to confidence in problem-solving: procedural knowledge. Students, regardless of whether they had work experience, utilized this type of knowledge to solve problems in a systematic fashion. During the think-aloud for both the well-structured and ill-structured problems, the participants did not just try to solve the problem, but explained a process for solving the problems. The majority of participants (regardless of group) said they would define the problem and break it down into smaller components. Surprisingly, even though engineering is a field based on solving problems, few students reported being explicitly taught this problem-solving process in their undergraduate program.

The quantitative analyses indicated time spent in a co-op or internship was not significant (alpha = .05) for these procedural problem-solving components that interview participants mentioned as key steps in problem-solving (defining a problem; breaking it down into smaller components). Time spent in a co-op or internship, however, was significant for the majority of the procedural types of problem-solving skills, specifically:

- Understand essential aspects of the engineering design process
- Apply systematic design procedures to open-ended problems
- Design solutions to meet desired needs
- Ensure that a process or product meets a variety of technical and practical criteria
- Compare and judge alternative outcomes

This aligns with some of the lessons learned from interviews with co-op or internship students who reported that their work experience taught them that in order to succeed in the real-world, they needed to develop procedural knowledge as well as theoretical knowledge. Procedural knowledge gained through engagement in engineering practice at a co-op or internship increased students' confidence in their problem-solving ability.

Limitations

The target population for both the quantitative and the qualitative components of this study included only senior engineering students. The qualitative component was even more restrictive including 17 purposefully selected senior engineering students in electrical engineering at a single institution. Thus, the findings from the qualitative component should not be generalized, even to electrical engineering seniors at the research site. Instead, the goal of the qualitative analysis was to begin the process of building a model of problem-solving skill development in engineering. Still, key findings from the interview data were supported by the quantitative analysis. The quantitative findings are generalizable only to *senior* engineering students.

The use of seniors self-reports of problem-solving skills may be considered a limitation of this study. Self-reports are not direct measures of skills and may not be considered the most accurate measure of an outcome. A growing number of studies, however, suggest that aggregate self-reports are valid proxies of objective measures when comparing differences between groups (Lattuca, Terenzini, & Volkwein, 2006). Since the goal of the quantitative component of this study is to compare differences between groups (students with different amounts of cooperative education and internship experiences) and not to predict problem-solving ability, self-reports are valid measures.

A limitation of the conceptual framework is that it does not account for external influences that may also affect the development of student learning outcomes. Some of the participants mentioned how having family members working in a science, technology, engineering, or mathematics (STEM) field helped them developed their problem-solving. These factors may influence the development of students' learning outcomes and should be considered as possible alternative influences on the development of students' problem-solving skills.

Implications for Research and Theory

Conceptual Framework

Expert-novice theories often describe the qualitative differences in knowledge, interest, and strategic processing between novices and experts. These theories, however, do not identify the mechanisms by which a person progresses towards expertise. Combining Alexander's Model of Domain Learning and Kolb and Fry's Experiential Learning Cycle into a single conceptual framework was an attempt to identify such a mechanism and thus to extend novice-expert theories. The basic premise is that a positive relationship exists between learning experiences (whether in school or other setting) and ability. These learning experiences can range from solving problems assigned for homework or to completing a task at work, where completion of these tasks influences (either positively or negatively) individual's knowledge, interest, and learning strategies.

Experience and Confidence. The most salient theme in the interview data was that a positive relationship existed between experiences in problem-solving and confidence in problem-solving ability. The more experience participants had in solving problems, the more confidence they reported in their problem-solving ability. Co-op and internship students found that completing assigned tasks at work were particularly useful experiences. All students, however, suggested that problems assigned for class work (whether these problems were problem sets or design-type problems) were also experiences that built their confidence in solving problems.

Participants reported that repeatedly solving similar types of problems allowed them to practice and test their abilities. Even though the analysis of the interview data did not render much insight about the components of Kolb and Fry’s Experiential Learning Cycle, this finding suggests that the cyclical dimension of the conceptual framework may exist. Future research is needed to test the premise that a learning cycle equates to a single learning experience, in this case, each cycle was hypothesized to begin and end with an opportunity to solve a problem. The conceptual framework is spiral-like, hypothesizing that the end of one cycle iteration is the beginning of a new one. Through repeated experience, whether it was solving a problem for class or completing a work assignment, students reportedly enhanced their knowledge, interest, and/or learning strategies, which in turn increased their confidence in solving problems.

Authenticity and Relevance. Participants in the study defined experience in problem-solving broadly. They also recognized, however, that certain experiences were more influential and valuable to their problem-solving development than others. The interview data indicated that some students perceived the most valuable experiences as those that addressed authentic problems with real consequences. Some participants said that they were more invested in solving these types of problems. An ill-structured problem assigned as a classroom assignment, however, may not be perceived to be as "authentic" as the same problem assigned as a work assignment. Students may perceive the problem when assigned by a professor to have minimal consequences (e.g., it may effect my mid-term grade), while the same problem assigned by a supervisor at work may be perceived as having serious consequences (i.e., it will affect company profits, or my future employment).

Although the authenticity of an experience is important, relevance may be as important in educational settings. If the student views a problem as relevant to her career goals, she may be more likely to perceive it as enhancing her knowledge, interest, and/or learning strategies. If instructors do not emphasize the material's importance to engineering practice, the student may not consider it relevant to their goals. When completing the same task assigned by an employer, the student may readily see the relevance of the assignment to the development of professional skills. Future research might test whether the perceived relevance of an experience is as influential as repeated problem-solving experiences in the development of engineering problem-solving skills. The level of relevance may explain why different learning experiences have different impacts on the development of knowledge, interest, and learning strategies.

Model of Domain Learning. The qualitative data suggest one mechanism that explains how a person progresses towards competency in engineering: repeated experience in problem-solving. It does not explain, however, what a person gains through that experience. Utilizing MDL, the proposed conceptual framework suggests that during a cycle, a person's types of knowledge, interest, and learning strategies may change due to the types of experiences they have and how these relate to their educational or personal goals. When comparing students with work experience to students without work experience, a difference between the two groups' perceptions of their knowledge and skills is apparent. Both the interview data and the *EC2000* data indicate that engineering seniors perceive they have an adequate to good foundation in theoretical knowledge; students with work experience, however, have more confidence in their procedural and practical knowledge in the academic domain of engineering. The interview data suggest that students with work experience are more likely to consider non-technical issues when solving problems (practical knowledge) and develop "how to" knowledge in solving problems (procedural knowledge).

The qualitative analysis also suggests that some co-op or internship students also seemed to develop more advanced learning strategies, such as metacognitive awareness, that improve their problem-solving ability. In addition, the analysis suggests that co-op/internship experiences can influence and transform situational interest into personal interest, thus deepening a students' commitment to the field. Both the qualitative and quantitative analysis suggests that the MDL components of the conceptual framework hold merit in explaining the progression towards competency.

Future Research on the Conceptual Framework. The interview data provided no insight into the "observation and reflection" and "forming abstract thought" phases in Kolb and Fry's Experiential Learning Cycle. Although this might be interpreted as a flaw in the conceptual framework, this may instead reflect a limitation in the design of this study. When asked to reflect upon their collegiate careers, many participants were unable to recall specific details. Many recognized that their problem-solving skills improved during their collegiate careers, but could not remember how these skills improved beyond the experience of practicing solving problems. A longitudinal design in which participants maintained a journal or a longitudinal design that collected repeated measures of different experiences and how these contributed to the development of problem-solving skills would remedy this. The data collected then would provide more insight into the different phases in Kolb and Fry's Experiential Learning Cycle and how experience influence the MDL components.

A longitudinal design would also provide insight into whether the proposed conceptual framework is valid for students at all competency levels. One of the limitations of this study is that the populations for both the qualitative and quantitative components were engineering seniors. Even though variations in proficiency existed between students, the targeted population for the qualitative component (a range of undergraduates from novices to experts) did not provide much variation. Future research would expand the population to include a variety of competency levels to further examine the validity of the conceptual framework.

Future Research on Cooperative Education. Future research regarding co-op or internship experiences should examine the long-term effects of such programs once students have graduated and worked in the profession. This study cannot tell us whether engineers with co-op or internship experience will always have more confidence in their problem-solving skills over engineers with no co-op or internship experience or whether the effect is temporary.

Like co-op or internship programs, design competitions are co-curricular experiences that provide opportunities in solving ill-structured problems. These hands-on projects, such as constructing an energy efficient home or building race car, simulate the work environment that co-op or internship students experience in that students often work on multidisciplinary teams in completing the project. The quantitative analysis suggest that participation in design competitions does influence students' perception and understanding of their engineering problem-solving as time spent in design competitions was significant. Future research may want to examine whether participation in such programs is as influential in improving engineering problem-solving skills as to participation in a co-op or internship program.

Implications for Undergraduate Engineering Education

Understanding how a person progresses toward expertise has both theoretical and practical implications. For curricular designers, knowing how individuals progress towards expertise allows for a more intentional design of curricular and co-curricular activities to develop students' competency within an academic domain. As suggested by Alexander's Model of Domain-Learning, curricular and co-curricular activities that enhance a person's knowledge, learning strategies, and interest are likely to lead to increased competency in a domain. In engineering, professors should design learning activities that not only develop a student's theoretical knowledge base, but also address the development of practical and procedural knowledge. Moreover, if we expect students to progress towards expertise, then programs must not only focus on different types of knowledge, but also promote the development of learning strategies to develop these types of knowledge and enhance interest.

Curricular designers should consider two factors when designing activities: the repetition of key ideas and skills, and the relevance of the learning activities. The qualitative component of this study suggested that students' confidence in their problem-solving skills increased with repeated opportunities to exercise those skills. Participants also suggested, however, that understanding why they were learning particular theories or concepts and knowing how they were applied in engineering practice was important. Relevant experiences motivated learning. If students perceive an experience as important to their future goals, then they are more likely to learn from the experience and enhance their knowledge, interest, or learning strategies when solving the problem (Alexander, 1997, 2003).

Course-level Recommendations

The following recommendations offer classroom practices that faculty members can implement when creating assignments for their students. The purpose of these assignments is not only to emphasize the importance of the theoretical knowledge taught in the classroom, but also illustrate how assignments can be expanded to enhance the other components needed in developing competent problem-solvers. The design of these activities then focuses on strengthening and enhancing students' theoretical knowledge, practical knowledge, procedural knowledge, interest and learning strategies.

Writing Exercises. Many study participants commented that their confidence in problem-solving grew through solving textbook problems. A concern for engineering educators, however, is whether students move beyond "matching patterns as their strategy for solutions" (Sheppard, Macatangay, Colby and Sullivan, 2008, p. 34). Failure to do so will hinder students from developing a deep understanding of the theories needed to solve engineering problems. Asking students to both solve and justify their answers through written explanations helps them develop metacognitive awareness and allows the instructor to gauge the depth of students' understanding of theories, principles, and laws. This approach places equal emphasis on the process of solving the problem (i.e., the procedural knowledge) and the theoretical knowledge needed to solve the problem. If students cannot articulate their reasoning then they probably do not have a deep understanding of the knowledge needed to solve the problem.

Explain the Relevance of what is Taught. In explaining theories, laws, principles, and concepts, professors should also make explicit the relevance of what is being taught. Relating material to the work of an engineer or showing how it applies to current issues or technologies will make the learning experience relevant to most students and should pique interest in the topic. The more interested a person has in a topic, the more likely she is to learn it (Alexander, 1997, 2003; Hidi, 1990).

Program-level Recommendations

Alexander's Model of Domain Learning separates knowledge into two forms: domain (person's breadth of declarative, procedural, and conditional knowledge of the field) and topic (person's depth of knowledge in a specific area within the field). One implication of this conceptualization, then, is to intentionally design a curriculum that not only requires students to develop their depth of knowledge but also their breadth of knowledge for engineering. Many engineering programs often provide opportunities to develop procedural knowledge only during the students' first-year design course and their senior capstone course with very few opportunities in their junior and senior years (Sheppard, Macatangay, Colby & Sullivan, 2008). These first-year and capstone courses often provide the only chance for students to solve real-world problems, asking them to apply the theoretical knowledge learned and to develop their procedural knowledge.

Evidence from this study suggests that work experience seems to improve engineering students' problem-solving skills by providing opportunities to solve real-world problems. More opportunities to solve real-world problems could be integrated into the undergraduate engineering curriculum. Currently, students must fulfill a number of technical electives courses that supposedly develop their depth of knowledge in their field. The curriculum could be designed so that students also fulfill a number of procedural knowledge courses. Redesigning an entire curriculum to include sequences of courses that focus on procedural knowledge, however, may not be feasible if faculty members resist such radical change. An alternative approach is to designate courses that meet certain criterions as procedural knowledge-intensive courses. These courses would emphasize real-world problems or design-type assignments to teach the necessary theoretical and practical knowledge to solve such problems, but also explicitly teach students "how" to solve problems. It is not necessary that all professors teach these types of courses; in fact, having too many procedural knowledge-intensive courses might overburden a student in a given semester. Because of their complexity, real-world problems often take a considerable amount of time to solve. The goal is to design courses that will simultaneously and synergistically develop students' procedural knowledge and theoretical knowledge.

Even though solving well-structured problems is influential in the development of theoretical knowledge, it does not provide students with the opportunity to understand the limitations of theory. Labs, like design competitions and co-ops/ internships, provide opportunities to engage with ill-structured problems where students can apply the knowledge learned in the classroom to real-world problems. Sheppard et al (2008) suggest that engineering lab sections can provide such opportunities for students, to "develop problem-solving skills as they work in a practice-like setting where theories may or may not work and instrumentation fails intermittently" (p. 57). In these types of settings, students could be building circuits strengthening their comprehension of Ohm's Law, but in the process begin to understand how the physical size of the device (i.e., is the resistor too large or too small) can influence the overall design of the circuit.

Cooperative Education and Problem-Solving Skills

The motivating purpose for this study was to examine the influence of cooperative education on engineering students' problem-solving skills by 1) determining whether participation in a cooperative education or internship program influences students' self-perceptions of their engineering problem-solving skills, and 2) understanding how cooperative education or internship students differ in their perceptions and understandings of their engineering problem-solving skills as compared to students with no experience.

When exclusively considering the theoretical knowledge of the academic domain (i.e., theories, laws, principles, and concepts) there appears to be no significant difference with respect to self-perceptions between students with and without experience and co-op/internship experience, after controlling for student's college GPA, socioeconomic status, major, and time spent in engineering design projects and design competitions beyond class requirements. From the quantitative analyses, most students rated their theoretical knowledge as adequate or higher.

The advantage in participating in a co-op or internship program beyond its effect on career opportunities or salary, appears to be the development of procedural knowledge or what Sheppard, Macatangay, Colby and Sullivan (2008) call the "know how" to solve problems. The results from the quantitative analysis suggest that co-op/internship students may have more advanced procedural knowledge compared to students with no engineering work experience. As time spent in a co-op or internship increased, students rated themselves higher in procedural type knowledge skills.

The qualitative analysis suggest that students developed their understanding of the theoretical knowledge of electrical engineering (theories, laws, and principles) primarily through classroom assignments. These assignments often involved solving textbook problems (or problems with a single correct solution). Most interviewees reported that the engineering curriculum did not provide enough opportunities to solve real-world problems or problems with multiple solutions. For students who completed a co-op or internship, engineering work experiences complemented the engineering curriculum by providing these opportunities to test their knowledge in real-world situations. In completing co-op or internship work assignments, these students began to understand the limits of their knowledge base and also learned that solving problems often involves non-technical issues (i.e., budgets, time constraints, availability of devices). Developing this practical knowledge gave co-op/internship students more confidence in their problem-solving ability.

When solving problems at work, co-op or internship students realized that it is impossible to know everything about the field. They discovered that real-world problems are often too complex for one person to solve. Instead of worrying about their lack of knowledge, some co-op or internship students began to develop strategies to overcome their lack of knowledge. These included asking a fellow co-worker for help, researching the problem, or breaking down a complex problem into simpler components. Co-op students understood the importance of theoretical and practical knowledge in solving problems, but viewed the development of procedural knowledge as equally important to their development as engineers. In the words of legendary baseball player and coach, Yogi Berra, these students learned that “In theory, there is no difference between theory and practice. But in practice, there is.”

REFERENCES

Accreditation Board for Engineering and Technology (ABET). (2007) Criteria for accrediting engineering programs. Baltimore, MD: ABET. Available online at http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2008-09%20EAC%20Criteria%2011-30-07.pdf.

Alexander, P. A. (1997). Mapping the multidimensional nature of domain learning: The interplay of cognitive, motivational, and strategic forces. *Advances in Motivation and Achievement*. M. L. Maehr and P. R. Pintrich. Greenwich, CT, JAI Press. 10, 213-250.

Alexander, P. A. (2003). The development of expertise: The journey from acclimation to proficiency. *Educational Researcher* 32(8), 10-14.

Alexander, P.A., Graham, S., & Harris, K. R. (1998). A perspective on strategy research: Progress and prospects. *Educational Psychology Review* 10(2), 129-154.

Alexander, P. A., Jetton, T. L., & Kulikowich, J. M. (1995). Interrelationship of knowledge, interest, and recall: Assessing a model of domain learning. *Journal of Educational Psychology* 87(4), 559-575.

Alexander, P. A. & Murphy P. K. (1998). Profiling the differences in students' knowledge, interest, and strategic processing. *Journal of Educational Psychology* 90(3), 435-447.

Alexander, P. A., Murphy P. K., Woods, B. S., Duhon, K. E., & Parker, D. (1997). College instruction and concomitant changes in students' knowledge, interest, and strategy use: A study of domain learning. *Contemporary Educational Psychology* 22, 125-146.

Alexander, P. A., Sperl, C. T., Buehl, M. M., Fives, H. & Chiu, S. (2004). Model of domain learning: Profiles from the field of special education. *Journal of Educational Psychology* 96(3), 545-557.

Altman, C. J., Adams, R. S., Cardella, M.E., Turns, J., Mosborg, S., & Saleem., J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education* 96(4), 359-389.

American Society for Engineering Education (2008). *Engineering College Profiles and Statistics* Retrieved August 18, 2009, from http://profiles.asee.org/.

Bandura, A. (1997). Self-efficacy: The exercise of control. New York, NY: Freeman.

Benner, P. (1982). From novice to expert. *American Journal of Nursing* 82, 402-407.

Benner, P. (2004, June). Using the Dreyfus model of skill acquisition to describe and interpret skill acquisition and clinical judgment in nursing practice and education. *Bulletin of Science, Technology & Society*, 24(3), 188-199.

Berliner, D. C. (1991). Educational psychology and pedagogical expertise: New findings and new opportunities for thinking about training. *Educational psychologist, 26* (2), 145-155.

Billing, D. (2007). Teaching for transfer of core/key skills in higher education: cognitive skills. *Higher Education, 53,* 483 – 516.

Blair, B.F, & Millea, M. (2004). Student academic performance and compensation. The impact of cooperative education. *College student Journal,* 38(4), 643-652.

Blair, B. F., Millea, M., & Hammer, J. (2004). The impact of cooperative education on academic performance and compensation of engineering majors. *Journal of Engineering Education, 93*(4), 333-338.

Carnegie Foundation for the Advancement of Teaching, The (2009). Carnegie classification: Basic classification description. Retrieved August 18, 2009, from http://www.carnegiefoundation.org/classifications/index.asp?key=791.

Carver, R. (1996). Theory for Practice: A Framework for Thinking about Experiential Education, *Journal of Experiential Education,* 19(1), 8-13.

Chi, M., Feltovich, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5(2), 121-152.

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

Chi, M. T., Glaser, R. & Farr M. J (eds.). (1988). *The nature of expertise*. Hillsdale, NJ: Erlbaum.

Committee on Science, Engineering, and Public Policy (COSEPUP). (2007). *Rising about the gathering storm: Energizing and employing America for a brighter economic future*. Washington, D.C.: National Academics Press.

Cooperative Education & Internship Association (CEIA). (2003). *The Dean Herman Schneider award.* Downloaded on March 15, 2008 at http://www.ceiainc.org/awards/schneider.htm.

Devon, R., Bilen, S., McKay, A., De Pennington, A., Serrafero, P., & Sierra, J. S. (2004). Integrated design: What knowledge is of most worth in engineering design education? *International Journal of Engineering Education,* 20 (3), 424-432.

Donald, J. G. (2002). *Learning to think: Disciplinary perspectives*. San Francisco, CA: Jossey Bass.

Dorf, R. C., & Svoboda, J. A. (1998). *Introduction to electric circuits* (4th ed.). New York, NY: John Wiley & Sons, inc.

Dreyfus, H. L. & Dreyfus, S. (2005). Expertise in real-world contexts. *Organization Studies* 26(5), 779-792.

Dunlap, J. (2005). Problem-based learning and self-efficacy: How a capstone course prepares students for a profession. *Educational Technology Research and Development* 53(1), 65-85.

Ethington, Corinna A. (1997). A hierarchical linear modeling approach to studying college effects. In J. Smart (Ed.), *Higher Education: Handbook of Theory and Research, Volume 12*. New York: Agathon Press.

Friedman, T. (2006). *The world is flat: A brief history of the twenty-first century*. New York, NY: Farrae, Straus, and Giroux.

Friel, T. (1995). Engineering cooperative education: A statistical analysis of employer benefits. *Journal of Engineering Education, 84(1)*, 1-6.

Hardiman, P. T., Dufresne, R. J. & Mestre, J. P. (1989). The relation between problem categorization and problem-solving among novices and experts. *Memory & Cognition* 17, 627-638.

Harvey Mudd College (2008). 2008 projects day program. Retrieved August 18, 2009, from http://www.hmc.edu/files/clinicprogram/2008%20Projects%20Day%20Program.pdf.

Heywood, J. (2005). Engineering education: Research and development in curriculum and instruction. Hoboken, NJ: John Wiley & Sons.

Hidi, S. (1990). Interest and its contribution as a mental resource for learning. *Review of Educational Research* 60(4), 549-571.

Hidi, S. & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist* 41(2), 111-127.

Houldsworth, B., O'Brien, J., Butler, J., & Edwards, J. (1997). Learning in the restructured workplace: A case study. *Education & Training*, 39(6), 211-218.

Howard, R. D., & Borland, J. W., Jr. (2007). The role of mixed method approaches in institutional research. In R.D. Howard (Ed.) *Using mixed methods in institutional research (pp. 2-7)*. Tallahassee, FL: Association for Institutional Research.

Hutchinson, M. A., Follman, D. K., Sumpter, M., & Bodner, G. M. (2006). Factors influencing the self-efficacy beliefs of first-year engineering students. *Journal of Engineering Education* 95 (1), 39-47.

Hutchinson-Green, M. A., Follman, D. K., & Bodner, G. M. (2008). Providing a voice: Qualitative investigation of the impact of a first-year engineering experience on students' efficacy beliefs. *Journal of Engineering Education* 97 (2), 177-190.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem-solving in engineering: Lessons for engineering educators. *Journal of Engineering Education* 95(2), 139-152.

Lattuca, L. R., Lambert, A. D., & Terenzini, P. T. (2008, March). *Academic environments and student learning: A finer-grained examination.* Paper presented at American Educational Research Association. New York, NY.

Lattuca, L. R., Terenzini, P. T., Harper, B. J. & Yin, A. C. (2008, March). *Academic environments in detail: Holland's theory at the subdiscipline level*. Paper presented at American Educational Research Association. New York, NY.

Lattuca, L. R., Terenzini, P. & Volkwein, J. F. (2006). Engineering change: A study of the impact of EC 2000. Baltimore, MD: ABET Inc.

Kerka, S. (1999). *New direction for cooperative education*. Columbus, OH: ERIC Clearinghouse on Adult Career and Vocational Education. (Eric Document Reproduction Service No. ED434245).

Kolb. D. A. & Fry, R. (1975). Toward an applied theory of experiential learning. In C. Cooper (Ed.) *Theories of Group Process*, London: John Wiley.

Krathwohl, D. R. (1998). *Methods of educational research and social science research: An integrated approach* (2nd ed.). Long Grove, IL: Waveland Press, Inc.

Mathias-Regal, B (2006). A good fit. *Prism* 15 (7). Available online at http://www.prism-magazine.org/mar06/tt_01.cfm.

Mayer, R.E. & Wittrock, M.C. (2006). Problem-solving. In P.A. Alexander & P.H. Winne (Eds.) *Handbook of Educational Psychology*, 2nd Edition. Lawrence Erlbaum.

Merriam, S. B., & Caffarella, R. S. (1999). *Learning in adulthood: A comprehensive guide (2nd. Edition).* San Francisco, CA: Jossey-Bass.

Murphy, P. K. & Alexander, P.A. (2002). What counts? The predictive powers of subject-matter knowledge, strategic processing, and interest in domain-specific performance. *The Journal of Experimental Education* 70(3), 197-214.

National Academy of Engineering (2004). *The engineer of 2020: Visions of engineering in the new century*. National Academy of Engineering: Washington, DC.

National Academy of Engineering (2005). *The engineer of 2020: Adapting engineering education to the new century*. National Academy of Engineering: Washington, DC.

National Commission for Cooperative Education (NCCE) (2002). The cooperative education model. Retrieved December 8, 2008, from http://www.co-op.edu/aboutcoop.htm.

Pajares, F. & Miller, M. D. (1994). Role of self-efficacy and self-concept beliefs in mathematical problem solving: A path analysis. *Journal of Educational Psychology* 86(2), 193-203.

Passow, H. J. (2007). *What competencies should undergraduate engineering programs emphasize? A dilemma of curricular design of practitioners' opinions can inform.* Unpublished doctoral dissertation, University of Michigan, Ann Arbor.

Pierrakos, O., Borrego, M., & Lo, J. (2008, June). *Preliminary findings from a quantitative study: What are students learning during cooperative education experiences?* Paper presented at American Society for Engineering Education Annual Conference & Exposition. Pittsburg, PA.

Perels, F., Gürtler, T., & Schmitz, B. (2005). Training of self-regulatory and problem-solving competence. *Learning and Instruction, 15,* 123 – 139.

Porter, S.R. (2005). What can multilevel models add to institutional research? In M.A. Coughlin (Ed.) *Applications of advanced statistics in institutional research*. Tallahassee: Association for Institutional Research.

Schraw, G., Crippen, K.J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education, 36,* 111 – 139.

Salomon, G. & Perkins, D.N. (1989). Rocky roads to transfer: Rethinking mechanisms of a neglected phenomenon. *Educational Psychologist, 24,* 113 – 142.

Schuurman, M.K., Pangborn, R. N. & McClintic (2007). Assessing the impact of engineering undergraduate work experience: Factoring in pre-work academic experience. *Journal of Engineering Education* 97(2), 207-212.

Seymour, E. & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder, CO: Westview Press.

Sheppard, S., Macatangay, K., Colby, A., & Sullivan, W., M. (2008). *Educating engineers: Designing for the future of the field*. San Francisco, CA: Jossey-Bass.

Smollins, J. (1999). The making of history: Ninety years of Northeaster co-op. *Northeastern University Magazine Online*. Retrieved on April 6, 2008 at http://www.northeastern.edu/magazine/9905/history.html.

Stark, J. S., & Lattuca, L. R. (1997). *Shaping the college curriculum: Academic plans in action.* Needham Heights, MA: Allyn & Bacon.

United States Department of Labor (2008). *Occupational outlook handbook, 2008-2009 edition.* Downloaded on August 18, 2009 at http://www.bls.gov/oco/ocos027.htm.

Usher, E. & Pajares, F. (2008). Sources of self-efficacy in school: Critical review of the literature and future directions. *Review of Educational Research* 78(4), 751-796.

Volkwein, J. F., Lattuca, L. R., Terenzini, P. T., Strauss, L. C. & Sukhbaatar, J. (2004). Engineering change: A study of the impact of EC2000. *International Journal of Engineering Education*, 20(3), 318-328.

Volkwein, J. F., & Yin, A. C. (2007, June). *Examining alternative explanations for student outcomes*. Paper presented at the Annual Forum of the Association for Institutional Research. Kansas City, MO.

Zusho, A., Pintrich, P. R., Coppola, B. (2003). Skill and will: The role of motivation and cognition in the learning of college chemistry. *International Journal of Science Education, 25,* 1081–1094.

APPENDIX A:

SURVEY OF SENIORS IN ENGINERRING PROGRAMS

Survey of Seniors in Engineering Programs

(Sponsored by ABET)

Conducted by:

The Pennsylvania State University
Center for the Study of Higher Education

PENNSTATE

1855

Please turn page to begin survey

Using pen or pencil, please fill in the appropriate box or circle with your response.

Part I. Personal Information

1. **When you entered this institution were you:**

   ○ A first-time college student ○ A transfer student from a two-year institution ○ A transfer student from a four-year institution

2. **What was your age when you entered this institution:** ☐☐

3. **Are you:** ○ Male ○ Female

4. **Are you a U.S. Citizen?** ○ Yes ○ No [If "no," please go to Question 6]

5. **If "Yes," with which of the following racial/ethnic groups do you closely identify? (Select all that apply.)**

   ○ White/European American ○ American Indian/Alaskan Native
   ○ Black/African American ○ Hawaiian or Pacific Islander
   ○ Hispanic or Latino ○ Other (please specify): ______________________
   ○ Asian

6. **What is the highest level of formal schooling attained by your parents or guardian?**

	Mother	**Father**	**Guardian**
High School Diploma, GED, or less	○	○	○
Some college (incl. Associate's degree)	○	○	○
Bachelor's degree	○	○	○
Advanced degree	○	○	○

7. **Approximately what is your parents'/guardians' annual family income?**

   ○ Below $20,000 ○ $90,001-$110,000
   ○ $20,001-$30,000 ○ $110,001-$130,000
   ○ $30,001-$50,000 ○ $130,001-$150,000
   ○ $50,001-$70,000 ○ More than $150,000
   ○ $70,001-$90,000

8. **Did you take the SAT or ACT tests? (Please select all that apply.)**

   ○ No. I did not take either exam.
   ○ Yes, I took the SAT exams, and my scores were approximately:
   SAT-Verbal ☐☐☐ SAT-Math ☐☐☐
   ○ Yes, I took the ACT exam, and my Composite Score was approximately: ☐☐

9. **Knowing what you know now, how well prepared were you for basic science and math courses when you entered college?**

   ○ Not at all
   ○ Slightly
   ○ Moderately
   ○ Very well prepared

10. What was your approximate overall academic average in:

	High School	College
3.50-4.00 (A- to A)	○	○
3.00-3.49 (B to A-)	○	○
2.50 2.99 (B to B)	○	○
2.00-2.49 (C to B-)	○	○
1.50-1.99 (C- to C)	○	○
Below 1.49 (Below C-)	○	○

11. As an undergraduate, were you (select all that apply):

a. Enrolled primarily as a ○ Full-time student ○ Part-time student

b. Employed primarily ○ Not employed while taking classes
○ On-campus, part-time while taking classes
○ Off-campus, part-time while taking classes
○ Full-time while taking classes

12. As an undergraduate, approximately <u>how many months</u> did you spend:

	None	1 - 4	5 - 8	9 - 12	More than 12 Months
As an intern or a co-op student in industry or an engineering firm	○	○	○	○	○
In a study abroad program	○	○	○	○	○
Traveling internationally (not study abroad)	○	○	○	○	○
Involved in student design project(s)/competition(s) beyond class requirements	○	○	○	○	○

13. As an undergraduate, how active have you been in a student chapter of a professional society or engineering organization?

○ Not at all ○ Somewhat ○ Moderately ○ Highly

Part II. Your Undergraduate Engineering Experiences

14. Thinking about your <u>in-class and out-of-class experiences</u>, please rate your ability to do the following:

<u>A. Technical Skills and Abilities</u>:	No Ability	Some Ability	Adequate Ability	More than Adequate Ability	High Ability
Apply knowledge of math	○	○	○	○	○
Apply knowledge of physical sciences	○	○	○	○	○
Apply discipline-specific engineering knowledge	○	○	○	○	○
Design an experiment	○	○	○	○	○
Carry out an experiment	○	○	○	○	○
Analyze evidence or data from an experiment	○	○	○	○	○
Interpret results of an experiment	○	○	○	○	○
Understand essential aspects of the engineering design process	○	○	○	○	○
Apply systematic design procedures to open-ended problems	○	○	○	○	○
Design solutions to meet desired needs	○	○	○	○	○
Define key engineering problems	○	○	○	○	○
Formulate a range of solutions to an engineering problem	○	○	○	○	○

B. Professional Skills:	No Ability	Some Ability	Adequate Ability	More than Adequate Ability	High Ability
Work in teams of people with a variety of skills and backgrounds	○	○	○	○	○
Work with others to accomplish team goals	○	○	○	○	○
Work in teams where knowledge and ideas from multiple engineering disciplines must be applied	○	○	○	○	○
Work through ethical issues in engineering	○	○	○	○	○
Consider ethical issues when working on engineering problems	○	○	○	○	○
Conduct yourself professionally	○	○	○	○	○
Understand the engineering code of ethics	○	○	○	○	○
Understand technical codes and standards	○	○	○	○	○
Convey ideas in writing	○	○	○	○	○
Convey ideas verbally	○	○	○	○	○
Convey ideas in formal presentations	○	○	○	○	○
Convey ideas in graphs, figures, etc.	○	○	○	○	○
Understand the impact of engineering solutions in a **global context**	○	○	○	○	○
Understand the impact of engineering solutions in a **societal context**	○	○	○	○	○
Understand contemporary issues (economic, environmental, political, societal, etc.) at the local, national, and world level	○	○	○	○	○
Understand that engineering decisions and contemporary issues can impact each other	○	○	○	○	○
Use knowledge of contemporary issues to make engineering decisions	○	○	○	○	○
Apply engineering **techniques** in engineering practice	○	○	○	○	○
Apply engineering **skills** in engineering practice	○	○	○	○	○
Apply engineering **tools** in engineering practice	○	○	○	○	○
Integrate engineering techniques, skills, and tools to solve real-world problems	○	○	○	○	○
Manage a project	○	○	○	○	○
Apply interpersonal skills in managing people	○	○	○	○	○

C. Analytical/Thinking Skills:	No Ability	Some Ability	Adequate Ability	More than Adequate Ability	High Ability
Break down complex problems to simpler ones	○	○	○	○	○
Apply fundamentals to problems that I haven't seen before	○	○	○	○	○
Identify critical variables, information, and/or relationships involved in a problem	○	○	○	○	○
Know when to use a formula, algorithm, or other rule	○	○	○	○	○
Recognize and understand organizing principles (laws, methods, rules, etc.) that underlie problems	○	○	○	○	○
Draw conclusions from evidence or premises	○	○	○	○	○
Develop a course of action based on my understanding of a whole system	○	○	○	○	○
Ensure that a process or product meets a variety of technical and practical criteria	○	○	○	○	○
Compare and judge alternative outcomes	○	○	○	○	○
Develop learning strategies that I can apply in my professional life	○	○	○	○	○

15. To what extent are you:	Not at All	Somewhat	Moderately	Highly
Motivated to acquire and apply new technologies and tools	○	○	○	○
Able to learn and apply new technologies and tools	○	○	○	○
Willing to take advantage of new opportunities to learn	○	○	○	○

16. How often did the following occur in the <u>courses you took in your department</u>?

	Almost Never	Occasionally	Often	Almost Always
Assignments and class activities were clearly explained.	○	○	○	○
Assignments, presentations, and learning activities were clearly related to one another.	○	○	○	○
Instructors made clear what was expected of students in the way of activities and effort.	○	○	○	○
I worked cooperatively with other students on course assignments.	○	○	○	○
Students taught and learned from each other.	○	○	○	○
We worked in groups	○	○	○	○
I discussed ideas with my classmates (individuals or groups).	○	○	○	○
I got feedback on my work or ideas from my classmates.	○	○	○	○
I interacted with other students in the course **outside of class**.	○	○	○	○
We did things that required students to be active participants in the teaching and learning process.	○	○	○	○
Instructors gave me **frequent** feedback on my work.	○	○	○	○
Instructors gave me **detailed** feedback on my work.	○	○	○	○
Instructors guided students' learning activities rather than lecturing or demonstrating the course material.	○	○	○	○
I interacted with instructors as part of the course.	○	○	○	○
I interacted with instructors **outside of class** (including office hours, advising, socializing, etc.).	○	○	○	○

17. How often did the following occur in your engineering major?

	Almost Never	Occasionally	Often	Almost Always
My engineering courses emphasized tolerance and respect for differences.	O	O	O	O
My engineering courses encouraged me to examine my beliefs and values.	O	O	O	O
My engineering friends and I discussed diversity issues.	O	O	O	O
In my major, I observed the use of offensive words, behaviors, or gestures directed at students because of their identity.	O	O	O	O
I was harassed or hassled by others in my major because of my identity.	O	O	O	O

18. Please indicate the extent to which you agree or disagree with the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
The faculty in my department are committed to treating all students fairly.	O	O	O	O	O
My department emphasizes the importance of diversity in the engineering workplace.	O	O	O	O	O
I know some students who feel like they don't fit in this department because of their identity.	O	O	O	O	O
The campus climate at this institution is generally one of openness and tolerance.	O	O	O	O	O

Part III. Additional Information and Plans

19. How satisfied are you with your engineering program overall?

O Very dissatisfied O Somewhat dissatisfied O Neither satisfied nor dissatisfied O Somewhat satisfied O Very satisfied

20. What is your anticipated graduation date?

O Spring '04 O Summer '04 O Fall '04 O Other

21. What is the major field of your bachelor's degree?

O Aerospace Engineering O Electrical Engineering

O Chemical Engineering O Industrial Engineering

O Civil Engineering O Mechanical Engineering

O Computer Engineering O Other (please specify): ______

22. Do you have a second major or minor?

O No O Yes

O in engineering, science, or math

O outside of engineering (please specify): ______

23. By the end of this academic year, will you have taken the Fundamentals of Engineering (FE) Examination?

O Yes O No (please go to #24)

a. If you have taken the FE, did you pass? O Yes O No

b. How important is it to you to do well on the exam?

O Not important O Slightly important O Moderately important O Very important

24. What are your plans for the next year?

Continue undergraduate education:
- O Full-time
- O Part-time

Employment:
- O In an engineering-related occupation full-time
- O In an engineering-related occupation part-time
- O Outside engineering full-time
- O Outside engineering part-time

Graduate School:
- O In an engineering discipline full-time
- O In an engineering discipline part-time
- O Outside engineering full-time
- O Outside engineering part-time
- O Other (please explain): ______________________________

Thank you for your participation!

Please return your completed survey in the prepaid envelope provided.

APPENDIX B:

INTERNSHIP AND CO-OP REPORT REQUIREMENTS

Internship Report Requirements

General Requirements

Format and Length

- The report must be typed (double spaced) and be 6-7 pages long using your best grammar.
- **You must include an abstract as the first page of your report.** An abstract is not an introduction, it is a brief (50-70 words) summary of your report.

Cover Page

- **You must have a cover page** in a format similar to the example provided in the Cover Page Packet. It should include a signature line that must be signed by your supervisor to signify that the report does not contain company proprietary information.
- Cover page format and example can be found on the Cooperative Education and Professional Internship Program website.

Submission and Due Dates

The original reports are due by 5:00 P.M. on the Thursday of the last week of classes each semester that you are on work assignment. It is recommended that you also make a copy to keep for your own records.
Students should send two copies of their final reports; the original and one copy.

The reports must be mailed to:
Engineering Cooperative Education
and Professional Internship Program
[ADDESS DELETED]

Do not send reports directly to your Co-op/Professional Internship advisor in your major. All reports within one week late will be reduced one letter grade, reports between one and two weeks late will be reduced two letter grades, reports received after two weeks will be an automatic failure.

Internship Report Specific Requirements

The majority of the report describes the company, its products, its competition, and the department in which you worked. This is followed by a brief description of the kind of work you did and an assessment of your internship experience. To organize your report, use the underlined phrases as headings in your report.

The Company at Which You Worked

- Describe the company or corporation at which you worked. (If your division is part of a large parent corporation, describe the Parent Corporation here.) Indicate the name and the location of its headquarters. How many employees does it have (worldwide)? How large are the U.S. and the world markets (annual sales volume in dollars)?

- If your division is part of a large parent corporation, describe the division in which you worked. Where is it located? How does the division fit into the parent corporation, with respect to products and market? How large is your division compared to the parent corporation (number of employees and annual budget)?

- What are your major product(s) of the division or corporation in which you worked? What is the intended use of the product? Who are the major competitors (U.S. and Worldwide) for the products made by your division or corporation?

- In which department or unit did you work? What is the primary responsibility of the department? How large (number of employees) is your department?
- How well did the company assist you in adjusting to your job? Did they help you find housing? Did they provide an orientation? Were your duties and their expectations clearly explained?

Your Professional Internship Work Assignment

- Describe a typical day at your internship work assignment. What kind of work did you do? Briefly describe the project (or projects) on which you worked. How much supervisory help did you receive? Were fellow workers helpful in answering questions? To what degree were you able to answer your own questions?

- Did you use any skills learned in your INSTITUTION courses? Did you feel that you were lacking particular technical abilities necessary for your assignment? If so, in what engineering course(s) would you expect to learn these skills?

Your Overall Professional Internship Experience

- Has this assignment motivated you obtain another internship?

- What advice would you give to a student who is ready to start his/her first internship assignment?

- How could the internship program be improved - both at INSTITUTION and at the company?

Co-op #1 Report Requirements

General Requirements

Format and Length

• The report must be typed (double spaced) and be 6-7 pages long using your best grammar.

• **You must include an abstract as the first page of your report.** An abstract is not an introduction, it is a brief (50-70 words) summary of your report.

Cover Page

• **You must have a cover page** in a format similar to the example provided in the Cover Page Packet. It should include a signature line that must be signed by your supervisor to signify that the report does not contain company proprietary information.

• Cover page format and example can be found on the Cooperative Education and Professional Internship Program website.

Submission and Due Dates

The original reports are due by 5:00 P.M. on the Thursday of the last week of classes each semester that you are on work assignment. It is recommended that you also make a copy to keep for your own records.

Students should send two copies of their final reports; the original and one copy.

The reports must be mailed to:
Engineering Cooperative Education
and Professional Internship Program
[ADDESS DELETED]

Do not send reports directly to your Co-op/Professional Internship advisor in your major. All reports within one week late will be reduced one letter grade, reports between one and two weeks late will be reduced two letter grades, reports received after two weeks will be an automatic failure.

Co-op # 1 Report Specific Requirements

Since this was your first work assignment, the majority of the report describes the company, its products, its competition and the department at which you worked. This is followed by a brief description of the kind of work you did and assessment of your overall experience on the job. To organize your report, use the underlined phrases as headings in your report.

The Company at Which You Worked

• Describe the company or corporation at which you worked. (If your division is part of a large parent corporation, describe the Parent Corporation here.) Indicate the name and the location of its headquarters. How many employees does it have (worldwide)? How large are the U.S. and the world markets (annual sales volume in dollars)?

• If your division is part of a large parent corporation, describe the division in which you worked. Where is it located? How does the division fit into the parent corporation, with respect to products and market? How large is your division compared to the parent corporation (number of employees and annual budget)?

• What are your major product(s) of the division or corporation in which you worked? What is the intended use of the product? Who are the major competitors (U.S. and Worldwide) for the products made by your division or corporation?

• In which department or unit did you work? What is the primary responsibility of the department? How large (number of employees) is your department?

• How well did the company assist you in adjusting to your job? Did they help you find housing? Did they provide an orientation? Were your duties and their expectations clearly explained?

Your Co-op Work Assignment

• Describe a typical day at your internship work assignment. What kind of work did you do? Briefly describe the project (or projects) on which you worked. How much supervisory help did you receive? Were fellow workers helpful in answering questions? To what degree were you able to answer your own questions?

• Did you use any skills learned in your INSTITUTION courses? Did you feel that you were lacking particular technical abilities necessary for your assignment? If so, in what engineering course(s) would you expect to learn these skills?

Your Overall Co-op Experience

• Has this assignment motivated you to remain in the program? Are you excited to return for a second work assignment?

• How well did the company assist you adjusting to your job? Did they help you find housing? Did they provide an orientation? Were your duties and expectations clearly explained?

• Did you use any skills learned in your INSTITUTION courses? Did you feel that you were lacking particular technical skills necessary for the assignment? If so, in what engineering course(s) would you expect to learn these skills?

• What advice would you give to a student who is ready to start his/her first work assignment?

• How could the experience be improved - both at INSTITUTION and at the corporation?

Co-op #2 Report Requirements

General Requirements

Format and Length

• The report must be typed (double spaced) and be 6-7 pages long using your best grammar.
• You **must include an abstract as the first page of your report.** An abstract is not an introduction, it is a brief (50-70 words) summary of your report.

Cover Page

• **You must have a cover page** in a format similar to the example provided in the Cover Page Packet. It should include a signature line that must be signed by your supervisor to signify that the report does not contain company proprietary information.

• Cover page format and example can be found on the Cooperative Education and Professional Internship Program website.

Submission and Due Dates

The original reports are due by 5:00 P.M. on the Thursday of the last week of classes each semester that you are on work assignment. It is recommended that you also make a copy to keep for your own records.
Students should send two copies of their final reports; the original and one copy.

The reports must be mailed to:
Engineering Cooperative Education
and Professional Internship Program
[ADDESS DELETED]

Do not send reports directly to your Co-op/Professional Internship advisor in your major. All reports within one week late will be reduced one letter grade, reports between one and two weeks late will be reduced two letter grades, reports received after two weeks will be an automatic failure.

Co-op # 2 Report Specific Requirements

Since this was your second work assignment there should be less emphasis on the company and more emphasis on your work. You should also provide an assessment of how your INSTIUTION education relates to your experience on the job. To organize your report, use the underlined phrases as headings in your report.

The Company at Which You Worked

Note: If you switched corporations or departments from your first or second assignments, provide details about your new corporation and department in regards to the Co-op #1 report contents.

• Provide the name, location and division of the corporation at which you worked. If your division is part of a large parent corporation, provide this
information as well.

• What are the major product(s) of the division or corporation in which you worked?

• In which department or unit did you work? What is the primary responsibility of the department? How large (number of employees) is your department?

<u>Your Co-op Work Assignment</u>

• Describe your job responsibilities and how they related to the objectives of department in which you worked.

• Describe the specific project(s) on which you worked. What was the technical content of this work? Example: Describe the engineering knowledge required in your job assignment. Was the work challenging?

• What INSTITUTION courses helped you in your work assignment?

• What future INSTITUTION courses would you need to fully meet the demands of the job? In other words, which INSTITUTION courses would of been of benefit to you in this work assignment?

• How did this work assignment affect your choice of future technical electives? Are the desired courses available at INSTITUTION? If not, what courses are needed?

<u>Your Overall Co-op Experience</u>

• Was this a good job assignment from the point of view development of your professional skills and interests?

• Is the type of work you can picture yourself doing after graduation?

• Discuss and offer suggestions on how this particular work assignment could have been improved.

• Discuss and offer suggestions on how the co-op program in general could be improved either at INSTITUTION or at your work assignment.

Co-op #3 Report Requirements

General Requirements

Format and Length

• The report must be typed (double spaced) and be 6-7 pages long using your best grammar.

• You **must include an abstract as the first page of your report.** An abstract is not an introduction, it is a brief (50-70 words) summary of your report.

Cover Page

• **You must have a cover page** in a format similar to the example provided in the Cover Page Packet. It should include a signature line that must be signed by your supervisor to signify that the report does not contain company proprietary information.

• Cover page format and example can be found on the Cooperative Education and Professional Internship Program website.

Submission and Due Dates

The original reports are due by 5:00 P.M. on the Thursday of the last week of classes each semester that you are on work assignment. It is recommended that you also make a copy to keep for your own records.
Students should send two copies of their final reports; the original and one copy.

The reports must be mailed to:
Engineering Cooperative Education
and Professional Internship Program
[ADDRESS DELETED]

Do not send reports directly to your Co-op/Professional Internship advisor in your major. All reports within one week late will be reduced one letter grade, reports between one and two weeks late will be reduced two letter grades, reports received after two weeks will be an automatic failure.

Co-op #3 Report Specific Requirements

Because this was your third (or greater) work assignment, the technical content of your job is emphasized in your report. This report should be 7-9 pages due to the required content. To organize your report, use the underlined phrases as headings in your report.

The Company at Which You Worked

Note: If you switched corporations or departments from your first or second assignments, provide details about your new corporation and department in regards to the Co-op #1 report contents.

• Provide the name, location and division of the corporation at which you worked. If your division is part of a large parent corporation, provide this information as well.

• What are the major product(s) of the division or corporation in which you worked?

• In which department or unit did you work? What is the primary responsibility of the department? How large (number of employees) is your department?

Your Co-op Work Assignment

• Describe your job responsibilities and how they related to the objectives of department in which you worked.

• Describe in some detail the specific project(s) on which you worked. Some figures and/or plots may be useful here. If a final project was written or presented to the employer, it or parts of it may be attached to this report as an appendix. Do not include information that is proprietary to your employer.

• What INSTITUTION courses helped you in your work assignment?

• How important were communication skills (written and verbal) as compared technical skills?

Your Overall Co-op Experience

• How has your work assignments adequately prepared you to enter the industry which you plan to pursue upon graduation? How can the co-op program be improved to meet the demands of industry and engineering students?

• Describe how Cooperative Education has enhanced your understanding of professional and ethical responsibility.

• How has Cooperative Education influenced your ability to identify, formulate and solve engineering problems?

• Describe how your work experience exposed you to the use of techniques, skills and modern engineering tools necessary for engineering practice. Which of these items were you exposed to at Penn State and which ere you only exposed to through your work experiences?

• How has your Co-op experience helped you to develop social, team building, and written and oral communication skills?

• Would you recommend Cooperative Education to a sophomore engineering student? Why or why not?

APPENDIX C:

SAS CODE FOR LOGIT MODELS

SAS Code for Apply Knowledge of Math

```
proc freq data=ABET NOPRINT;
	tables q14a_around * Major * q10bround * q12around * q12dround * q7round / out=ABETq14aa;
run;

proc logist data=ABETq14aa;
	freq count;
	class q14a_around (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	model q14a_around = q12around q10bround q7round Major q12dround / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14aa;
	freq count;
	 class Major (ref=last)/ param=ref;
	 class q10bround  (ref=last)/ param=ref;
   c	lass q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	model q14a_around (order=data descending) = q12around q10bround q7round Major q12dround /
link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Apply Knowledge of Physical Sciences

```
proc freq data=ABET NOPRINT;
	tables q14a_bround * Major * q10bround * q12around * q12dround * q7round / out=ABETq14ab;
run;

proc logist data=ABETq14ab;
	freq count;
	class q14a_bround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	model q14a_bround = q12around q10bround q7round Major q12dround / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ab;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	model q14a_bround (order=data descending) = q12around q10bround q7round Major q12dround / 
link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Apply Discipline-specific Engineering Knowledge

```
proc freq data=ABET NOPRINT;
	tables q14a_cround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14ac;
run;

proc logist data=ABETq14ac;
	freq count;
	class q14a_cround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_cround = q12around q10bround q7round Major q12dround urbanization/ link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ac;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_cround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Understand Essential Aspects of the Engineering Design Process

```
proc freq data=ABET NOPRINT;
	tables q14a_hround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14ah;
run;

proc logist data=ABETq14ah;
	freq count;
	class q14a_hround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_hround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ah;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_hround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Apply Systematic Design Procedures

```
proc freq data=ABET NOPRINT;
	tables q14a_iround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14ai;
run;

proc logist data=ABETq14ai;
	freq count;
	class q14a_iround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	 class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_iround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ai;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_iround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Design Solutions to Meet Desired Needs

```
proc freq data=ABET NOPRINT;
	tables q14a_jround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14aj;
run;

proc logist data=ABETq14aj;
	freq count;
	class q14a_jround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_jround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14aj;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_jround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Define Key Engineering Problems

```
proc freq data=ABET NOPRINT;
	tables q14a_kround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14ak;
run;

proc logist data=ABETq14ak;
	freq count;
	class q14a_kround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_kround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ak;
	freq count;
	 class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14a_kround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Formulate a Range of Solutions to an Engineering Problem

```
proc freq data=ABET NOPRINT;
        tables q14a_lround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14al;
run;

proc logist data=ABETq14al;
        freq count;
        class q14a_lround (ref='5')/ param=ref;
        class Major (ref=last)/ param=ref;
        class q10bround  (ref=last)/ param=ref;
        class q12around  (ref=last)/ param=ref;
        class q7round (ref=last) / param = ref;
        class q12dround (ref=last) / param =ref;
        class urbanization (ref=last) / param =ref;
        model q14a_lround = q12around q10bround q7round Major q12dround urbanization / link=glogit
         aggregate rsquare scale=none;
run;

proc logist data=ABETq14al;
        freq count;
        class Major (ref=last)/ param=ref;
        class q10bround  (ref=last)/ param=ref;
        class q12around  (ref=last)/ param=ref;
        class q7round (ref=last) / param = ref;
        class q12dround (ref=last) / param =ref;
        class urbanization (ref=last) / param =ref;
        model q14a_lround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
         aggregate rsquare scale=none;
run;
```

SAS Code for Break Down Complex Problems to Simpler Ones

```
proc freq data=ABET NOPRINT;
	tables q14c_around * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14ca;
run;

proc logist data=ABETq14ca;
	freq count;
	class q14c_around (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_around = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ca;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_around (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Apply Fundamentals to Problems that I haven't seen Before

```
proc freq data=ABET NOPRINT;
	tables q14c_bround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14cb;
run;

proc logist data=ABETq14cb;
	freq count;
	class q14c_bround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_bround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14cb;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_bround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Identify Critical Variables, Information, and/or Relationship Involved in a Problems

```
proc freq data=ABET NOPRINT;
	tables q14c_cround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14cc;
run;

proc logist data=ABETq14cc;
	freq count;
	class q14c_cround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_cround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14cc;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_cround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Know when to use a Formula, Algorithm, or Other Rule

```
proc freq data=ABET NOPRINT;
	tables q14c_dround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14cd;
run;

proc logist data=ABETq14cd;
	freq count;
	class q14c_dround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_dround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14cd;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_dround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Recognize and Understand Organizing Principles (laws, methods, rules, etc.) that Underlie Problems

```
proc freq data=ABET NOPRINT;
	tables q14c_eround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14ce;
run;

proc logist data=ABETq14ce;
	freq count;
	class q14c_eround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_eround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ce;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_eround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Draw Conclusions from Evidence or Premises

```
proc freq data=ABET NOPRINT;
        tables q14c_fround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14cf;
run;

proc logist data=ABETq14cf;
        freq count;
        class q14c_fround (ref='5')/ param=ref;
        class Major (ref=last)/ param=ref;
        class q10bround  (ref=last)/ param=ref;
        class q12around  (ref=last)/ param=ref;
        class q7round (ref=last) / param = ref;
        class q12dround (ref=last) / param =ref;
        class urbanization (ref=last) / param =ref;
        model q14c_fround = q12around q10bround q7round Major q12dround urbanization / link=glogit
         aggregate rsquare scale=none;
run;

proc logist data=ABETq14cf;
        freq count;
        class Major (ref=last)/ param=ref;
        class q10bround  (ref=last)/ param=ref;
        class q12around  (ref=last)/ param=ref;
        class q7round (ref=last) / param = ref;
        class q12dround (ref=last) / param =ref;
        class urbanization (ref=last) / param =ref;
        model q14c_fround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
         aggregate rsquare scale=none;
run;
```

SAS Code for Develop a Course of Action Based on My Understanding of a Whole System

```
proc freq data=ABET NOPRINT;
	tables q14c_ground * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14cg;
run;

proc logist data=ABETq14cg;
	freq count;
	class q14c_ground (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_ground = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14cg;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_ground (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Ensure that a Process or Product Meets a Variety of Technical and Practical Criteria

```
proc freq data=ABET NOPRINT;
	tables q14c_hround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14ch;
run;

proc logist data=ABETq14ch;
	freq count;
	class q14c_hround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_hround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ch;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_hround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Compare and Judge Alternative Outcomes

```
proc freq data=ABET NOPRINT;
	tables q14c_iround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14ci;
run;

proc logist data=ABETq14ci;
	freq count;
	class q14c_iround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_iround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14ci;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_iround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

SAS Code for Develop Learning Strategies that I can apply in my Professional Life

```
proc freq data=ABET NOPRINT;
	tables q14c_jround * Major * q10bround * q12around * q12dround * q7round * urbanization/
out=ABETq14cj;
run;

proc logist data=ABETq14cj;
	freq count;
	class q14c_jround (ref='5')/ param=ref;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_jround = q12around q10bround q7round Major q12dround urbanization / link=glogit
	 aggregate rsquare scale=none;
run;

proc logist data=ABETq14cj;
	freq count;
	class Major (ref=last)/ param=ref;
	class q10bround  (ref=last)/ param=ref;
	class q12around  (ref=last)/ param=ref;
	class q7round (ref=last) / param = ref;
	class q12dround (ref=last) / param =ref;
	class urbanization (ref=last) / param =ref;
	model q14c_jround (order=data descending) = q12around q10bround q7round Major q12dround
urbanization / link=logit
	 aggregate rsquare scale=none;
run;
```

APPENDIX D:

SEMI-STRUCTURED INTERVIEW PROTOCOL

1. Why did you choose your specialty within electrical engineering (power, systems and control, circuit, digital signal processing …)?

   Probe: What developed your interest in your chosen specialty?
2. What are your immediate and long term plans within the field of engineering? Where do you see yourself in five, ten years from now? What experiences influenced these plans?
3. What kinds of engineering problems have you encountered in your classes? Extracurricular activities?
4. How would you rate your problem-solving ability on a scale from 1-10 (with 1 being low ability and 10 being high ability)? Why did you rate yourself that way?
5. Tell me how good you are solving a textbook type problem. What factors has influenced your comfort level?
6. Tell me how good you are solving a non-textbook type problem (i.e., your capstone project)? What factors has influenced your comfort level?
7. Tell me the steps in solving this problem [see figure x]? What are the steps you would take in solving this problem? What are the steps you would take in solving a problem that you can't solve?
8. Tell me the steps in solving this problem [see figure x]? What are the steps you would take in solving this problem? When did you know you solved the problem? What are the steps you would take in solving a problem that you can't solve?
9. What do you consider the most important component in problem-solving and why? What is the second most important component in problem-solving and why?

Is there anything you learned in your classes that you think was not important/or not matter in helping you solve engineering problems? Why?

10. Where and how did you learn those problem-solving components? Can you provide specific examples?

    (Probe: Did you have an instructor/student/mentor guiding you, showing you?)

11. When and how did you know your problem-solving skills improved?

    (Note: Refer back to the problem they've described)

12. When you think back to when you started at PSU, has your approach to **problem-solving** changed? If so, what caused these changes (personal experiences, extracurricular experiences)?

13. When you think back to when you started at PSU, has your approach to **learning** changed? If so, what caused these changes (personal experiences, extracurricular experiences)?

14. You mentioned problem-solving in classes; did any of this help you solve other kinds of problems? If so, how? If not, why not?

15. Tell me the engineering electives you selected and why you select these. Did you consider other courses? What made you finally decide?

16. What co-curricular activities are you involved in (current and previous)? Why did you select these activities?

For Co-op/Internship student

17. In question you mention how [insert example] help you developed this skills in problem-solving,

    - Did people at your co-op/internship help you develop your problem-solving skills? If so, how?

- What kinds of problem-solving did you do in your co-op/internship experience? Where these new kinds of problems? Did they require you to develop any problem-solving skills?
- Were the types of assigned work problems influential in the development of your problem-solving skills? If so, how?
- What did you learn from participating in your co-op/internship(s) that you would not have learned if you hadn't participated?

18. How did your co-op/internship experience influence your learning in the classroom? In extracurricular activities?
19. **If not mentioned ask:** Did your co-op/internship experience have any influence on your course selections?
20. **If not mentioned ask:** Did your co-op/internship experience influence your choice of extra-curricular activities?

APPENDIX E:

STATISTICAL MODEL ESTIMATES

Complete Model Estimates of Fixed Effects for Basic Skills

Parameter	Estimate	Std. Error	df	t	p-value
Intercept	4.249	.096	4136	44.16	0.000
Co-op/ Internship					
Did not participate	-.024	.033	4136	-.72	0.469
1-4 months	.004	.037	4136	.11	0.912
5-8 months	-.065	.037	4136	-1.75	0.081
9-12 months	-.088	.039	4136	-2.24	0.025
>12 months					
College GPA					
<2.50	-.549	.047	4136	-11.79	0.000
2.50-2.99 (B- to B)	-.387	.029	4136	-13.49	0.000
3.00-3.49 (B to A-)	-.237	.024	4136	-9.67	0.000
3.50-4.00 (A- to A)					
SES	.031	.005	4136	6.41	0.000
Major					
Aerospace Engineering	.101	.103	4136	.98	0.326
Chemical Engineering	.029	.037	4136	.80	0.424
Civil Engineering	-.033	.033	4136	-1.01	0.313
Computer Engineering	-.002	.044	4136	-.04	0.965
Electrical Engineering	-.008	.028	4136	-.30	0.765
Industrial Engineering	-.167	.043	4136	-3.90	0.000
Mechanical Engineering					
Time Spent in Design Competition					
Did not participate	-.162	.044	4136	-3.69	0.000
1-4 months	-.110	.047	4136	-2.35	0.019
5-8 months	-.096	.056	4136	-1.70	0.089
9-12 months	.008	.064	4136	.13	0.899
>12 months					
Urbanization					
City: Large	.045	.045	4136	1.01	0.313
City: Midsize	.028	.049	4136	.57	0.565
City: Small	.019	.046	4136	.41	0.679
Suburb: Large	.022	.096	4136	.23	0.819
Suburb: Mid	.057	.061	4136	.94	0.347
Town: Fringe	.004	.071	4136	.06	0.952
Town: Distant	-.175	.136	4136	-1.28	0.199
Rural: Fringe					
Carnegie Classification					
Research Extensive	.019	.064	4136	.29	0.769
Research Intensive	-.046	.081	4136	-.57	0.572
Masters	.022	.078	4136	.29	0.774
Bachelors					

Complete Model Estimates of Fixed Effects for Design and Problem-Solving Skills

Parameter	Estimate	Std. Error	df	t	p-value
Intercept	4.196	.097	4136	43.31	0.000
Co-op/ Internship					
Did not participate	-.120	.033	4136	-3.65	0.000
1-4 months	-.114	.037	4136	-3.04	0.002
5-8 months	-.121	.038	4136	-3.22	0.001
9-12 months	-.102	.039	4136	-2.58	0.010
>12 months					
College GPA					
<2.50	-.401	.047	4136	-8.56	0.000
2.50-2.99 (B- to B)	-.257	.029	4136	-8.90	0.000
3.00-3.49 (B to A-)	-.189	.025	4136	-7.67	0.000
3.50-4.00 (A- to A)					
SES	.038	.005	4136	7.74	0.000
Major					
Aerospace Engineering	.119	.104	4136	1.15	0.251
Chemical Engineering	-.141	.037	4136	-3.81	0.000
Civil Engineering	.014	.033	4136	.42	0.676
Computer Engineering	.177	.044	4136	4.00	0.000
Electrical Engineering	-.052	.028	4136	-1.86	0.063
Industrial Engineering	.098	.043	4136	2.28	0.023
Mechanical Engineering					
Time Spent in Design Competition					
Did not participate	-.401	.044	4136	-9.07	0.000
1-4 months	-.199	.047	4136	-4.22	0.000
5-8 months	-.130	.057	4136	-2.28	0.023
9-12 months	-.066	.065	4136	-1.01	0.311
>12 months					
Urbanization					
City: Large	.001	.045	4136	.02	0.982
City: Midsize	.127	.049	4136	2.57	0.010
City: Small	.044	.046	4136	.96	0.339
Suburb: Large	.203	.097	4136	2.09	0.037
Suburb: Mid	.038	.061	4136	.62	0.538
Town: Fringe	-.015	.071	4136	-.20	0.839
Town: Distant	-.030	.137	4136	-.22	0.828
Rural: Fringe					
Carnegie Classification					
Research Extensive	.032	.064	4136	.50	0.615
Research Intensive	-.018	.082	4136	-.21	0.830
Masters	.005	.079	4136	.06	0.953
Bachelors					

Complete Model Estimates of Fixed Effects for Engineering Thinking Skills

Parameter	Estimate	Std. Error	df	t	p-value
Intercept	4.026	.093	4136	43.52	0.000
Co-op/ Internship					
Did not participate	-.070	.031	4136	-2.23	0.025
1-4 months	-.060	.036	4136	-1.69	0.092
5-8 months	-.077	.036	4136	-2.13	0.033
9-12 months	-.090	.038	4136	-2.39	0.017
>12 months					
College GPA					
<2.50	-.400	.045	4136	-8.94	0.000
2.50-2.99 (B- to B)	-.300	.028	4136	-10.87	0.000
3.00-3.49 (B to A-)	-.205	.024	4136	-8.72	0.000
3.50-4.00 (A- to A)					
SES	.039	.005	4136	8.23	0.000
Major					
Aerospace Engineering	.097	.099	4136	.97	0.330
Chemical Engineering	.034	.035	4136	.97	0.332
Civil Engineering	.038	.032	4136	1.18	0.238
Computer Engineering	.208	.042	4136	4.91	0.000
Electrical Engineering	.077	.027	4136	2.86	0.004
Industrial Engineering	.152	.041	4136	3.70	0.000
Mechanical Engineering					
Time Spent in Design Competition					
Did not participate	-.302	.042	4136	-7.15	0.000
1-4 months	-.140	.045	4136	-3.12	0.002
5-8 months	-.157	.054	4136	-2.89	0.004
9-12 months	-.023	.062	4136	-.36	0.716
>12 months					
Urbanization					
City: Large	-.016	.043	4136	-.37	0.709
City: Midsize	.045	.047	4136	.96	0.338
City: Small	-.029	.044	4136	-.65	0.518
Suburb: Large	.176	.093	4136	1.90	0.058
Suburb: Mid	-.121	.058	4136	-2.08	0.037
Town: Fringe	-.057	.068	4136	-.84	0.401
Town: Distant	-.219	.131	4136	-1.67	0.096
Rural: Fringe					
Carnegie Classification					
Research Extensive	.069	.062	4136	1.13	0.259
Research Intensive	-.032	.078	4136	-.41	0.678
Masters	.055	.075	4136	.73	0.464
Bachelors					

Parameter Estimates for Apply Knowledge of Math

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-27.409	1559.7	.00	.9860	-3.544	.786	20.34	<.0001	-1.066	.264	16.30	<.0001	-.0178	.196	.01	.9275
Co-op																
0 months	>1000	725.4	.00	.9883	.983	.443	.00	.9688	1.098	.141	.44	.5067	.886	.108	1.25	.2631
1-4 months	.310	984.8	.00	.9991	1.401	.490	.47	.4916	.823	.171	1.30	.2537	.993	.123	.00	.9555
5-8 months	.305	1018.1	.00	.9991	.997	.547	.00	.9960	1.173	.167	.92	.3376	1.047	.126	.14	.7122
9-12 months	.520	1046.1	.00	.9995	1.463	.533	.51	.4749	1.281	.174	2.04	.1530	1.097	.131	.50	.4784
> 12 months																
Major																
Other	>1000	641.9	.00	.9818	1.078	.527	.02	.8869	.885	.210	.34	.5603	.843	.172	.98	.3219
Aerospace	.803	1480.9	.00	.9999	.485	.638	1.28	.2572	.681	.198	3.76	.0526	.817	.150	1.82	.1774
Chemical	.659	1310.1	.00	.9997	.741	.520	.33	.5632	.748	.179	2.62	.1054	1.043	.133	.10	.7530
Civil	1.227	1143.3	.00	.9999	.259	.633	4.57	.0326	.920	.153	.30	.5858	.984	.123	.02	.8982
Computer	.603	1175.6	.00	.9997	.536	.456	1.87	.1717	.587	.156	11.70	.0006	.644	.121	13.28	.0003
Electrical	.402	947.1	.00	.9992	.604	.369	1.87	.1714	.625	.131	12.84	.0003	.755	.102	7.64	.0057
Industrial	.608	1387.8	.00	.9997	.776	.520	.24	.6254	.640	.198	5.07	.0244	.928	.145	.26	.6078
Mechanical																
College GPA																
< 2.50	6.410	1.537	1.46	.2269	11.634	.602	16.60	<.0001	9.510	.213	111.78	<.0001	3.977	.192	51.61	<.0001
2.50-2.99	<0.001	595.1	.00	.9831	10.185	.416	31.08	<.0001	4.216	.128	125.80	<.0001	2.479	.098	86.00	<.0001
3.00-3.49	<0.001	438.6	.00	.9774	3.340	.422	8.18	.0042	2.521	.113	66.79	<.0001	1.855	.079	61.30	<.0001
3.50-4.00																
SES	.662	.415	.99	.3204	.887	.064	3.56	.0593	.910	.021	20.03	<.0001	.955	.016	8.45	.0037
Design																
0 months	5.464	1338.	.00	.9990	.920	.544	.02	.8777	1.304	.199	1.79	.1812	1.167	.146	1.13	.2876
1-4 months	<0.001	1441.1	.00	.9942	.701	.601	.35	.5546	1.104	.212	.22	.6422	1.078	.156	.23	.6308
5-8 months	<0.001	1629.2	.00	.9952	1.193	.667	.07	.7915	1.082	.253	.10	.7556	.985	.187	.01	.9354
9-12 months	<0.001	1743.7	.00	.9949	.300	1.134	1.13	.2881	1.043	.288	.02	.8824	.937	.214	.09	.7628
> 12 months																

Parameter Estimates for Apply Knowledge of Physical Sciences

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-42.107	1603.5	.00	.9790	-3.836	.68	31.84	<.0001	-1.462	.261	31.28	<.0001	-.213	.202	1.11	.2929
Co-op																
0 months	>1000	623.7	.00	.9845	.948	.314	.03	.8662	1.052	.139	.13	.7156	.888	.116	1.03	.3092
1-4 months	>1000	623.7	.00	.9833	.834	.383	.22	.6356	1.054	.161	.11	.7445	.968	.134	.06	.8053
5-8 months	1.038	976.8	.00	1.0000	1.07	.395	.03	.8647	1.395	.163	4.17	.0413	1.13	.137	.79	.3729
9-12 months	1.102	1042.3	.00	.9999	1.372	.386	.67	.4117	1.282	.17	2.14	.1431	1.067	.142	.21	.6456
> 12 months																
Major																
Other	>1000	1013.7	.00	.9873	5.032	.387	17.48	<.0001	1.784	.208	7.74	.0054	.889	.189	.39	.5327
Aerospace	.59	2567.2	.00	.9998	.197	1.039	2.45	.1179	.743	.203	2.16	.1418	.838	.15	1.38	.2408
Chemical	.766	2226.2	.00	.9999	.892	.526	.05	.8282	1.217	.173	1.29	.2565	1.099	.139	.46	.4980
Civil	>1000	1013.7	.00	.9882	.768	.491	.29	.5913	1.677	.153	11.37	.0007	1.11	.131	.63	.4256
Computer	1.033	1998.	.00	1.0000	4.588	.328	21.61	<.0001	1.835	.155	15.37	<.0001	1.158	.133	1.22	.2701
Electrical	.624	1567.1	.00	.9998	2.427	.314	7.96	.0048	1.528	.13	10.63	.0011	1.073	.108	.43	.5122
Industrial	1.436	2457.4	.00	.9999	6.19	.409	19.88	<.0001	4.628	.202	57.42	<.0001	1.943	.189	12.32	.0004
Mechanical																
College GPA																
< 2.50	12.871	1.49	2.94	.0864	17.349	.398	51.53	<.0001	8.944	.244	80.77	<.0001	3.934	.236	33.68	<.0001
2.50-2.99	1.539	1.451	.09	.7665	5.913	.285	38.80	<.0001	3.345	.124	95.01	<.0001	2.171	.106	53.20	<.0001
3.00-3.49	<0.001	410.4	.00	.9760	2.623	.276	12.23	.0005	2.42	.105	71.47	<.0001	1.912	.085	57.90	<.0001
3.50-4.00																
SES	.601	.36	2.01	.1565	.839	.048	13.55	.0002	.9	.021	26.44	<.0001	.972	.017	2.68	.1015
Design																
0 months	>1000	1074.4	.00	.9901	2.615	.531	3.28	.0702	2.504	.197	21.68	<.0001	1.72	.147	13.60	.0002
1-4 months	1.175	1205.6	.00	.9999	1.352	.57	.28	.5967	1.739	.21	6.98	.0083	1.397	.158	4.50	.0339
5-8 months	.995	1423.4	.00	1.0000	1.88	.627	1.01	.3143	1.372	.252	1.58	.2086	1.29	.19	1.80	.1799
9-12 months	1.221	1449.	.00	.9999	1.813	.703	.72	.3977	1.501	.284	2.05	.1527	1.201	.219	.70	.4032
> 12 months																

Parameter Estimates for Apply Discipline-specific Engineering Knowledge

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P\ (>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-28.828	915. 1	.00	.9749	-2.937	. 683	18.51	<.0001	-1.523	. 324	22.06	<.0001	-.297	. 248	1.44	.2303
Co-op																
0 months	>1000	508	.00	.9826	1.923	. 325	4.05	.0441	1.367	. 142	4.86	.0274	1.392	. 113	8.53	.0035
1-4 months	>1000	508	.00	.9788	1.905	. 373	2.99	.0839	1.474	. 164	5.58	.0182	1.378	. 131	6.03	.0141
5-8 months	>1000	508	.00	.9804	1.850	. 384	2.57	.1090	1.725	. 165	10.91	.0010	1.460	. 133	8.13	.0044
9-12 months	.604	833. 8	.00	.9995	2.324	. 378	4.98	.0256	1.352	. 176	2.95	.0860	1.424	. 136	6.72	.0095
> 12 months																
Major																
Other	6.690	1. 331	2.04	.1533	.734	. 451	.47	.4920	.717	. 218	2.34	.1264	.811	. 18	1.35	.2446
Aerospace	<0.001	971. 5	.00	.9898	.730	. 425	.55	.4589	.555	. 209	7.92	.0049	.863	. 157	.89	.3461
Chemical	4.685	1. 529	1.02	.3123	1.093	. 359	.06	.8037	1.144	. 174	.60	.4377	1.064	. 147	.18	.6698
Civil	<0.001	521. 4	.00	.9811	.898	. 331	.11	.7438	.652	. 164	6.85	.0089	1.061	. 129	.21	.6471
Computer	<0.001	638. 5	.00	.9840	.611	. 314	2.47	.1162	.406	. 162	31.17	<.0001	.545	. 126	23.17	<.0001
Electrical	1.618	1. 288	.14	.7086	.857	. 273	.32	.5715	.954	. 13	.14	.7133	.783	. 111	4.82	.0281
Industrial	<0.001	756. 5	.00	.9866	.852	. 377	.18	.6707	.537	. 197	9.94	.0016	.772	. 153	2.86	.0910
Mechanical																
College GPA																
< 2.50	31.611	1. 112	9.65	.0019	4.495	. 41	13.42	.0002	6.518	. 211	79.09	<.0001	2.211	. 194	16.69	<.0001
2.50-2.99	1.488	1. 312	.09	.7621	4.018	. 26	28.52	<.0001	4.495	. 129	136.77	<.0001	1.995	. 105	43.70	<.0001
3.00-3.49	<0.001	433. 9	.00	.9769	2.613	. 241	15.91	<.0001	2.925	. 111	93.02	<.0001	1.807	. 083	50.38	<.0001
3.50-4.00																
SES	.825	. 209	.84	.3593	.837	. 045	15.94	<.0001	.870	. 021	43.64	<.0001	.930	. 017	18.45	<.0001
Design																
0 months	>1000	761. 1	.00	.9860	3.280	. 475	6.25	.0124	3.512	. 21	35.92	<.0001	2.182	. 147	28.29	<.0001
1-4 months	.874	887. 8	.00	.9999	1.347	. 516	.33	.5641	1.708	. 224	5.74	.0166	1.645	. 156	10.25	.0014
5-8 months	.796	1109	.00	.9998	1.663	. 591	.74	.3891	1.633	. 265	3.43	.0640	1.479	. 188	4.34	.0371
9-12 months	.414	1693	.00	.9996	1.069	. 75	.01	.9287	1.264	. 31	.57	.4495	1.481	. 213	3.40	.0650
> 12 months																
Urbanization																
City: Large	-0.786	.456	1. 30	.37	.5458	.779	. 298	.70	.4021	1.219	. 18	1.20	.2725	1.044	. 149	.08
City: Midsize	-1.6727	.188	1. 56	1.15	.2838	.400	. 349	6.89	.0087	.880	. 191	.45	.5036	.802	. 156	2.00
City: Small	-0.6079	.544	1. 37	.20	.6562	.558	. 324	3.24	.0717	1.023	. 187	.02	.9022	.977	. 154	.02
Suburb: Large	-13.841	<0.001	1175	.00	.9906	<0.001	1548	.00	.9917	.958	. 35	.02	.9025	.777	. 284	.79
Suburb: Mid	-12.671	<0.001	830	.00	.9878	.521	. 506	1.66	.1970	1.137	. 25	.26	.6082	1.247	. 2	1.22
Town: Fringe	-13.978	<0.001	916.	.00	.9878	.722	. 55	.35	.5543	1.061	. 303	.04	.8454	1.358	. 241	1.62
Town: Distant	-11.562	<0.001	1699	.00	.9946	<0.001	2362	.00	.9945	.676	. 544	.52	.4720	.982	. 399	.00
Rural: Fringe																

Parameter Estimates for Understand Essential Aspects of the Engineering Design Process

	Odds Est.	Std. Error	χ^2	p-value
Intercept				
α_1	-.157	.199	.62	.4299
α_2	1.926	.201	91.70	<.0001
α_3	4.278	.216	393.35	<.0001
α_4	6.826	.351	379.00	<.0001
Co-op				
0 months	.685	.090	17.61	<.0001
1-4 months	.728	.104	9.36	.0022
5-8 months	.705	.105	11.09	.0009
9-12 months	.790	.109	4.66	.0309
> 12 months				
Major				
Other	.730	.138	5.20	.0226
Aerospace	1.376	.127	6.37	.0116
Chemical	.694	.110	11.09	.0009
Civil	.981	.099	.04	.8473
Computer	1.304	.100	7.02	.0081
Electrical	.892	.084	1.87	.1717
Industrial	1.118	.121	.86	.3535
Mechanical				
College GPA				
< 2.50	.416	.130	45.13	<.0001
2.50-2.99	.617	.079	37.40	<.0001
3.00-3.49	.727	.067	22.41	<.0001
3.50-4.00				
SES	1.092	.013	44.085	<.0001
Design				
0 months	.388	.125	57.23	<.0001
1-4 months	.603	.133	14.45	.0001
5-8 months	.647	.159	7.51	.0061
9-12 months	.749	.182	2.52	.1121
> 12 months				
Urbanization				
City: Large	.947	.112	.24	.6244
City: Midsize	1.264	.120	3.86	.0495
City: Small	1.207	.117	2.60	.1072
Suburb: Large	1.403	.227	2.23	.1358
Suburb: Mid	1.257	.154	2.22	.1366
Town: Fringe	1.050	.181	.07	.7874
Town: Distant	1.170	.322	.24	.6257
Rural: Fringe				

α_1 is the intercept for the logit model of $\left(\frac{P(High\ Ability)}{P(>Adequate\ Ability+Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_2 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>\ Adequate\ Ability)}{P(Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_3 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability\ +Adequate\ Ability)}{P(Some\ Ability+No\ Ability)}\right)$

α_4 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability\ +Adequate\ Ability+Some\ Ability)}{P(No\ Ability)}\right)$

Parameter Estimates for Apply Systematic Design Procedures

	Odds Est.	Std. Error	χ^2	p-value
Intercept				
α_1	-.511	.196	6.82	.0090
α_2	1.403	.197	50.88	<.0001
α_3	3.466	.204	290.10	<.0001
α_4	5.959	.268	494.88	<.0001
Co-op				
0 months	.723	.089	13.34	.0003
1-4 months	.754	.102	7.60	.0058
5-8 months	.680	.103	13.94	.0002
9-12 months	.851	.107	2.24	.1344
> 12 months				
Major				
Other	.765	.136	3.85	.0499
Aerospace	1.003	.124	.00	.9804
Chemical	.658	.108	14.94	.0001
Civil	.871	.098	2.01	.1567
Computer	1.427	.099	12.95	.0003
Electrical	.863	.083	3.17	.0749
Industrial	1.242	.119	3.34	.0678
Mechanical				
College GPA				
< 2.50	.439	.129	40.73	<.0001
2.50-2.99	.586	.078	47.03	<.0001
3.00-3.49	.672	.066	36.02	<.0001
3.50-4.00				
SES	1.109	.013	62.23	<.0001
Design				
0 months	.391	.122	59.16	<.0001
1-4 months	.601	.130	15.46	<.0001
5-8 months	.842	.156	1.22	.2694
9-12 months	.846	.178	.87	.3497
> 12 months				
Urbanization				
City: Large	.869	.111	1.61	.2045
City: Midsize	1.150	.118	1.41	.2352
City: Small	1.050	.115	.18	.6735
Suburb: Large	1.603	.224	4.43	.0353
Suburb: Mid	1.024	.151	.02	.8747
Town: Fringe	.790	.178	1.75	.1859
Town: Distant	.655	.317	1.79	.1811
Rural: Fringe				

α_1 is the intercept for the logit model of $\left(\frac{P(High\ Ability)}{P(>Adequate\ Ability + Adequate\ Ability + Some\ Ability + No\ Ability)}\right)$

α_2 is the intercept for the logit model of $\left(\frac{P(High\ Ability + >\ Adequate\ Ability)}{P(Adequate\ Ability + Some\ Ability + No\ Ability)}\right)$

α_3 is the intercept for the logit model of $\left(\frac{P(High\ Ability + >Adequate\ Ability + Adequate\ Ability)}{P(Some\ Ability + No\ Ability)}\right)$

α_4 is the intercept for the logit model of $\left(\frac{P(High\ Ability + >Adequate\ Ability + Adequate\ Ability + Some\ Ability)}{P(No\ Ability)}\right)$

Parameter Estimates for Design Solutions to Meet Desired Needs

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-15.124	270.1	.00	.9553	-3.109	.593	27.45	<.0001	-1.292	.315	16.87	<.0001	-.214	.256	.70	.4038
Co-op																
0 months	>1000	270.1	.00	.9632	2.324	.263	10.26	.0014	1.558	.136	10.57	.0011	1.575	.117	15.07	.0001
1-4 months	>1000	270.1	.00	.9626	1.750	.309	3.28	.0700	1.538	.157	7.54	.0060	1.389	.135	5.93	.0149
5-8 months	>1000	270.1	.00	.9630	1.589	.327	2.00	.1573	1.861	.159	15.29	<.0001	1.605	.138	11.74	.0006
9-12 months	>1000	270.1	.00	.9662	1.042	.362	.01	.9100	1.453	.165	5.14	.0234	1.373	.14	5.12	.0237
> 12 months																
Major																
Other	2.594	.954	1.00	.3174	1.759	.345	2.69	.1012	.985	.214	.00	.9456	1.013	.188	.00	.9458
Aerospace	1.235	1.187	.03	.8587	1.294	.367	.49	.4831	.999	.197	.00	.9950	1.203	.165	1.25	.2632
Chemical	5.753	.802	4.76	.0291	3.361	.29	17.46	<.0001	1.813	.178	11.20	.0008	1.653	.161	9.76	.0018
Civil	2.440	.836	1.14	.2861	.979	.322	.00	.9486	1.162	.151	1.00	.3183	1.164	.133	1.30	.2540
Computer	.449	1.174	.47	.4949	.476	.335	4.91	.0266	.568	.154	13.53	.0002	.764	.128	4.45	.0349
Electrical	1.781	.757	.58	.4459	2.104	.229	10.59	.0011	1.235	.129	2.69	.1010	1.123	.115	1.02	.3132
Industrial	<0.001	369.9	.00	.9746	.772	.399	.42	.5157	.884	.186	.44	.5072	1.081	.159	.24	.6235
Mechanical																
College GPA																
< 2.50	5.658	.786	4.87	.0274	4.613	.307	24.74	<.0001	2.713	.209	22.82	<.0001	1.472	.199	3.79	.0514
2.50-2.99	1.716	.658	.67	.4119	1.758	.229	6.09	.0136	1.923	.12	29.59	<.0001	1.264	.107	4.85	.0276
3.00-3.49	1.224	.622	.11	.7448	1.920	.197	10.94	.0009	1.630	.104	21.92	<.0001	1.435	.088	16.77	<.0001
3.50-4.00																
SES	.668	.126	10.3	.0013	.864	.037	15.63	<.0001	.883	.021	36.98	<.0001	.935	.018	14.55	.0001
Design																
0 months	3.276	1.059	1.26	.2625	4.099	.407	12.01	.0005	4.157	.202	49.69	<.0001	2.247	.148	29.95	<.0001
1-4 months	.351	1.433	.53	.4648	1.409	.443	.60	.4383	2.233	.213	14.25	.0002	1.527	.157	7.28	.0070
5-8 months	.882	1.438	.01	.9306	.754	.579	.24	.6264	1.444	.256	2.07	.1502	1.302	.187	1.98	.1595
9-12 months	<0.001	507.	.00	.9815	1.236	.613	.12	.7292	1.646	.287	3.02	.0824	1.333	.216	1.77	.1837
> 12 months																
Urbanization																
City: Large	.356	.705	2.14	.1431	1.114	.284	.15	.7028	1.172	.18	.78	.3784	.905	.158	.40	.5272
City: Midsize	.187	.892	3.52	.0605	.570	.32	3.10	.0785	.804	.19	1.31	.2518	.803	.165	1.77	.1834
City: Small	.760	.661	.17	.6778	.815	.304	.45	.5027	1.000	.186	.00	.9982	.897	.163	.44	.5053
Suburb: Large	<0.001	785.6	.00	.9864	.332	.789	1.96	.1619	.694	.362	1.02	.3127	.857	.292	.28	.5968
Suburb: Mid	<0.001	427.3	.00	.9763	.570	.48	1.37	.2414	.953	.241	.04	.8420	.928	.207	.13	.7200
Town: Fringe	<0.001	513.2	.00	.9807	1.202	.535	.12	.7303	1.816	.306	3.81	.0509	1.822	.271	4.90	.0269
Town: Distant	<0.001	1317.1	.00	.9925	2.222	.875	.83	.3618	1.814	.555	1.15	.2828	1.857	.495	1.57	.2109
Rural: Fringe																

Parameter Estimates for Define Key Engineering Problems

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P\ (>\ Adequate\ \ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-16.940	464	.00	.9709	-2.009	.606	10.99	.0009	-1.061	.316	11.30	.0008	.289	.264	1.20	.2724
Co-op																
0 months	2.050	1.096	.43	.5126	2.223	.289	7.67	.0056	1.592	.138	11.30	.0008	1.207	.121	2.43	.1191
1-4 months	1.799	1.241	.22	.6363	2.056	.328	4.82	.0281	1.494	.159	6.35	.0117	1.194	.139	1.63	.2020
5-8 months	3.025	1.177	.88	.3470	1.617	.349	1.89	.1691	1.561	.161	7.68	.0056	1.240	.141	2.35	.1253
9-12 months	1.424	1.432	.06	.8049	1.531	.37	1.32	.2498	1.418	.17	4.20	.0404	1.425	.145	5.93	.0149
> 12 months																
Major																
Other	4.551	.861	3.10	.0784	1.525	.339	1.55	.2130	.928	.217	.12	.7314	.954	.194	.06	.8090
Aerospace	1.206	1.188	.02	.8745	.546	.417	2.12	.1456	.770	.192	1.85	.1738	.891	.165	.50	.4811
Chemical	2.363	.943	.83	.3618	2.046	.299	5.74	.0166	1.587	.177	6.79	.0091	1.466	.163	5.50	.0190
Civil	1.406	.932	.13	.7144	.911	.309	.09	.7638	.987	.155	.01	.9345	1.171	.137	1.33	.2490
Computer	1.319	.938	.09	.7678	.604	.315	2.57	.1091	.937	.152	.18	.6685	.929	.137	.29	.5905
Electrical	.426	1.173	.53	.4671	1.393	.23	2.07	.1499	1.220	.131	2.31	.1284	1.170	.119	1.74	.1866
Industrial	<0.001	469.7	.00	.9789	.369	.496	4.03	.0448	.820	.183	1.18	.2778	.979	.162	.02	.8956
Mechanical																
College GPA																
< 2.50	6.210	.968	3.56	.0591	3.060	.337	11.01	.0009	2.922	.216	24.54	<.0001	1.608	.209	5.20	.0226
2.50-2.99	1.593	.842	.31	.5803	1.413	.23	2.26	.1331	1.927	.121	29.44	<.0001	1.193	.11	2.59	.1073
3.00-3.49	1.972	.722	.89	.3468	1.531	.198	4.63	.0315	1.705	.105	25.88	<.0001	1.405	.091	13.92	.0002
3.50-4.00																
SES	.804	.135	2.60	.1071	.767	.04	44.56	<.0001	.876	.021	41.17	<.0001	.913	.018	24.86	<.0001
Design																
0 months	>1000	464	.00	.9769	4.165	.409	12.18	.0005	4.388	.199	55.46	<.0001	2.247	.149	29.41	<.0001
1-4 months	>1000	464	.00	.9802	1.112	.458	.05	.8159	2.356	.21	16.68	<.0001	1.643	.158	9.82	.0017
5-8 months	1.881	588.9	.00	.9991	1.387	.52	.39	.5297	1.749	.25	5.00	.0253	1.427	.191	3.45	.0633
9-12 months	1.998	646	.00	.9991	.511	.824	.66	.4150	1.719	.284	3.65	.0560	1.450	.219	2.89	.0891
> 12 months																
Urbanization																
City: Large	.460	.937	.69	.4071	1.032	.294	.01	.9153	1.079	.183	.17	.6783	.896	.166	.44	.5072
City: Midsize	.414	1.027	.74	.3911	.624	.323	2.14	.1433	.802	.192	1.31	.2522	.722	.172	3.57	.0589
City: Small	1.554	.839	.28	.5996	.674	.322	1.51	.2193	1.072	.189	.14	.7131	.899	.171	.39	.5331
Suburb: Large	<0.001	765.7	.00	.9872	.518	.68	.93	.3337	.584	.363	2.19	.1392	.740	.297	1.03	.3098
Suburb: Mid	<0.001	501.2	.00	.9797	.265	.585	5.17	.0230	.884	.236	.27	.6020	.611	.214	5.32	.0211
Town: Fringe	<0.001	578.5	.00	.9830	.527	.604	1.13	.2885	1.399	.286	1.37	.2410	.890	.266	.19	.6623
Town: Distant	<0.001	1648.9	.00	.9940	1.827	.895	.45	.5010	1.691	.583	.81	.3679	1.699	.526	1.02	.3132
Rural: Fringe																

Parameter Estimates for Formulate a Range of Solutions to an Engineering Problem

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-15.429	308.7	.00	.9601	-2.163	.555	15.18	<.0001	-.933	.305	9.33	.0023	-.017	.267	.00	.9495
Co-op																
0 months	3.064	1.084	1.07	.3017	1.918	.255	6.55	.0105	1.457	.137	7.55	.0060	1.305	.123	4.67	.0307
1-4 months	1.899	1.245	.27	.6067	1.703	.295	3.25	.0713	1.377	.157	4.15	.0417	1.220	.141	1.98	.1592
5-8 months	2.198	1.243	.40	.5265	1.564	.307	2.13	.1444	1.511	.158	6.84	.0089	1.229	.143	2.07	.1498
9-12 months	1.556	1.432	.10	.7574	1.371	.334	.89	.3453	1.464	.168	5.14	.0234	1.530	.149	8.15	.0043
> 12 months																
Major																
Other	3.527	.856	2.17	.1411	1.420	.323	1.18	.2778	.925	.213	.13	.7163	.886	.197	.38	.5385
Aerospace	1.273	1.189	.04	.8388	.984	.351	.00	.9644	1.052	.192	.07	.7935	1.086	.174	.23	.6332
Chemical	2.276	.941	.76	.3822	2.353	.279	9.38	.0022	1.616	.181	7.03	.0080	1.666	.169	9.15	.0025
Civil	.725	1.17	.08	.7831	.863	.289	.26	.6094	1.077	.153	.23	.6288	1.173	.141	1.28	.2572
Computer	1.004	.938	.00	.9970	.665	.286	2.03	.1540	.814	.155	1.77	.1837	1.022	.139	.03	.8732
Electrical	.931	.841	.01	.9318	1.302	.215	1.50	.2203	1.067	.13	.25	.6184	1.085	.12	.47	.4950
Industrial	.672	1.177	.11	.7354	.193	.54	9.28	.0023	.629	.18	6.67	.0098	.786	.16	2.28	.1315
Mechanical																
College GPA																
< 2.50	7.444	.819	6.00	.0143	4.682	.32	23.30	<.0001	3.235	.221	28.32	<.0001	1.918	.216	9.13	.0025
2.50-2.99	1.317	.787	.12	.7265	2.330	.214	15.58	<.0001	2.111	.123	37.13	<.0001	1.587	.113	16.77	<.0001
3.00-3.49	1.561	.66	.46	.4998	1.905	.19	11.54	.0007	1.788	.103	31.74	<.0001	1.572	.092	24.09	<.0001
3.50-4.00																
SES	.754	.129	4.81	.0282	.773	.037	48.08	<.0001	.886	.021	34.41	<.0001	.911	.019	24.98	<.0001
Design																
0 months	>1000	308.7	.00	.9679	3.878	.367	13.66	.0002	3.678	.188	47.91	<.0001	2.230	.153	27.50	<.0001
1-4 months	>1000	308.7	.00	.9729	.965	.415	.01	.9315	2.054	.199	13.06	.0003	1.634	.162	9.17	.0025
5-8 months	>1000	308.7	.00	.9703	1.212	.481	.16	.6888	1.591	.241	3.72	.0538	1.507	.196	4.39	.0362
9-12 months	2.137	406.5	.00	.9985	.753	.631	.20	.6536	1.345	.276	1.15	.2836	1.421	.222	2.52	.1127
> 12 months																
Urbanization																
City: Large	.419	.792	1.21	.2721	1.399	.285	1.39	.2385	1.258	.179	1.64	.2007	1.001	.165	.00	.9965
City: Midsize	.482	.846	.75	.3880	.813	.312	.44	.5064	.825	.19	1.03	.3104	.943	.171	.12	.7340
City: Small	.779	.769	.11	.7456	.887	.308	.15	.6964	1.113	.185	.34	.5625	1.004	.169	.00	.9795
Suburb: Large	<0.001	467.3	.00	.9798	.391	.793	1.40	.2361	.733	.353	.78	.3778	.927	.302	.06	.8031
Suburb: Mid	.846	1.215	.02	.8905	.767	.466	.32	.5701	1.240	.24	.80	.3699	1.046	.22	.04	.8373
Town: Fringe	<0.001	290.9	.00	.9691	.763	.561	.23	.6288	1.532	.288	2.20	.1378	1.183	.269	.39	.5315
Town: Distant	<0.001	1041.1	.00	.9909	3.710	.665	3.89	.0486	1.572	.508	.79	.3730	.901	.499	.04	.8339
Rural: Fringe																

Parameter Estimates for Break down Complex Problems to Simpler Ones

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-15.535	976.6	.00	.9873	-2.204	.661	11.11	.0009	-.866	.311	7.76	.0054	.149	.252	.35	.5527
Co-op																
0 months	.991	1.266	.00	.9941	1.368	.292	1.15	.2835	1.298	.137	3.61	.0573	1.116	.116	.89	.3457
1-4 months	<0.001	477.9	.00	.9795	1.396	.34	.96	.3264	1.243	.161	1.83	.1759	1.301	.134	3.86	.0494
5-8 months	<0.001	485.8	.00	.9799	.905	.372	.07	.7895	1.287	.16	2.47	.1158	1.180	.135	1.51	.2195
9-12 months	1.882	1.524	.17	.6782	1.011	.396	.00	.9775	1.369	.17	3.44	.0638	1.387	.141	5.42	.0199
> 12 months																
Major																
Other	3.437	1.274	.94	.3326	.475	.444	2.80	.0941	.500	.214	10.49	.0012	.586	.18	8.85	.0029
Aerospace	2.404	1.468	.36	.5502	.426	.503	2.88	.0899	1.016	.189	.01	.9345	.823	.169	1.33	.2495
Chemical	<0.001	1076.5	.00	.9899	1.020	.324	.00	.9524	.729	.173	3.36	.0669	.838	.147	1.45	.2290
Civil	1.664	1.469	.12	.7289	1.002	.301	.00	.9956	.931	.156	.21	.6449	.955	.138	.11	.7384
Computer	<0.001	1412.5	.00	.9915	.200	.408	15.57	<.0001	.361	.155	43.02	<.0001	.470	.129	34.50	<.0001
Electrical	<0.001	974.8	.00	.9879	.579	.259	4.45	.0349	.534	.13	23.27	<.0001	.602	.112	20.51	<.0001
Industrial	<0.001	1197.6	.00	.9911	.345	.463	5.29	.0215	.517	.188	12.32	.0004	.674	.156	6.39	.0115
Mechanical																
College GPA																
< 2.50	3.934	1.351	1.03	.3105	7.632	.348	34.08	<.0001	4.245	.21	47.25	<.0001	2.212	.198	16.10	<.0001
2.50-2.99	<0.001	351.6	.00	.9726	3.495	.26	23.24	<.0001	2.790	.122	70.69	<.0001	1.788	.106	30.35	<.0001
3.00-3.49	.888	1.039	.01	.9090	1.872	.25	6.32	.0120	2.037	.104	46.53	<.0001	1.667	.085	36.27	<.0001
3.50-4.00																
SES	.792	.238	.96	.3284	.820	.045	19.40	<.0001	.871	.021	45.05	<.0001	.944	.017	11.38	.0007
Design																
0 months	>1000	976.6	.00	.9893	2.818	.441	5.51	.0189	2.956	.195	30.97	<.0001	2.071	.15	23.72	<.0001
1-4 months	>1000	976.6	.00	.9892	1.238	.483	.20	.6586	1.814	.207	8.32	.0039	1.521	.159	6.96	.0083
5-8 months	2.707	1154.1	.00	.9993	1.657	.566	.79	.3728	1.858	.25	6.13	.0133	1.882	.193	10.71	.0011
9-12 months	.856	1429.7	.00	.9999	.766	.731	.13	.7153	1.151	.285	.24	.6216	1.169	.216	.52	.4707
> 12 months																
Urbanization																
City: Large	.634	1.23	.14	.7109	.854	.345	.21	.6476	1.295	.18	2.07	.1498	.899	.149	.51	.4754
City: Midsize	.346	1.502	.50	.4795	.737	.37	.68	.4098	.992	.19	.00	.9672	.759	.156	3.13	.0770
City: Small	<0.001	358.1	.00	.9715	.961	.354	.01	.9101	1.110	.187	.31	.5775	.891	.154	.56	.4536
Suburb: Large	<0.001	1525.4	.00	.9928	.223	1.07	1.97	.1610	.760	.341	.65	.4213	.540	.283	4.74	.0295
Suburb: Mid	<0.001	1290.3	.00	.9917	.730	.533	.35	.5558	1.630	.237	4.25	.0392	.870	.204	.47	.4938
Town: Fringe	<0.001	3009.6	.00	.9961	.553	.684	.75	.3867	1.494	.287	1.97	.1610	1.076	.245	.09	.7641
Town: Distant	<0.001	9493.6	.00	.9987	2.510	.891	1.07	.3016	1.936	.566	1.36	.2427	1.693	.49	1.16	.2825
Rural: Fringe																

Parameter Estimates for Apply Fundamentals to Problems that I haven't seen Before

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-14.616	444.3	.00	.9738	-1.443	.496	8.48	.0036	-.630	.306	4.25	.0392	.221	.276	.64	.4228
Co-op																
0 months	2.884	1.085	.95	.3289	1.704	.23	5.35	.0207	1.109	.137	.57	.4516	1.120	.129	.78	.3787
1-4 months	3.998	1.142	1.47	.2248	1.373	.273	1.35	.2454	1.204	.158	1.37	.2415	1.171	.148	1.13	.2873
5-8 months	2.287	1.249	.44	.5077	1.638	.269	3.36	.0669	1.202	.161	1.31	.2518	1.202	.15	1.49	.2217
9-12 months	3.711	1.252	1.10	.2950	1.589	.288	2.60	.1072	1.369	.167	3.52	.0606	1.283	.157	2.53	.1118
> 12 months																
Major																
Other	1.036	.91	.00	.9688	.638	.328	1.88	.1701	.715	.213	2.48	.1154	.783	.199	1.51	.2188
Aerospace	<0.001	357.9	.00	.9728	.832	.306	.36	.5466	1.074	.194	.14	.7131	.948	.183	.09	.7689
Chemical	<0.001	294.2	.00	.9669	.934	.252	.07	.7856	.884	.171	.52	.4727	.841	.163	1.12	.2897
Civil	1.969	.74	.84	.3598	.918	.245	.12	.7280	1.160	.162	.84	.3594	1.179	.155	1.12	.2889
Computer	.217	1.138	1.80	.1800	.397	.258	12.84	.0003	.497	.159	19.48	<.0001	.838	.141	1.57	.2101
Electrical	.932	.655	.01	.9140	.605	.201	6.22	.0126	.803	.13	2.84	.0921	.765	.124	4.64	.0312
Industrial	.620	1.138	.18	.6745	.556	.3	3.84	.0501	.688	.186	4.06	.0439	.778	.174	2.07	.1503
Mechanical																
College GPA																
< 2.50	6.996	.821	5.61	.0178	6.388	.292	40.37	<.0001	3.659	.228	32.49	<.0001	2.079	.224	10.71	.0011
2.50-2.99	3.396	.668	3.35	.0671	3.946	.192	50.91	<.0001	3.134	.127	80.39	<.0001	1.884	.12	27.69	<.0001
3.00-3.49	1.642	.663	.56	.4541	1.920	.177	13.59	.0002	2.345	.102	69.44	<.0001	1.521	.094	20.01	<.0001
3.50-4.00																
SES	.651	.132	10.6	.0011	.798	.034	44.79	<.0001	.889	.021	33.22	<.0001	.955	.019	5.87	.0154
Design																
0 months	>1000	444.3	.00	.9768	3.184	.327	12.54	.0004	3.027	.181	37.42	<.0001	2.023	.16	19.35	<.0001
1-4 months	>1000	444.3	.00	.9784	1.654	.348	2.09	.1481	1.585	.193	5.72	.0168	1.471	.169	5.20	.0227
5-8 months	>1000	444.3	.00	.9770	1.179	.437	.14	.7067	1.456	.235	2.56	.1097	1.593	.205	5.17	.0230
9-12 months	1.231	669.8	.00	.9998	.798	.537	.18	.6733	1.165	.266	.33	.5672	1.302	.231	1.31	.2531
> 12 months																
Urbanization																
City: Large	.266	.626	4.48	.0343	.874	.257	.28	.5993	1.310	.186	2.11	.1461	.829	.166	1.28	.2582
City: Midsize	.168	.767	5.39	.0202	.581	.28	3.76	.0525	1.012	.194	.00	.9492	.671	.174	5.28	.0216
City: Small	.252	.719	3.68	.0552	.803	.272	.65	.4193	1.463	.192	3.91	.0480	.906	.173	.33	.5676
Suburb: Large	<0.001	724.4	.00	.9847	.460	.599	1.68	.1949	.778	.348	.52	.4713	.661	.305	1.84	.1744
Suburb: Mid	<0.001	479.6	.00	.9783	1.537	.366	1.38	.2398	2.336	.257	10.94	.0009	1.234	.239	.77	.3787
Town: Fringe	<0.001	593.9	.00	.9820	1.024	.437	.00	.9568	1.936	.295	5.01	.0251	.949	.28	.04	.8506
Town: Distant	<0.001	1419.2	.00	.9928	3.854	.813	2.76	.0969	4.479	.663	5.11	.0238	2.154	.655	1.37	.2412
Rural: Fringe																

Parameter Estimates for Identify Critical Variables, Information, and/or Relationship Involved in a Problem

	Odds Est.	Std. Error	χ^2	p-value
Intercept				
α_1	-1.026	.197	27.00	<.0001
α_2	1.020	.197	26.69	<.0001
α_3	3.545	.211	283.05	<.0001
α_4	7.301	.536	185.35	<.0001
Co-op				
0 months	.839	.089	3.83	.0502
1-4 months	.856	.103	2.26	.1324
5-8 months	.840	.104	2.80	.0940
9-12 months	.858	.108	1.99	.1585
> 12 months				
Major				
Other	1.043	.138	.10	.7575
Aerospace	1.036	.125	.08	.7755
Chemical	1.189	.109	2.50	.1136
Civil	1.066	.098	.42	.5153
Computer	1.574	.1	20.63	<.0001
Electrical	1.262	.084	7.73	.0054
Industrial	1.365	.12	6.71	.0096
Mechanical				
College GPA				
< 2.50	.323	.131	74.48	<.0001
2.50-2.99	.486	.079	83.59	<.0001
3.00-3.49	.585	.067	63.65	<.0001
3.50-4.00				
SES	1.126	.013	80.00	<.0001
Design				
0 months	.615	.122	15.85	<.0001
1-4 months	.880	.13	.96	.3275
5-8 months	.741	.156	3.69	.0546
9-12 months	1.079	.179	.18	.6724
> 12 months				
Urbanization				
City: Large	.993	.112	.00	.9519
City: Midsize	1.204	.119	2.43	.1188
City: Small	1.008	.116	.00	.9481
Suburb: Large	1.331	.226	1.60	.2054
Suburb: Mid	.701	.153	5.40	.0202
Town: Fringe	.819	.18	1.22	.2690
Town: Distant	.596	.321	2.60	.1068
Rural: Fringe				

α_1 is the intercept for the logit model of $\left(\frac{P(High\ Ability)}{P(>Adequate\ Ability+Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_2 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>\ Adequate\ Ability)}{P(Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_3 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability+Adequate\ Ability)}{P(Some\ Ability+No\ Ability)}\right)$

α_4 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability+Adequate\ Ability+Some\ Ability)}{P(No\ Ability)}\right)$

Parameter Estimates for Know when to use a Formula, Algorithm, or Other Rule

	Odds Est.	Std. Error	χ^2	p-value
Intercept				
α_1	-.934	.195	22.89	<.0001
α_2	.943	.195	23.31	<.0001
α_3	3.112	.203	236.26	<.0001
α_4	6.262	.33	359.88	<.0001
Co-op				
0 months	1.055	.088	.37	.5452
1-4 months	.985	.102	.02	.8795
5-8 months	.933	.103	.46	.4989
9-12 months	.938	.107	.36	.5487
> 12 months				
Major				
Other	1.346	.137	4.74	.0294
Aerospace	1.366	.124	6.35	.0118
Chemical	1.202	.108	2.90	.0884
Civil	1.240	.098	4.87	.0274
Computer	1.714	.099	29.69	<.0001
Electrical	1.544	.083	27.46	<.0001
Industrial	1.181	.119	1.97	.1607
Mechanical				
College GPA				
< 2.50	.299	.13	86.52	<.0001
2.50-2.99	.374	.079	155.62	<.0001
3.00-3.49	.528	.067	91.58	<.0001
3.50-4.00				
SES	1.059	.013	19.23	<.0001
Design				
0 months	.646	.121	13.16	.0003
1-4 months	.964	.129	.08	.7775
5-8 months	.966	.155	.05	.8237
9-12 months	1.132	.177	.49	.4824
> 12 months				
Urbanization				
City: Large	.842	.111	2.39	.1217
City: Midsize	1.101	.118	.67	.4144
City: Small	.881	.115	1.22	.2693
Suburb: Large	1.076	.223	.11	.7428
Suburb: Mid	.757	.151	3.40	.0651
Town: Fringe	.751	.178	2.58	.1083
Town: Distant	.534	.318	3.90	.0482
Rural: Fringe				

α_1 is the intercept for the logit model of $\left(\frac{P(High\ Ability)}{P(>Adequate\ Ability+Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_2 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>\ Adequate\ Ability)}{P(Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_3 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability\ +Adequate\ Ability)}{P(Some\ Ability+No\ Ability)}\right)$

α_4 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability\ +Adequate\ Ability+Some\ Ability)}{P(No\ Ability)}\right)$

Parameter Estimates for Recognize and Understand Organizing Principles (laws, methods, rules, etc.) that Underlie Problems

	Odds Est.	Std. Error	χ^2	p-value
Intercept				
α_1	-.910	.196	21.48	<.0001
α_2	1.128	.197	32.86	<.0001
α_3	3.365	.205	270.09	<.0001
α_4	6.879	.387	316.76	<.0001
Co-op				
0 months	.989	.089	.02	.8967
1-4 months	.995	.103	.00	.9584
5-8 months	.888	.104	1.33	.2492
9-12 months	.927	.108	.50	.4810
> 12 months				
Major				
Other	1.423	.137	6.60	.0102
Aerospace	1.218	.124	2.51	.1129
Chemical	1.057	.109	.26	.6112
Civil	1.124	.098	1.42	.2341
Computer	1.625	.099	23.89	<.0001
Electrical	1.277	.083	8.64	.0033
Industrial	1.212	.119	2.61	.1063
Mechanical				
College GPA				
< 2.50	.340	.13	68.55	<.0001
2.50-2.99	.452	.079	101.27	<.0001
3.00-3.49	.560	.067	75.14	<.0001
3.50-4.00				
SES	1.075	.013	30.05	<.0001
Design				
0 months	.550	.121	24.29	<.0001
1-4 months	.841	.129	1.80	.1797
5-8 months	.793	.155	2.24	.1344
9-12 months	1.086	.178	.21	.6441
> 12 months				
Urbanization				
City: Large	.823	.112	3.04	.0810
City: Midsize	.940	.119	.27	.6036
City: Small	.777	.116	4.73	.0297
Suburb: Large	1.343	.225	1.72	.1903
Suburb: Mid	.667	.152	7.10	.0077
Town: Fringe	.758	.179	2.39	.1219
Town: Distant	.334	.321	11.68	.0006
Rural: Fringe				

α_1 is the intercept for the logit model of $\left(\frac{P(High\ Ability)}{P(>Adequate\ Ability+Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_2 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>\ Adequate\ Ability)}{P(Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_3 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability\ +Adequate\ Ability)}{P(Some\ Ability+No\ Ability)}\right)$

α_4 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability\ +Adequate\ Ability+Some\ Ability)}{P(No\ Ability)}\right)$

Parameter Estimates for Draw Conclusions from Evidence or Premises

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-28.249	1014.1	.00	.9778	-2.117	.665	10.15	.0014	-.838	.313	7.16	.0074	.462	.257	3.24	.0718
Co-op																
0 months	>1000	602.6	.00	.9838	1.542	.287	2.27	.1320	1.509	.139	8.80	.0030	1.262	.118	3.88	.0489
1-4 months	.840	858.1	.00	.9998	1.521	.33	1.62	.2037	1.398	.159	4.42	.0356	1.155	.136	1.13	.2881
5-8 months	>1000	602.6	.00	.9819	1.126	.362	.11	.7434	1.512	.162	6.52	.0107	1.262	.138	2.84	.0917
9-12 months	1.247	934.8	.00	.9998	1.282	.368	.45	.5001	1.283	.172	2.12	.1457	1.349	.142	4.46	.0348
> 12 months																
Major																
Other	2.771	1.143	.80	.3724	.623	.449	1.11	.2913	.738	.214	2.02	.1550	.795	.19	1.45	.2278
Aerospace	<0.001	1515.2	.00	.9926	1.250	.34	.43	.5116	.711	.194	3.07	.0798	.746	.169	3.00	.0830
Chemical	<0.001	1196.5	.00	.9906	1.024	.321	.01	.9411	.710	.176	3.79	.0516	.891	.152	.58	.4453
Civil	<0.001	657.6	.00	.9839	.334	.41	7.13	.0076	.818	.155	1.70	.1922	.866	.138	1.09	.2964
Computer	.629	1.301	.13	.7216	.553	.308	3.69	.0548	.478	.156	22.35	<.0001	.620	.133	12.85	.0003
Electrical	<0.001	557.2	.00	.9806	.928	.246	.09	.7624	.692	.131	7.88	.0050	.759	.117	5.56	.0184
Industrial	<0.001	898.4	.00	.9876	.334	.464	5.60	.0179	.472	.19	15.58	<.0001	.686	.158	5.68	.0172
Mechanical																
College GPA																
< 2.50	14.014	1.342	3.87	.0492	3.295	.35	11.62	.0007	3.151	.205	31.34	<.0001	1.453	.195	3.68	.0552
2.50-2.99	1.628	1.475	.11	.7412	2.511	.232	15.80	<.0001	2.419	.124	50.96	<.0001	1.525	.108	15.34	<.0001
3.00-3.49	1.180	1.461	.01	.9096	1.386	.222	2.18	.1401	2.141	.105	52.31	<.0001	1.530	.088	23.42	<.0001
3.50-4.00																
SES	.838	.242	.53	.4658	.788	.043	30.94	<.0001	.891	.021	31.43	<.0001	.933	.018	15.12	.0001
Design																
0 months	>1000	815.6	.00	.9872	3.391	.478	6.52	.0106	2.628	.2	23.38	<.0001	1.440	.152	5.74	.0166
1-4 months	.809	997.6	.00	.9998	1.734	.505	1.19	.2758	1.452	.212	3.09	.0787	1.121	.161	.50	.4804
5-8 months	.960	1165.5	.00	1.0000	.916	.656	.02	.8940	1.771	.246	5.39	.0203	1.006	.197	.00	.9769
9-12 months	.471	1733.1	.00	.9997	.775	.754	.11	.7355	.950	.288	.03	.8582	.794	.219	1.12	.2909
> 12 months																
Urbanization																
City: Large	.525	1.313	.24	.6234	.975	.314	.01	.9344	1.213	.175	1.22	.2700	.944	.151	.14	.7035
City: Midsize	<0.001	496.1	.00	.9788	.974	.335	.01	.9367	1.044	.187	.05	.8161	.974	.159	.03	.8673
City: Small	.906	1.369	.01	.9427	.948	.341	.02	.8749	1.406	.184	3.43	.0639	1.307	.158	2.88	.0898
Suburb: Large	<0.001	1828.7	.00	.9948	.308	1.069	1.22	.2702	1.116	.351	.10	.7549	1.146	.297	.21	.6458
Suburb: Mid	<0.001	1006.	.00	.9899	1.332	.465	.38	.5366	1.561	.242	3.38	.0658	1.317	.209	1.74	.1869
Town: Fringe	<0.001	1486.7	.00	.9926	1.037	.615	.00	.9531	1.891	.297	4.59	.0322	1.730	.261	4.40	.0359
Town: Distant	<0.001	5472.7	.00	.9979	2.717	.878	1.30	.2550	2.117	.545	1.89	.1687	1.686	.493	1.12	.2896
Rural: Fringe																

Parameter Estimates for Develop a Course of Action Based on My Understanding of a Whole System

	Odds Est.	Std. Error	χ^2	p-value
Intercept				
α_1	-.764	.198	14.88	.0001
α_2	1.375	.199	47.83	<.0001
α_3	3.712	.211	310.20	<.0001
α_4	6.645	.373	318.20	<.0001
Co-op				
0 months	.779	.09	7.72	.0055
1-4 months	.804	.104	4.42	.0355
5-8 months	.808	.105	4.18	.0409
9-12 months	.906	.109	.83	.3615
> 12 months				
Major				
Other	1.110	.138	.57	.4502
Aerospace	1.208	.125	2.27	.1319
Chemical	.952	.109	.20	.6560
Civil	1.013	.099	.02	.8983
Computer	1.474	.1	15.04	.0001
Electrical	1.146	.084	2.65	.1033
Industrial	1.541	.121	12.85	.0003
Mechanical				
College GPA				
< 2.50	.520	.13	25.24	<.0001
2.50-2.99	.606	.079	40.19	<.0001
3.00-3.49	.692	.067	30.12	<.0001
3.50-4.00				
SES	1.109	.013	60.62	<.0001
Design				
0 months	.462	.123	39.45	<.0001
1-4 months	.689	.131	8.09	.0045
5-8 months	.629	.157	8.70	.0032
9-12 months	.982	.18	.01	.9182
> 12 months				
Urbanization				
City: Large	.959	.112	.14	.7103
City: Midsize	1.091	.119	.53	.4666
City: Small	.923	.117	.47	.4940
Suburb: Large	1.447	.227	2.66	.1032
Suburb: Mid	.824	.153	1.60	.2052
Town: Fringe	.938	.181	.13	.7232
Town: Distant	.700	.321	1.23	.2672
Rural: Fringe				

α_1 is the intercept for the logit model of $\left(\frac{P(High\ Ability)}{P(>Adequate\ Ability+Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_2 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>\ Adequate\ Ability)}{P(Adequate\ Ability+Some\ Ability+No\ Ability)}\right)$

α_3 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability\ +Adequate\ Ability)}{P(Some\ Ability+No\ Ability)}\right)$

α_4 is the intercept for the logit model of $\left(\frac{P(High\ Ability+>Adequate\ Ability\ +Adequate\ Ability+Some\ Ability)}{P(No\ Ability)}\right)$

Parameter Estimates for Ensure that a Process or Product Meets a Variety of Technical and Practical Criteria

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-16.846	382.8	.00	.9649	-2.372	.577	16.89	<.0001	-.596	.306	3.78	.0518	.102	.266	.15	.7007
Co-op																
0 months	1.399	.672	.25	.6173	1.709	.264	4.11	.0425	1.715	.138	15.22	<.0001	1.293	.122	4.47	.0345
1-4 months	.327	1.171	.91	.3393	1.660	.302	2.82	.0930	1.596	.16	8.51	.0035	1.293	.14	3.34	.0676
5-8 months	1.834	.755	.65	.4218	1.197	.322	.31	.5762	1.477	.162	5.77	.0163	1.312	.141	3.71	.0541
9-12 months	.440	1.174	.49	.4848	.821	.373	.28	.5964	1.572	.168	7.23	.0072	1.358	.147	4.36	.0368
> 12 months																
Major																
Other	3.789	.754	3.13	.0771	1.076	.418	.03	.8603	.774	.218	1.37	.2411	.882	.197	.41	.5221
Aerospace	2.865	.805	1.71	.1910	1.051	.398	.02	.8999	.791	.197	1.41	.2350	.929	.174	.18	.6705
Chemical	3.946	.704	3.80	.0511	1.877	.308	4.19	.0406	1.061	.176	.11	.7348	1.006	.161	.00	.9725
Civil	.508	1.134	.36	.5500	1.421	.302	1.35	.2448	1.117	.156	.50	.4783	.990	.145	.00	.9440
Computer	.813	.89	.05	.8156	.909	.313	.09	.7614	.682	.157	5.91	.0151	.878	.14	.87	.3519
Electrical	.750	.734	.15	.6950	1.389	.248	1.76	.1845	.730	.13	5.89	.0152	.740	.118	6.49	.0109
Industrial	.690	1.14	.11	.7448	.394	.468	3.95	.0469	.564	.188	9.32	.0023	.741	.161	3.48	.0623
Mechanical																
College GPA																
< 2.50	10.274	.732	10.1	.0015	3.689	.336	15.10	.0001	2.638	.22	19.42	<.0001	1.836	.208	8.56	.0034
2.50-2.99	2.657	.637	2.35	.1249	1.698	.234	5.12	.0236	2.068	.124	34.42	<.0001	1.465	.112	11.59	.0007
3.00-3.49	2.070	.574	1.61	.2047	1.440	.202	3.25	.0712	1.796	.104	31.84	<.0001	1.339	.091	10.25	.0014
3.50-4.00																
SES	.843	.102	2.82	.0934	.902	.039	6.88	.0087	.881	.021	37.25	<.0001	.966	.018	3.43	.0641
Design																
0 months	>1000	382.8	.00	.9730	2.615	.369	6.80	.0091	2.724	.187	28.66	<.0001	1.964	.154	19.24	<.0001
1-4 months	>1000	382.8	.00	.9745	.973	.414	.00	.9469	1.775	.199	8.29	.0040	1.603	.164	8.31	.0039
5-8 months	>1000	382.8	.00	.9735	.621	.583	.67	.4145	1.953	.238	7.93	.0049	1.533	.201	4.52	.0335
9-12 months	1.609	514.4	.00	.9993	.694	.629	.34	.5608	1.258	.269	.73	.3937	1.089	.223	.15	.7015
> 12 months																
Urbanization																
City: Large	1.546	.798	.30	.5854	.782	.302	.66	.4163	1.136	.179	.51	.4755	.873	.163	.70	.4034
City: Midsize	1.640	.841	.35	.5561	.680	.332	1.35	.2455	.926	.191	.16	.6884	.996	.171	.00	.9823
City: Small	1.162	.865	.03	.8623	.949	.314	.03	.8675	1.026	.186	.02	.8911	1.046	.168	.07	.7885
Suburb: Large	<0.001	686.8	.00	.9858	.166	1.061	2.87	.0903	.544	.362	2.82	.0931	.852	.294	.29	.5872
Suburb: Mid	<0.001	421.2	.00	.9773	1.568	.393	1.31	.2527	.943	.249	.06	.8146	1.126	.218	.30	.5846
Town: Fringe	<0.001	431.2	.00	.9781	.248	.781	3.19	.0742	1.050	.283	.03	.8639	.979	.255	.01	.9327
Town: Distant	17.144	1.371	4.29	.0382	4.400	.739	4.02	.0448	2.005	.56	1.54	.2144	1.346	.541	.30	.5828
Rural: Fringe																

Parameter Estimates for Compare and Judge Alternative Outcomes

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-15.453	633.6	.00	.9805	-2.471	.646	14.62	.0001	-.641	.315	4.14	.0419	.302	.258	1.37	.2419
Co-op																
0 months	.477	1.228	.36	.5463	1.367	.27	1.34	.2478	1.626	.139	12.32	.0004	1.331	.118	5.84	.0157
1-4 months	<0.001	385.7	.00	.9743	1.622	.305	2.51	.1134	1.340	.161	3.30	.0691	1.271	.135	3.14	.0763
5-8 months	1.759	1.311	.19	.6669	.942	.353	.03	.8648	1.485	.164	5.83	.0158	1.472	.138	7.89	.0050
9-12 months	1.613	1.491	.10	.7487	.566	.435	1.71	.1908	1.450	.172	4.65	.0311	1.610	.143	11.12	.0009
> 12 months																
Major																
Other	7.899	.996	4.31	.0379	.549	.514	1.36	.2441	.724	.221	2.14	.1438	.921	.189	.19	.6631
Aerospace	<0.001	1420.2	.00	.9924	.806	.428	.26	.6132	.685	.199	3.61	.0574	.875	.166	.64	.4231
Chemical	1.295	1.286	.04	.8407	2.158	.313	6.05	.0139	.974	.177	.02	.8823	1.022	.156	.02	.8886
Civil	<0.001	683.	.00	.9842	.929	.333	.05	.8258	.846	.158	1.12	.2898	.971	.137	.05	.8316
Computer	<0.001	828.4	.00	.9868	.711	.328	1.08	.2981	.633	.154	8.89	.0029	.662	.134	9.42	.0021
Electrical	.566	1.27	.20	.6537	1.395	.253	1.73	.1888	.825	.131	2.15	.1424	.802	.117	3.58	.0585
Industrial	<0.001	933.8	.00	.9882	.193	.622	7.00	.0082	.411	.193	21.20	<.0001	.629	.153	9.17	.0025
Mechanical																
College GPA																
< 2.50	11.218	1.113	4.72	.0299	5.167	.346	22.54	<.0001	2.641	.215	20.48	<.0001	1.691	.2	6.88	.0087
2.50-2.99	2.260	1.073	.58	.4472	2.510	.249	13.68	.0002	1.885	.123	26.56	<.0001	1.340	.108	7.42	.0065
3.00-3.49	.487	1.249	.33	.5644	1.806	.228	6.74	.0094	1.604	.105	20.17	<.0001	1.396	.088	14.24	.0002
3.50-4.00																
SES	.692	.21	3.06	.0801	.830	.042	19.48	<.0001	.863	.021	49.72	<.0001	.939	.018	12.54	.0004
Design																
0 months	>1000	633.6	.00	.9834	3.166	.44	6.88	.0087	3.228	.199	34.78	<.0001	1.941	.149	19.90	<.0001
1-4 months	1.111	725.9	.00	.9999	1.060	.492	.01	.9061	2.036	.211	11.35	.0008	1.618	.158	9.22	.0024
5-8 months	1.217	829.9	.00	.9998	1.546	.554	.62	.4313	1.761	.251	5.07	.0243	1.469	.193	3.99	.0459
9-12 months	.411	1021.9	.00	.9993	1.847	.609	1.02	.3134	1.404	.292	1.35	.2448	1.354	.219	1.91	.1668
> 12 months																
Urbanization																
City: Large	.304	1.469	.66	.4171	1.022	.333	.00	.9472	1.097	.182	.26	.6105	.845	.158	1.15	.2844
City: Midsize	1.178	1.31	.02	.9006	.932	.354	.04	.8417	.929	.192	.15	.6995	.763	.166	2.68	.1014
City: Small	1.643	1.26	.16	.6936	.805	.356	.37	.5422	.943	.189	.10	.7560	.907	.162	.36	.5490
Suburb: Large	<0.001	1299.	.00	.9930	.228	1.074	1.90	.1684	.859	.348	.19	.6624	.720	.296	1.24	.2660
Suburb: Mid	<0.001	855.2	.00	.9881	1.071	.476	.02	.8849	1.117	.248	.20	.6546	1.020	.211	.01	.9240
Town: Fringe	<0.001	1310.8	.00	.9917	.584	.686	.62	.4328	1.444	.293	1.57	.2095	1.116	.259	.18	.6714
Town: Distant	<0.001	4790.2	.00	.9977	1.666	.865	.35	.5549	1.271	.504	.23	.6338	.842	.457	.14	.7067
Rural: Fringe																

Parameter Estimates for Develop Learning Strategies that I can apply in my Professional Life

	$\left(\frac{P(No\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Some\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(Adequate\ Ability)}{P(High\ Ability)}\right)$				$\left(\frac{P(>\ Adequate\ Ability)}{P(High\ Ability)}\right)$			
	Odds Est.	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**	**Odds Est.**	**Std. Error**	χ^2	**p-value**
Intercept	-14.551	392.2	.00	.9704	-2.093	.596	12.32	.0004	-.966	.31	9.72	.0018	.234	.252	.87	.3522
Co-op																
0 months	1.184	.702	.06	.8098	1.557	.274	2.62	.1054	1.458	.137	7.53	.0061	1.183	.118	2.06	.1515
1-4 months	2.189	.719	1.19	.2757	1.368	.317	.98	.3225	1.225	.159	1.64	.2001	1.078	.134	.31	.5767
5-8 months	.334	1.17	.88	.3483	.867	.356	.16	.6895	1.318	.161	2.94	.0863	1.229	.136	2.31	.1288
9-12 months	1.012	.936	.00	.9901	.855	.37	.18	.6724	1.187	.168	1.04	.3081	1.172	.139	1.29	.2555
> 12 months																
Major																
Other	1.400	.703	.23	.6324	.617	.474	1.04	.3076	.892	.219	.27	.6009	1.045	.191	.05	.8200
Aerospace	.674	.825	.23	.6327	.832	.39	.22	.6373	.820	.197	1.01	.3137	1.008	.167	.00	.9619
Chemical	.164	1.068	2.86	.0911	1.130	.3	.17	.6843	.629	.171	7.32	.0068	.737	.146	4.41	.0358
Civil	.434	.677	1.52	.2179	.534	.353	3.16	.0754	.802	.152	2.13	.1443	.843	.134	1.64	.2003
Computer	<0.001	287.8	.00	.9630	.831	.289	.41	.5221	.634	.154	8.70	.0032	.754	.133	4.47	.0344
Electrical	.276	.617	4.36	.0368	.904	.245	.17	.6794	.701	.128	7.62	.0058	.719	.114	8.41	.0037
Industrial	<0.001	412.9	.00	.9734	.313	.46	6.38	.0116	.451	.186	18.33	<.0001	.597	.154	11.27	.0008
Mechanical																
College GPA																
< 2.50	2.423	.718	1.52	.2177	2.956	.364	8.89	.0029	2.787	.203	25.39	<.0001	1.467	.19	4.06	.0438
2.50-2.99	1.310	.526	.26	.6075	2.228	.24	11.10	.0009	2.202	.122	41.67	<.0001	1.390	.106	9.66	.0019
3.00-3.49	.389	.613	2.37	.1235	1.737	.215	6.62	.0101	1.802	.104	32.11	<.0001	1.255	.086	6.94	.0084
3.50-4.00																
SES	.726	.111	8.30	.0040	.877	.04	10.65	.0011	.873	.02	44.27	<.0001	.918	.017	24.03	<.0001
Design																
0 months	>1000	392.2	.00	.9728	2.769	.409	6.21	.0127	3.231	.195	36.03	<.0001	2.072	.149	24.06	<.0001
1-4 months	>1000	392.2	.00	.9752	1.223	.446	.20	.6513	1.773	.207	7.63	.0057	1.483	.157	6.28	.0122
5-8 months	>1000	392.2	.00	.9741	.865	.577	.06	.8023	1.726	.245	4.96	.0259	1.388	.191	2.94	.0862
9-12 months	1.296	564.2	.00	.9996	1.252	.611	.14	.7129	1.365	.285	1.19	.2754	1.333	.217	1.75	.1864
> 12 months																
Urbanization																
City: Large	.701	.846	.18	.6739	.701	.279	1.62	.2028	1.377	.176	3.29	.0698	1.000	.15	.00	.9995
City: Midsize	.767	.894	.09	.7671	.594	.31	2.83	.0926	1.120	.188	.37	.5443	1.001	.157	.00	.9945
City: Small	1.328	.837	.11	.7348	.650	.303	2.03	.1546	1.333	.184	2.45	.1179	1.181	.155	1.16	.2822
Suburb: Large	1.663	1.283	.16	.6919	.182	1.052	2.62	.1058	.925	.35	.05	.8233	.920	.285	.09	.7703
Suburb: Mid	1.409	1.282	.07	.7892	1.009	.427	.00	.9839	1.907	.245	6.96	.0083	1.623	.209	5.38	.0203
Town: Fringe	1.893	1.286	.25	.6199	.422	.654	1.75	.1864	1.740	.281	3.88	.0490	1.323	.246	1.29	.2554
Town: Distant	8.597	1.358	2.51	.1130	.812	1.106	.04	.8509	2.712	.509	3.85	.0497	1.474	.478	.66	.4175
Rural: Fringe																

APPENDIX F: STUDENTS' CODED RESPONSES TO THINK-ALOUD PROBLEMS

Participant	Well-Structured	Ill-Structured
Cooperative Education Students		
Andrew	• Research the problem • Apply discipline-specific engineering knowledge • Identify critical variables, information and or relationship involved in a problem • Know when to use a formula	• Apply discipline-specific engineering knowledge • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem
Bob	• Research the problem • Apply discipline-specific engineering knowledge • Break down complex problems to simpler ones • Define key engineering problems • Develop a course of action based on my understanding of a whole system • Identify critical variables, information and or relationship involved in a problem	• Apply systematic design procedure to open-ended problem • Break down complex problems to simpler ones • Define key engineering problems • Develop a course of action based on my understanding of a whole system • Ensure that a process or product meets a variety of technical and practical criteria • Identify critical variables, information and or relationship involved in a problem
Matt	• Research the problem • Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem • Know when to use a formula	• Apply discipline-specific engineering knowledge • Compare and judge alternative outcomes • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem

Participant	Well-Structured	Ill-Structured
Cooperative Education Students		
Spencer	• Research the problem • Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Break down complex problems to simpler ones • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem	• Research the problem • Apply systematic design procedure to open-ended problem • Break down complex problems to simpler ones • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem • Understand essential aspects of the engineering design process
Internship Students		
Carl	• Research the problem • Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Break down complex problems to simpler ones • Define key engineering problems • Ensure that a process or product meets a variety of technical and practical criteria • Identify critical variables, information and or relationship involved in a problem • Know when to use a formula	• Apply discipline-specific engineering knowledge • Compare and judge alternative outcomes • Define key engineering problems • Ensure that a process or product meets a variety of technical and practical criteria • Formulate a range of solutions to an engineering problem • Identify critical variables, information and or relationship involved in a problem
Christina	• Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Know when to use a formula	• Break down complex problems to simpler ones • Identify critical variables, information and or relationship involved in a problem

Participant	Well-Structured	Ill-Structured
Internship Students (con't)		
David	• Research the problem (use textbook) • Apply discipline-specific engineering knowledge • Break down complex problems to simpler ones • Define key engineering problems • Develop a course of action • Identify critical variables, information and or relationship involved in a problem	• Apply discipline-specific engineering knowledge • Break down complex problems to simpler ones • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem
Jill	• Research the problem • Work with others (simulate with matlab or then ask a professor for help) • Apply discipline-specific engineering knowledge • Identify critical variables, information and or relationship involved in a problem • Know when to use a formula	• Break down complex problems to simpler ones • Ensure that a process or product meets a variety of technical and practical criteria • Identify critical variables, information and or relationship involved in a problem
Jim	• Research the problem • Apply discipline-specific engineering knowledge • Break down complex problems to simpler ones • Identify critical variables, information and or relationship involved in a problem	• Research the problem • Break down complex problems to simpler ones • Develop a course of action
Steven	• Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Break down complex problems to simpler ones • Identify critical variables, information and or relationship involved in a problem	• Define key engineering problems • Ensure that a process or product meets a variety of technical and practical criteria • Identify critical variables, information and or relationship involved in a problem

Participant	Well-Structured	Ill-Structured
Internship Students (con't)		
Vanessa	• Research the problem (most recent textbook) • Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Break down complex problems to simpler ones • Ensure that a process or product • Identify critical variables, information and or relationship involved in a problem • Know when to use a formula	• Apply discipline-specific engineering knowledge • Break down complex problems to simpler ones • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem • Understand essential aspects of the engineering design process
William	• Research the problem • Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Break down complex problems to simpler ones • Compare and judge alternative outcomes • Define key engineering problems • Develop a course of action • Identify critical variables, information and or relationship involved in a problem • Know when to use a formula	• Apply discipline-specific engineering knowledge • Apply systematic design procedure to open-ended problem • Break down complex problems to simpler ones • Compare and judge alternative outcomes • Define key engineering problems • Develop a course of action • Identify critical variables, information and or relationship involved in a problem

Participant	Well-Structured	Ill-Structured
Neither Co-op nor Internship		
Brian	• Research the problem • Apply discipline-specific engineering knowledge • Break down complex problems to simpler ones • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem • Know when to use a formula	• Research the problem • Apply discipline-specific engineering knowledge • Break down complex problems to simpler ones • Define key engineering problems • Ensure that a process or product meets a variety of technical and practical criteria
Issac	• Research the problems • Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Define key engineering problems	• Break down complex problems to simpler ones • Compare and judge alternative outcomes • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem
Kevin	• Research the problem • Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Break down complex problems to simpler ones • Identify critical variables, information and or relationship involved in a problem	• Apply discipline-specific engineering knowledge • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem
Keith	• Research the problem • Apply discipline-specific engineering knowledge • Break down complex problems to simpler ones • Develop a course of action • Identify critical variables, information and or relationship involved in a problem	• Apply discipline-specific engineering knowledge • Compare and judge alternative outcomes • Define key engineering problems • Identify critical variables, information and or relationship involved in a problem

Participant	Well-Structured	Ill-Structured
Neither Co-op nor Internship(con't)		
Larry	• Apply discipline-specific engineering knowledge • Apply fundamentals to problems that I haven't seen before • Break down complex problems to simpler ones • Define key engineering problems • Ensure that a process or product meets a variety of technical and practical criteria • Identify critical variables, information and or relationship involved in a problem • Know when to use a formula	• Apply discipline-specific engineering knowledge • Apply systematic design procedure to open-ended problem • Define key engineering problems • Ensure that a process or product meets a variety of technical and practical criteria • Identify critical variables, information and or relationship involved in a problem

Alexander Yin's Vita

Education

The Pennsylvania State University 2005 – 2009
Ph.D., Higher Education
Master's in Applied Statistics
Minor in Educational Psychology
Graduate Certificate in Institutional Research

Georgia Institute of Technology 1997-2001
M.S., Electrical and Computer Engineering
B.S., Electrical Engineering (with Highest Honors)

Publications (Refereed)

Lattuca, L. R., Terenzini, P. T., Harper, B.J., & Yin, A. C. (2009). Academic environments in detail: Holland's theory at the subdiscipline level. *Research in Higher Education.*

Volkwein, J. F. & Yin, A.C. (in revision). Examining alternative explanations for student outcomes. *Research in Higher Education.*

Grants

Developing Engineering Problem Solving Skills through Cooperative Education. Yin, A. C. (Principal Investigator). $3,000 over 12 months from American Society for Engineering Education, Cooperative Education Division, awarded September 2009.

National and Regional Presentations

Okudan, G., Yin, A.C., Gupta, S., Lattuca, L. R., Terenzini, P. T., (2009, June 14-17). Validation of a design pedagogy framework using qualitative analysis. Paper presented at the annual meeting of the American Society for Engineering Education, Austin, TX.

Masters, C. B., Yin, A. C., Okudan, G.,Schuurman, M., (2009, June 14-17). Assessing growth of engineering students using E-portfolios: A MDL-based approach. Paper presented at the annual meeting of the American Society for Engineering Education, Austin, TX.

Yin, A. C. (2009, May 30-June 3). Understanding and developing hierarchical linear models. Workshop presented at the annual meeting of the Association of Institutional Research, Atlanta, GA

Pecht, J. & Yin, A. C. (2008, May 24-28). Student drop-outs: In relation to student goals. Paper presented at the annual meeting of the Association of Institutional Research, Seattle, WA.

Yin, A. C. (2008, March 24-28). Developing problem-solving skills through cooperative education: Findings from a national study of engineering education. Paper presented at the AERA annual meeting, New York, NY.

Lattuca, L. R., Terenzini, P. T., Harper, B. J., & Yin, A. C. (2008, March 24-28). Academic environments in detail: Holland's Theory at the subdiscipline level. Paper presented at the AERA annual meeting, New York, NY.

Honors

Graduate Student Recognition Award, College of Education, Penn State 2009
Graduate Fellowship, Association for Institutional Research 2008
AIR/ IES-NCES/ NSF Data Policy Institute Fellowship, Association for Institutional Research 2007
Outstanding Teaching Assistant, Electrical Engineering Georgia Tech 2001