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Approved by Major Professor(s): Johannes Strobel

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ENGINEERING STUDENTS' EXPERIENCES AND PERCEPTIONS OF WORKPLACE PROBLEM SOLVING

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ABSTRACT

Pan, Rui. Ph.D., Purdue University, May 2014. Engineering Students' Experiences and Perceptions of Workplace Problem Solving. Major Professor: Johannes Strobel.

In this study, I interviewed 22 engineering Co-Op students about their workplace problem solving experiences and reflections and explored: 1) Of Co-Op students who experienced workplace problem solving, what are the different ways in which students experience workplace problem solving? 2) How do students perceive a) the differences between workplace problem solving and classroom problem solving and b) in what areas are they prepared by their college education to solve workplace problems? To answer my first research question, I analyzed data through the lens of phenomenography and I conducted thematic analysis to answer my second research question. The analysis results show that students experienced workplace problem solving in six different ways, which are: 1) workplace problem solving is following orders and executing the plan; 2) workplace problem solving is implementing customers' ideas and satisfying customer needs; 3) workplace problem solving is using mathematical and technical knowledge and skills to solve technical problems; 4) workplace problem solving is consulting different people and collecting their inputs; 5) workplace problem solving is using multiple resources to draw conclusions and make decisions; 6) workplace problem solving is exploration and freedom. Further analysis of the relationship between six ways of

experiencing workplace problem solving resulted in a two-dimensional outcome space, based on the extent to which students were involved in problem definition and formulation and solution generation and selection. In this study, students identified and discussed the differences between workplace problem solving and classroom problem solving from six major aspects: 1) Workplace problems are different from classroom problems in that they have less given information and different types of constraints. 2) Workplace problems are different from classroom problems in that they are more practical and the solutions are more realistic. 3) Workplace problem solving is different from classroom problem solving in that it requires different knowledge and skills. 4) Workplace problem solving is different from classroom problem solving in that the professional engineering environment is different from the classroom setting. 5) Workplace problem solving is different from classroom problem solving in that workplace problem solving has less guidance. 6) Workplace problem solving is different from classroom problem solving in that it has open-ended solutions. Students felt that their college engineering education prepared them for workplace problem solving in four major areas: knowledge of how to work and communicate with people, knowledge of the problem solving process, software and computer skills, and technical knowledge.

The results of this study have implications for engineering education and engineering practice. Specifically, the results reveal the different ways students experience workplace problem solving, which provide engineering educators and practicing engineers a better understanding of the nature of workplace engineering. In addition, the results indicate that there is still a gap between classroom engineering and workplace engineering. For engineering educators who aspire to prepare students to be future engineers, it is imperative to design problem solving experiences that can better prepare students with workplace competency.

CHAPTER 1. INTRODUCTION

1.1 Introduction

Problem solving is the central part of engineering work and engineering students are expected to be problem solvers after graduation (National Academy of Engineering, 2004). For instance, ABET (2013) specifies the "ability to identify, formulate, and solve engineering problems" (p. 3) as one important criterion for accrediting engineering programs. The Royal Academy of Engineering (2010) emphasizes: "Engineering degrees aim to provide a firm grounding in the principles of engineering science and technology, while inculcating an engineering method and approach that enable graduates to enter the world of work and tackle 'real world' problems with creative yet practical results" (p. 1). Previous research indicates that workplace problems are different from traditional textbook or classroom problems in many different aspects (Regev, Gause, and Wegmann, 2008; Weinstein, Gilchrist IV, Hebsch, and Stevens, 2002; Jonassen, Strobel, and Lee, 2006). For example, by interviewing over one hundred professional engineers, Jonassen, Strobel, and Lee (2006) found some unique attributes of workplace problems including: conflicting goals, various solution methods, different types of constraints, etc. Because of this uniqueness, practicing engineering in the real world is different from solving classroom problems in school. Yet, it is still not clear how engineering students experience and understand workplace problem solving. Since students are expected to be engineering practitioners after graduation, it is important that they understand the nature of problems that they will encounter in the workplace and the challenges they will face in the real world. Therefore, in this study, I want to explore workplace problem solving from the varied perspectives of engineering students.

1.2 Motivation

Not much research investigates how students experience and perceive engineering workplace problems. Some of the existing studies which I have found suggest that students might not have a clear picture of what engineering workplace looks like. Research indicates that there is a lack of understanding regarding both engineering practices and the engineer as a professional among engineering students, which leads these students to be under prepared to work in the real world (Jocuns, Stevens, Garrison, and Amos, 2008; Matusovich, Streveler, Miller, and Olds, 2009; Shuman, Delaney, Wolfe, Scalise, and Besterfield-Sacre, 1999). Dissatisfactions expressed by industry employers further confirm students' under-preparedness. For example, feedback from within the industry indicates that "graduating engineers need better preparation in solving open-ended problems, thinking 'outside the box', working in teams, and in developing strong communication skills" (Grubbs and Ostheimer, 2001, p. 1).

Because industry employers often detect students' lack of workplace problem solving skills, they encourage universities to emphasize the teaching and learning of those practical skills (Grubbs and Ostheimer, 2001; Aanstoos and Nichols, 2001). Brumm, Hanneman, and Mickelson (2005) proposed that one of the best ways to prepare students with workplace competencies is experiential education, which could be broadly defined as “a philosophy and methodology in which educators purposefully engage with learners in direct experience and focused reflection in order to increase knowledge, develop skills, and clarify values” (p. 2). In the College of Engineering at Purdue University, one type of experiential learning programs provided to engineering undergraduates is the Co-Op program. Although previous studies indicate that the Co-Op program benefits students in various ways (Garavan and Murphy, 2001), it is still not clear how students actually experience and understand workplace problem solving. Therefore, in this study, it is my desire to explore students’ experiences in workplace engineering problem solving and their perceptions of the differences between workplace problem solving and classroom problem solving as well as their preparedness to solve these problems.

1.3 Research Questions

The research questions which guided this study are as follows:

1) Of Co-Op students who participated in workplace problem solving, what are the different ways in which students experience workplace problem solving?
2) How do students perceive a) the differences between workplace problem solving and classroom problem solving b) in what areas are they prepared by their college education to solve workplace problems?

1.4 Significance of the Study

The findings of this study have potential impact on engineering education and engineering practice. The results could provide engineering educators with a better understanding of the nature of problem solving and engineering workplace.

Understanding how students experience and understand workplace problem solving could offer guidance to help engineering educators design meaningful problem solving experiences for students. Furthermore, the findings might be used to advise the design of training program for novice engineers to facilitate their transition from students to practicing engineers.

CHAPTER 2. LITERATURE REVIEW

2.1 Characteristics of Engineering Workplace Problems

Workplace problems differ from traditional textbook or classroom problems in many aspects. For instance, in classroom problem solving the specifications and scope of problems are often well-defined before they are given to students, and solutions are either known by the professor or can be found in the textbook (Regev, Gause, and Wegmann, 2008; Weinstein, Gilchrist IV, Hebsch, and Stevens, 2002). In contrast, workplace problems are ill-defined and more complex than classroom problems.

In the literature, researchers have described workplace problems as "ill-structured problems" (Jonassen, Strobel, and Lee, 2006) or "wicked problems" (Regev, Gause, and Wegmann, 2008). By interviewing more than one hundred professional engineers, Jonassen, Strobel, and Lee (2006) concluded that workplace problems are viewed as ill-structured because they have, among other things, conflicting goals, various solution methods, and different types of constraints; these authors then pointed out that solving workplace problems requires comprehensive collaboration and teamwork. Buckingham Shum, MacLean, Bellotti, and Hammond (1997, p. 274) listed some prominent features of wicked problems:

- Cannot be easily defined so that all stakeholders agree on the problem to solve.

- Have no clear stopping rules.
- Have better or worse solutions, not right and wrong ones.
- Have no objective measure of success.
- Require iteration—every trial counts.
- Have no given alternative solutions—they must be discovered.
- Require complex judgments about the level of abstraction at which to define the problem.
- Often have strong moral, political, or professional dimensions that cannot be easily formalized.

A complete summary of the unique attributes of workplace problems and classroom problems, illustrating how they differ from each other, is presented by Regev, Gause, and Wegmann (2008, p. 87) and is shown in table 2-1.

Table 2-1 Comparison Between Workplace Problems and Classroom Problems (Regev, Gause, and Wegmann, 2008, p. 87)

Experience	Classroom	Workplace
Problem definition	Well defined.	Ill-defined. Half of the challenge is just defining the problem. Often, in fact, a solution is implied by a mutually acceptable definition.
Problem approach	Strongly indicated by most recently presented classroom material. Problems tend to be carefully compartmentalized to reinforce specific methodologies.	Few hints as to how to approach the problem. In small companies, there will likely be no one to go to for help. You will, nearly always, be required to go beyond past studies and methods and may be required to invent new methods.

Table 2-1 Continued.

Problem solution	Professor always knows the solution. If the problem is an odd numbered problem, the solution is in the back of the book.	A solution to the problem will only be apparent when it has been accepted by management.
Problem scope	Many problems are "scoped" so that they can be solved by one person (student) in a few days or weeks.	The scope of the problem will not be recognized and you will be expected to produce the resources and time necessary to achieve the end result. In general, problems require a team of several people working over a period of many months.
Social environment	Working as an individual with implied competition.	Working as a team member, cooperation being essential.
Information levels	Accurate, well defined, explicitly stated.	Vague, unrecognizably ambiguous. Occasional hidden agendas. Credibility of the source and timeliness of the information is always an issue.
Solution methods	Given by an authority figure, usually to reinforce material recently presented. Veracity and efficacy never an issue.	May have to invent a new method as part of the problem solving process. Authority figure often projects his/her solution as the method of approach.
Design team	Same group of members from beginning to end of project (14 weeks).	New members join the team and old, experienced members leave the team, sometimes at the worst possible times.
Stability of problem statement	Once stated, the problem statement is rarely, if ever changed.	The problem statement changes frequently as new information becomes available and new clients are brought into the picture.

Table 2-1 Continued.

Information channels	Heavy use of well-documented, written form.	Some documentation but much critical information is conveyed in "expedient" verbal (sometimes, off-hand) forms such as one-on-one meetings, telephone and other informal conversations.
Conflict	Conflict with authorities is strongly discouraged. Conflict with colleagues is best ignored as it will go away in 15 weeks.	Conflict with authorities is strongly discouraged. Conflict with colleagues is best ignored as it will go away by project end.

By interviewing 17 newly hired engineers, Korte, Sheppard and Jordan (2008) identified four subthemes describing the problem solving process in engineering workplace: "organize, define, and understand a problem; gather, analyze, and interpret data; document and present the results; and project-manage the overall problem-solving process" (p. 6).

Although much research has been conducted on the subject of workplace problems, how such problems are experienced and understood by college engineering students is still unclear. As students are expected to be problem-solvers within the engineering workplace after graduation, it is important that they understand the nature of the problems they will encounter and the specific challenges they will face in the real world.

2.2 Knowledge and Skills Needed to Solve Workplace Problems

Because workplace problems are different from classroom problems, practicing engineering in the real world differs from solving problems in the classroom. For example, in the classroom the knowledge and skills required to develop solutions are often closely related to what is taught; therefore, students are often passively waiting for the instructor to teach a specific method for solving a designated problem. In the real world, however, they have to explore the problem space and discover all of the relevant information by themselves (Regev, Gause, and Wegmann, 2008).

Moreover, although previous literature indicates that engineering students have a good technical background because of their college education (Weinstein, Gilchrist IV, Hebsch, and Stevens, 2002), the complexity of the engineering workplace problems and the level of professionalism involved in real world engineering practice require that engineering graduates are equipped with a broad knowledge base and skills—rather than technical competencies alone—in order to succeed in performing real world engineering tasks. Chatarajupalli, Venkatswamy, and Aryasri (2010) listed a set of specific problem solving skills needed in the workplace, which included: "drawing on the subject knowledge used; applying a variety of tactics and heuristics; monitoring and reflecting on the process used; having an overall approach that applies fundamentals rather than trying to combine various known solutions; being organized and systematic, and yet being flexible" (p. 107). Another summary of real world skills compiled by Ropella, Kelso, and Enderle (2001) included "critical thinking; team work; interpersonal skills; group decision-making; analytic and problem-solving mechanism; oral and written communication (including selling ideas, and formulating and presenting an argument)" (p. 2).

In summary, solving engineering problems in the real world requires a broader skill set, compared with problem solving in the classroom. In order to better prepare students to be professionals in the workplace after graduation, it is important for engineering educators to ensure that students understand the exigent challenges in the real world and are equipped with the essential knowledge and skills required by the engineering profession.

2.3 Students' Perceptions of Engineering Workplace Problem Solving

Not much research has investigated students' perceptions of engineering workplace problem solving. Some of the existing studies I have found suggest that students might not have a particularly clear sense of what the engineering workplace looks like.

Shuman, Delaney, Wolfe, Scalise, and Besterfield-Sacre (1999) claimed that first-year engineering students often suffered from a lack of information about both what the field of engineering is and what engineers do. A similar idea was proposed by Au, Bayles, and Ross (2008), who studied chemical engineering freshmen and claimed that those students came into the field of chemical engineering with little understanding of their major and what type of work they would do in the future.

Because first year students do not have a lot of knowledge about engineering, one might expect that graduating engineering students would have gained a better understanding of the field of engineering. However, previous research indicates that this might not be the case. Jocuns, Stevens, Garrison, and Amos (2008) studied how students' perceptions of engineering and of engineers changed during their undergraduate years. They found that students often came to engineering with vague notions of what defines a "good engineer," and a large proportion of students developed this idea based on their high school experiences. With more exposure to engineering over time, students will gradually develop more precise images of what is required of a good engineer. Jocuns et al. also found that "students' workplace images changed from being hopeful expectations in early interviews and later years' responses becoming more mundane/less high status" (p. 6), which was closer to what happened in the real world, as young engineers discovered when they progressed in the field. Unfortunately, not all the students in the study of Jocuns et al. were able to reach a clear understanding of workplace engineering. The study showed that there were students whose hopeful images were never altered, and as a result they graduated from engineering without an idea of what the actual workplace should look like. Similar findings are shared in work presented by Matusovich, Streveler, Miller, and Olds (2009). They collected data over a four year period with 10 students to examine these students' perceptions of themselves as engineers, and they summarized that students' views of themselves as future engineers were of "being good in math and science, being good communicators, being good at teamwork and enjoying activities they believe engineers do, doing problem-solving and having/applying technical knowledge" (p. 1). However, three out of 10 participants in their study were uncertain about what engineering is and what it means to be an engineer even when they already completed three or four year engineering education in college.

2.4 Industry's Perceptions of Students' Preparation for Workplace Problem Solving

Today, over two-thirds of engineering students advance into the engineering industry immediately upon graduation (Ropella, Kelso, and Enderle, 2001). However, are those students prepared with an adequate skill level to meet the demands of the industry and to survive in real world engineering?

Weinstein, Gilchrist IV, Hebsch, and Stevens (2002) claimed that companies expected their employees to "have the ability to interpret, critically analyze and solve problems, work effectively in teams and be able to communicate across various segments of a business" (p. 3). Lozano-Nieto (1999) defined industry demands for their employees according to two categories: technical knowledge and non-technical skills, such as team work and communication skills. A closer look at the literature reveals that the competencies industry employers expect their employees to have are similar to the knowledge and skills required in workplace problem solving — similar to those that researchers such as Jonassen, Strobel, and Lee (2006) and Ropella, Kelso, and Enderle (2001) have identified. For example, they all recognized the importance of problem solving skills, teamwork spirit, and communication skills.

Although companies have those expectations of their employees, unfortunately, as Grubbs and Ostheimer (2001) pointed out, a large number of today's engineering graduates do not have sufficient skills to directly work in the industry upon graduation. Todd, Sorensen, and Magleby (1993) examined the industry's views on new engineering graduates and identified several weaknesses from the feedback, including:

- Technical arrogance
- No understanding of manufacturing processes
- A desire for complicated and "high-tech" solutions
- Lack of design capability or creativity
- Lack of appreciation for considering alternatives
- No knowledge of value engineering
- Lack of appreciation for variation
- All wanting to be analysts
- Poor perception of the overall project engineering process

- Narrow view of engineering and related disciplines
- Not wanting to get their hands dirty
- Considering manufacturing work as boring
- No understanding of the quality process
- Weak communication skills
- Little skill or experience working in teams
- Being taught primarily to work as individuals. (p. 93)

Other workplace competencies graduating engineers need better preparation in were "solving open-ended problems, thinking 'outside the box', and working in teams, and in developing strong communication skills" (Grubbs and Ostheimer, 2001, p. 1). Furthermore, the Society of Manufacturing Engineers conducted extensive research within the industry and identified some critical competency gaps between new graduates and what was required by the manufacturing industry (Tuncer, 2003), which include: "business knowledge/skills; supply chain management; project management; international perspective; materials; manufacturing process control; written and oral communication; product/process design; quality; specific manufacturing processes; manufacturing systems; problem solving; teamwork/working effectively with others; personal attributes; engineering fundamentals" (p. 17). Banik (2008) examined the differences between engineering graduates' and employers' opinions of the level of achievement of engineering graduates and found that employers rated graduate achievement lower in written skills, define and solve problems, lead others effectively and ability to resolve conflicts.

It is not only the employers who have such concerns; engineering graduates who have already started working in the field realize that they have come to their positions without being fully prepared. For example, when Martin, Maytham, Case, and Fraser (2005) explored chemical engineering graduates' perceptions of how well they were prepared for work in the industry, they found that graduates often felt that they were well-prepared in "technical background, problem solving skills, formal communication skills and life-long learning abilities" (p. 167). Those recent graduates identified their weaknesses as their lack of ability in "work in multi-disciplinary teams, leadership, practical preparation and management skills" (p. 167). Mechanical engineering alumni from the University of Texas at Austin were asked to reflect on what courses/assets offered by their undergraduate program were believed to be the most helpful on the job (Aanstoos and Nichols, 2001). A summary of their comments is listed in the table below (Aanstoos and Nichols, 2001, p. 6). It is evident that a great number of skills identified as critical to workplace engineering, unfortunately, had not been taught in the university.

Table 2-2 Summary of Comments (Aanstoos and Nichols, 2001, p. 6)

	"Hard" Topics	"Soft" Topics	Intangibles
Courses/assets available; not job-critical	• Physics • Numerical analysis •Calculus/differential equations	• Mandatory history and government • Non-technical electives	
Courses/assets available; job-critical	• Thermodynamics • Material sciences • Statics/dynamics	• Internships	

Table 2-2 Continued.

Courses/assets not available; job-critical	• Computer programming • Software applications • Numerical analysis •Ceramics/Composites • Solid modeling • Manufacturing processes	• Technical writing • Oral communications • Team skills • Labor relations • Quality engineering • Negotiation skills • Budgeting/cost controls •Finance/marketing •Diversity/sensitivity • Ethics • Safety • Management • Regulatory requirements	• Interpersonal relationships • Work experience • Problem solving • Work ethic • Time management • Multi-disciplinary studies •Sports/extracurricular activities

Because industry employers frequently notice students' lack of workplace problem solving skills, they encourage universities to emphasize the teaching and learning of those practical skills (Grubbs and Ostheimer, 2001; Aanstoos and Nichols, 2001). However, engineering educators are still providing insufficient attention to the practical preparation of their students for real world engineering. For example, as Grubbs and Ostheimer (2001) claimed, "[m]ost engineering schools have concentrated their efforts in preparing engineers to go to graduate school, or have simply neglected the more practical aspects of the profession" (p. 1). Similarly, Ropella, Kelso, and Enderle (2001) indicated that engineering educators were struggling "to establish that balance between theory and practice" and "[m]any fear that too much 'real-world' is simply job training" (p. 1). They further pointed to the unpleasant result of this inadequate education on real world engineering: it would leave students with "little practical experience" and "naive problem solving skills and no appreciation for approximation, optimization and error" (p. 1).

One reason that may explain why universities do not emphasize the teaching of real world skills is that they feel the industry should train its own employees (Grubbs and Ostheimer, 2001). The literature does suggest that those professional skills are usually taught by internal training within the companies or by programs that every newly hired engineer is expected to complete (Aanstoos and Nichols, 2001). For example, Aanstoos and Nichols (2001) interviewed practicing engineers, the majority of whom reported that they had to go through two to six months of initial training before beginning work. However, engineers implied that the period could be shortened if the undergraduate engineering education could bridge the gap between the classroom and workplace. Similar ideas are expressed in the study presented by Jonassen, Strobel, and Lee (2006). Their interviews with professional engineers suggested that most engineers felt "graduates will 'really' learn how to be an engineer during the first year or two on the job" (p. 146). In order to better prepare students to solve workplace problems, engineers recommend that engineering schools put more emphasis on teaching students "client interaction, collaboration, making oral presentations and writing, as well as the ability to deal with ambiguity and complexity" (p. 146). Therefore, in order to reduce the time required for the student to become a workplace engineer, engineering schools should better prepare students with the actual knowledge and skills required in the workplace.

In conclusion, industry employers expect engineering graduates to be equipped with workplace problem solving skills and related knowledge. Nevertheless, research with industry employers and engineering graduates shows that engineering students are not well-prepared to handle workplace problems. Thus, engineering schools, which are blamed for not preparing students with those competencies, are urged to incorporate teaching of knowledge and skills needed in the real world.

2.5 Experiential Learning and the Co-Op Program

Because workplace problems are distinct from classroom problems and engineers need a much wider range of knowledge and skills in order to solve workplace problems, it is important for engineering educators to ensure that their students are properly prepared with the required knowledge and skills. Previous research indicates that classroom teaching that does not engage students in practical work fails to equip students with the skill set they need. For example, Regev, Gause, and Wegmann (2008) pointed out that many students "who have been only trained in the academic curriculum" (p. 88) were only comfortable with solving classroom problems. So, instead of exploring the problem space by themselves, students were often left passively waiting for the instructor to teach them how to solve these problems. Ropella, Kelso, and Enderle (2001) further pointed out that insufficient education in real world engineering would leave students with "little practical experience" and "naive problem solving skills and no appreciation for approximation, optimization and error" (p. 1). Students who were trained with "classic science and math courses and theory-laden textbooks" might not be able to perform some simple "everyday tasks" and be left feeling "frustrated by the seemly disconnect between higher education and the 'real world'" (p. 1). Because the skills and knowledge that students attain from solving textbook problems do not adequately prepare them to deal with workplace challenges, "it is imperative for universities to provide students with learning experiences on real engineering problems so they can develop the necessary skills to address complex open-ended problems and to meet the industry need for highly qualified engineers to compete in a global market" (Lai-Yuen and Herrera, 2009, p. 1).

Brumm, Hanneman, and Mickelson (2005) proposed that one of the best ways to train students in workplace competencies is experiential education. They stated that "experiential education can be broadly defined as a philosophy and methodology in which educators purposefully engage with learners in direct experience and focused reflection in order to increase knowledge, develop skills, and clarify values" (p. 2). Brumm et al. further narrowed down this definition, arguing that "it is work experience in an engineering setting, outside of the academic classroom, and before graduation" (p. 2). They believed such experiential engineering education programs might be "the best place to directly observe and measure students developing and demonstrating competencies while engaged in the practice of engineering at the professional level" (p. 2).

The College of Engineering at Purdue University offers one type of experiential learning program to engineering undergraduates in the form of the Co-Op program. Co-Op is "a unique form of education and experiential learning, which integrates classroom study with paid, planned and supervised work experience in the private and public sector" (Garavan and Murphy, 2001, p. 281). Harrisberger, Heydinger, Seeley, and Talburtt (1976) pointed out that experiential learning activities can be grouped into two categories: simulations and authentic involvement. Tener, Winstead, and Smaglik (2001) explained that "simulations consist of fabricated situations that are carefully designed to meet selected learning objectives and are under close faculty control" (p. 10), while "'authentic involvement' exposes the student to real situations with open-ended outcomes, although the faculty may influence the selection of the situations and set performance criteria to assure that established learning objectives are attained" (p. 10). Ortmeyer, Cunningham, and Sathyamoorthy (2000) mentioned that working in a real workplace setting could provide students with "a perspective that is difficult to achieve in either the classroom or teaching laboratory," while at the same time enabling these students to make "a successful transition from academic life to engineering careers" (p. 1). The Co-Op program at Purdue offers students opportunities to experience workplace environment and participate in problem solving activities. It consists of student participation in activities of "authentic involvement," which means that they take place in an actual engineering workplace setting and allow students direct involvement with engineering work and people involved in the workplace. Some of the potential benefits of the Co-Op program for students include:

1) Enhanced student self-confidence, self-concept and improved social skills.
2) Enhancement of practical knowledge and skills.
3) Enhanced employment opportunities.
4) Attainment of necessary skills to supplement theoretical training.
5) Enhancement of the induction process when the student joins the labour market. (Garavan and Murphy, 2001, p. 282)

In summary, previous research indicates that the Co-Op program provides students with opportunities to experience real world engineering problem solving. However, it is still not clear how students experience real world engineering and how they perceive workplace problem solving.

2.6 Research Questions

While previous studies point out that engineering workplace problems differ from textbook problems and the solution of such problems demands a variety of knowledge and skills, it is uncertain whether students have any knowledge of the challenges they will face in workplace problem solving and the extent to which they are prepared to meet those challenges. The literature indicates that among engineering students there may still be a lack of understanding both of engineering practice and of the engineer as a professional, a fact which tends to leave students underprepared to operate in the real world. The dissatisfaction of industry employers further confirms this lack of preparedness among student job seekers. In order to better prepare students for real world engineering, experiential education is proposed, which can provide opportunities for students to observe engineering in the workplace and benefit students in a number of ways. In this study, I want to identify the range of students' experiences of problem solving in the engineering workplace and areas in which these students are prepared by their college education to solve workplace problems. The research questions which guided my study are:

1) Of Co-Op students who participated in workplace problem solving, what are the different ways in which students experience workplace problem solving?
2) How do students perceive a) the differences between workplace problem solving and classroom problem solving b) in what areas are they prepared by their college education to solve workplace problems?

CHAPTER 3. METHODOLOGY

3.1 Theoretical Framework

Two theoretical frameworks guide my study: The first is the workplace engineering problem solving theory developed by Jonassen, Strobel, and Lee (2006). By interviewing practicing engineers, Jonassen et al. found that workplace problems are substantively different from classroom problems in that "they possess conflicting goals, multiple solution methods, non-engineering success standards, non-engineering constraints, unanticipated problems, distributed knowledge, collaborative activity systems, the importance of experience, and multiple forms of problem representation" (p. 139). In my study, I want to explore workplace problems from the perspectives of engineering students in order to determine the different ways students experience workplace problem solving and whether students recognize the challenges involved in solving those problems.

The second theoretical framework is the model of domain learning (MDL) proposed by Alexander (1997), which explains how learners develop expertise in an academic field. In this model, Alexander divides the process of expertise development into three stages: acclimation, competence and proficiency/expertise. Learners start with little knowledge (acclimation), gradually acquire well-structured, solid, basic knowledge (competence) and finally become experts with a broad and deep knowledge base (expertise) (Alexander, 2003). During this process, learners become more involved in their areas of study and their knowledge of the domain, strategies and interest in the domain develop, which in turn promotes learners' expertise development (Alexander, 2003; Alexander, 1997).

As researchers (Shuman, Delaney, Wolfe, Scalise, and Besterfield-Sacre, 1999; Au, Bayles, and Ross, 2008) observed that students often came to engineering without a clear picture of what engineering is and what engineers do, it is reasonable for us to infer that those undergraduate students are at the acclimation stage and only possess very limited knowledge of the engineering profession and engineering skills. While college education can help students make remarkable progress in their transformation into competence, real world engineering education such as the Co-Op program might also play a significant role in this transformation process, as Urban-Lurain**,** Anderson, Parker & Richmond (2006) pointed out that not only formal education but also professional practice can provide students with opportunities to get more exposure to the domain and facilitate the transformation of a novice to an expert. In this study, I want to investigate students' perceptions of the differences between workplace problem solving and classroom problem solving as well as their preparedness for the sake of exploring whether students who have real world experience develop a better understanding of workplace problems.

3.2 Methodological Framework

Two methodological frameworks guide my research. The first one is termed "phenomenography". Because different people will experience and understand any given phenomenon in varying ways, the aim of phenomenography is to "uncover the variation in ways of experiencing a particular aspect of the world" (Daly, 2008, p. 39). Instead of investigating the particular phenomenon or people who experience it, the focus of phenomenographic research is to understand the relationship between these two (Bowden, 2005; Mann, Dall'Alba, and Radcliffe, 2007). In this study, I want to explore the different ways students experience workplace problem solving through the lens of phenomenography.

It is (Bowden et al., 1992; Marton, 1986) believed that each phenomenon can be understood or experienced "in a limited number of qualitatively different ways" (Bucks and Oakes, 2011, p. 4). In order to explore such variations, researchers conduct in-depth interviews to elicit the understanding or experience that an individual has of a phenomenon (Bucks and Oakes, 2011). The result of a phenomenographic study is known as the "outcome space" (Bucks and Oakes, 2011; Daly, 2008), constituted by the "categories of description" (Bowden et al., 1992, p. 263), a term that describes the differing ways in which people may experience and understand the phenomenon (Bucks and Oakes, 2011). These categories are often organized in a hierarchical form, from "a less complete understanding" to "a more complete understanding" (Bucks and Oakes, 2011, p. 4).

The second theoretical framework guiding my study is thematic analysis, which is "a method for identifying, analysing and reporting patterns (themes) within data" (Braun & Clarke, 2006, p. 79). Thematic analysis usually involves searching for repeated patterns or themes among a number of interviews (Braun & Clarke, 2006). In this study, I used thematic analysis to identify the major differences between workplace problem solving and classroom problem solving as discerned by students as well as their perceived areas of preparedness.

3.3 Research Design

The nature of my research questions determines that this is a qualitative study. My research questions ask: 1) Of Co-Op students who participated in workplace problem solving, what are the different ways in which students experience workplace problem solving? 2) How do students perceive a) the differences between workplace problem solving and classroom problem solving and b) in what areas are they prepared by their college education to solve workplace problems? In order to have “a complex, detailed understanding” of these questions, I want individual students to “share their stories” (Creswell, 2007, p. 40), a process which would allow me to identify their different experiences and explore how these experiences shape their understanding of workplace engineering. Since these details can only be discovered by talking to people and listening to their stories, qualitative research is required for this study.

3.4 Data Collection

The qualitative data were usually collected through semi-structured interviews (Åkerlind, Bowden and Green, 2005) and the literature has suggested that the minimum number of participants in a phenomenographic study is 15 and most phenomenographic studies contain 20 to 30 interviews (Daly, 2008; Trigwell, 2000; Bowden, 2005). In this study, I conducted 22 interviews in total with each interview lasting approximately one hour. All interviews were audio recorded.

3.5 Participant Recruitment and Selection

To recruit participants, an invitation email was sent to students currently enrolled in the Co-Op program requesting participation in my study. A recruitment survey was included in the email, designed to help me collect the students' background information. The survey questions can be found in appendix A. From those who agreed to participate, I selected the final 22 students by using a purposeful sampling technique called the "maximum variation" approach, which is described below.

Because the aim of a phenomenographic study is to explore variation in experience and understanding, the selection of participants is guided by "an attempt to gain the largest diversity in experiences" (Daly, 2008, p. 41, Åkerlind, 2005a). This entails "the use of a purposeful sampling method" (Bucks and Oakes, 2011, p. 5). In order to obtain the maximum variation in experience, 22 students with different learning experiences were purposefully selected based on the following criteria: number of times of experience, major, academic year, sex, ethnicity, and size of the company the student worked for. The number of times a student had participated in the program was considered as it was reasonable to assume that each student's understanding of workplace engineering would change when work experience was accumulated. Similarly, it was felt that the students' academic year and major might influence their experience and the variation in sex and ethnicity might also have an impact on their experience and understanding. Therefore, those factors were all taken into consideration when selecting participants. Creswell (2007) indicated that this type of qualitative sampling strategy is called the "maximum variation" approach and the benefit of using the "maximum variation" strategy is that "it increases the likelihood that the findings will reflect differences or different perspectives" (p. 126), which is generally preferred in phenomenographic study.

A summary of participant information is listed in table 3-1. Of the 22 participants, four were working on their first Co-Op session when they completed the survey, four completed one Co-Op session, two completed two Co-Op sessions, three completed three Co-Op sessions, four completed four Co-Op sessions, and five completed five Co-Op sessions. Five of the participants were sophomores, five were juniors, seven were seniors, and five were in their fifth year or above. The students represented seven different majors, including biomedical engineering, electrical and computer engineering, mechanical engineering, chemical engineering, industrial engineering, civil engineering, and nuclear engineering. Fifteen of the participants were white, four were Asian, two were mixed race and one was black or Africa American. Fifteen of the participants were male and seven were female. The majority of the participants (18) were working in large sized companies, two were working in midsized companies, and two were working in small sized companies.

Table 3-1 Summary of Participants

Pseudonym	Number of Co-Op sessions finished	Academic year	Major	Ethnicity	Sex	Size of Company
Greg	working on 1st Co-Op	Fourth year	Biomedical engineering	Asian	Male	Large
Mark	working on 1st Co-Op	Second year	Electrical and computer engineering	Asian	Male	Large

Table 3-1 Continued.

Zack	working on 1st Co-Op	Second year	Mechanical engineering	White	Male	Large
James	working on 1st Co-Op	Third year	Mechanical engineering	Asian	Male	Midsized
Clare	1	Third year	Biomedical engineering	White	Female	Midsized
Ethan	1	Second year	Mechanical engineering	White	Male	Large
Alisa	1	Second year	Chemical engineering	White	Female	Large
Todd	1	Second year	Mechanical engineering	White	Male	Large
Alice	2	Third year	Electrical and computer engineering	White	Female	Large
Nick	2	Third year	Chemical engineering	White	Male	Large
Tony	3	Third year	Chemical engineering	Black or African American	Male	Large
Kelly	3	Fourth year	Industrial engineering	White	Female	Small
John	3	Fourth year	Mechanical engineering	White	Male	Large
Jennifer	4	Fourth year	Electrical and computer engineering	Mixed	Female	Large
Jason	4	Fourth year	Mechanical engineering	Asian	Male	Large
Linda	4	Fourth year	Chemical engineering	Mixed	Female	Large
Eric	4	Fourth year	Mechanical engineering	White	Male	Large
Ryan	5	Fifth year and above	Nuclear engineering	White	Male	Large
Roy	5	Fifth year and above	Mechanical engineering	White	Male	Small

Table 3-1 Continued.

Sarah	5	Fifth year and above	Civil engineering	White	Female	Large
Bruce	5	Fifth year and above	Electrical and computer engineering	White	Male	Large
Steve	5	Fifth year and above	Mechanical engineering	White	Male	Large

3.6 Instrument Design

The main purpose of a phenomenographic interview is to let the participants reflect on their concrete experience and discuss the meaning they derive from that experience (Åkerlind, 2005a; Åkerlind, Bowden and Green, 2005; Daly, 2008). Consequently, the focus of the interview is not just to discover concrete experiences but also to explore how those experiences are understood and discussed by the participants (Daly, 2008). This implies that the interview questions should be designed in a manner that first encourages the participants to discuss a concrete experience and then prompts them to reflect on their experience and express their understanding of that experience (Daly, 2008, Åkerlind, 2005a). This became the first principle in the design of my interview questions.

The concrete process of developing interview questions was guided by the two theoretical frameworks I have used—i.e. the workplace problem solving theory and model of domain learning. For example, the workplace problem solving theory provided me with an evidence-based conclusion that workplace problems differ from classroom problems and that solving workplace problems requires knowledge and skills beyond the level necessary to solve classroom problems. Many researchers (Jonassen, Strobel, and Lee, 2006; Regev, Gause, and Wegmann, 2008; Weinstein, Gilchrist IV, Hebsch, and Stevens, 2002) have compared workplace problem solving and classroom problem solving and expounded the differences between them according to various aspects, as I have shown in my literature review. Based on their explanations, I have designed my research questions to let students reflect on their workplace problem solving experience and compare workplace problem solving with classroom problem solving.

After the interview questions were designed, they were pilot tested. Three engineering undergraduate students who had real world engineering work experience were asked to go through the questions and comment on each one. Based on the pilot test results, I refined my questions and developed a final version of the interview protocol to be used in my study (Appendix B).

3.7 Phenomenographic Data Analysis

Åkerlind (2005b) has described the major procedures used to analyze phenomenographic data. He suggests that "[t]he analysis usually starts with a search for meaning, or variation in meaning, across interview transcripts, and is then supplemented by a search for structural relationships between meanings" (p. 324). In the early stages of data analysis, the researcher should remain open-minded, searching for meaning and interpretations by reading through the transcripts repeatedly. Åkerlind (2005b) emphasized that "[p]aramount is the importance of attempting, as far as possible, to maintain an open mind during the analysis, minimizing any predetermined views or too rapid foreclosure in views about the nature of the categories of description" (p. 323).

Because the expected outcomes of a phenomenographic study are "categories of description" (Bowden et al., 1992, p. 263), the researcher should search for similarities and differences among transcripts or quotes, and then group and regroup data according to these similarities and differences. As a result, transcripts or quotes sharing similar themes will be put into the same category and a description of each category will be generated. Then the transcripts will be read once more to make sure that each transcript fits into the category to which it has been assigned. This repetition will stop when the researcher feels that all transcripts or quotes map into their corresponding categories and that the description of each category represents the major idea of the transcripts belonging to that category. Then, the categories of description will be regarded as the result of this study. This process is documented in Daly (2008) and Zoltowski (2010)'s work and described by Marton (1986) as "[d]efinitions for categories are tested against the data, adjusted, retested, and adjusted again. There is, however, a decreasing rate of change, and eventually the whole system of meanings is stabilized" (p. 43).

In summary, the whole process of phenomenographic data analysis is "a strongly iterative and comparative one, involving the continual sorting and resorting of data, plus ongoing comparisons between the data and the developing categories of description, as well as between the categories themselves" (Åkerlind, 2005b, p. 324).

Based on the guidelines provided by Åkerlind (2005b), the data were analyzed in the following way: after the interviews were recorded and professionally transcribed, I listened to the interviews once more to check the accuracy of each transcript. This process also helped me to become more familiar with each interview transcript. Because of the large amount of data, I re-read each transcript two to three times and then summarized the main ideas presented that could help me better recall the basic idea of each transcript later on. Data analysis continued with open coding. In the open coding stage, I made notes on the transcripts and coded the data for their main information. At the end of open coding, I revised my previous summary of transcripts, and an initial set of themes of how students experience workplace engineering was established. Next, transcripts that shared similar themes were put into the same group and all the transcripts were read and sorted again to make sure they belonged to that group. During this process, axial coding was used to help me combine and identify themes and assemble data in new ways. The whole process was iterative, as I would detect new themes or combine similar themes in the coding and re-assemble data into categories based on the new set of themes. Once I felt the groups became stable and each group represented a distinct way of experiencing workplace problem solving, I attempted to generate a description for each group. After the descriptions of how students experience workplace problem solving were generated, I read all the transcripts again, which resulted in another iteration of grouping and generation of categories of description. The iterations ended when I found that all transcripts mapped into their corresponding categories and the description of each category was unique and represented the main idea of data belonging to that category. The final categories of description were then created and organized based on the structural relationship between categories, which formed the outcome space of the phenomenographic study.

In this study, the data analysis consisted of five iterations. Tables 3-2 − 3-4 are sample products of my process. The first attempt at generating categories of how students experience workplace problem solving is summarized in table 3-2.

Table 3-2 First Iteration of Categories of Description

Categories	Categories of Description
1	Workplace problem solving is following orders and executing the plan. The method of how to solve problems is known/given in this category and engineers solve problems by following the procedures.(Alisa and Linda)
2	Workplace problem solving is improving current solution and satisfying customers' needs. The problem is identified by customers and many constraints/problem solving related information is given to engineers by customers. The aim of problem solving is to satisfy customers' need. (James, Jason, Roy, and Steve)
3	Workplace problem solving is using technical knowledge to meet the requirements and achieve goals. This way of experiencing workplace problem solving is about coming up with technical solutions within constraints. (Jennifer, Ethan, Sarah, and Ryan)
4	Workplace problem solving is finding evidence to make decisions. Engineers in this category have to use data or other information to support their engineering decisions. (Nick and Kelly)
5	Workplace problem solving is working with different people to find out the solution. In those cases, engineers need to consult the problem with different people and people's opinions/schedule/input become critical for engineers in finding solutions. (Clare and Zack)
6	Workplace problem solving is exploration. It involves a lot of trial and error. (Todd)
7	Workplace problem solving is defining the problem and then coming up with solutions. Workplace problems are usually ill-defined and the first step of problem solving is defining the problem. (Eric, John, Alice and Greg)
8	Workplace problem solving is freedom. The majority of the parameters in the problem solving process are defined by engineers. (Tony and Bruce)
9	Workplace problem solving is a learning process. (Mark)

In my first attempt to generate categories of description, there was no attempt to find the hierarchical structure, so the categories were not presented in a hierarchical form. After the first iteration was generated, all the transcripts were read again to see if the ones that belonged to the same category represented similar ways of experiencing workplace problem solving and if the description encapsulated the key information of students' experiences within that category.

Initially, I put Sarah into category 3 (Workplace problem solving is using technical knowledge to meet the requirements and achieve goals) because I felt she talked a lot about the technical aspects of her work. As I read her transcript again, however, I noticed that while she mentioned how she used her technical knowledge and skills to solve the problem, she emphasized more that her work was designing for her client. Additionally, in my first attempt I put Eric, John, Alice, and Greg into category 7 because I felt they talked a lot about the ill-defined objectives of problems. However, later I realized this only provided the background information of the problems they solved and this was not the core of their problem solving experiences.

As I read all the transcripts and descriptions again, I started to consider the critical variations between categories as well as some similarities I had not noticed before. For example, in my first attempt I put Todd, Tony, Bruce, and Mark into different categories, but when I read their transcripts again I felt all of them emphasized how engineers should take the initiative to explore the different parameters in the problem space. Furthermore, they all felt that workplace problem solving was a learning experience and they developed better engineering knowledge and skills during the problem solving process. Such regrouping led me to my second iteration of generating categories of description.

Table 3-3 Second Iteration of Categories of Description

Categories	Categories of Description
1	Workplace engineering problem solving is following orders and executing the plan. The method of solving problems is known and engineers solve problems by following the given procedures. (Alisa and Linda)

Table 3-3 Continued.

2	Workplace engineering problem solving is satisfying customer needs. The problem is identified by customers and many constraints/pieces of problem solving related information are given to engineers by customers. The aim of problem solving is satisfying customer needs. (Steve, Roy, Sarah, and James)
3	Workplace problem solving is using technical knowledge to generate solutions to achieve the goal. (Eason, Jennifer, and Ryan)
4	Workplace problem solving is consulting or coordinating with people. (Clare and Zack)
5	Workplace problem solving is using evidences to draw conclusions or support decisions. (Nick, Kelly, Alice, Greg, Todd, and Jason)
6	Workplace problem solving is an exploration and learning process. (Bruce, Tony, Mark, Eric, and John)

After the second iteration, I discussed results with my advisor and reviewed all the transcripts again. Several changes were made in this iteration. For example, Alisa's transcript was moved to the fourth category because I felt the way she generated problem solving solutions was largely impacted by external experts and the operator's inputs. Other changes in the third iteration are shown in table 3-4.

Table 3-4 Third Iteration of Categories of Description

Categories	Categories of Description
1	Workplace engineering problem solving is following orders and executing the plan. The method of solving problems is known and engineers solve problems by following the given procedures. (Linda)
2	Workplace engineering problem solving is satisfying customer needs. The problem is identified by customers and many constraints/pieces of problem solving related information are given to engineers by customers. The aim of problem solving is satisfying customer need. (Steve, Roy, Sarah, and James)
3	Workplace problem solving is using technical knowledge to generate solutions to achieve the goal. (Alice, Jennifer, Ethan, Ryan, and Clare)

Table 3-4 Continued.

4	Workplace problem solving is consulting with people and using others' suggestions to solve the problem.(Alisa and Greg)
5	Workplace problem solving is coordinating with people and finishing work. (Zack)
6	Workplace problem solving is using evidence to draw conclusions or support decisions. (Kelly, Nick, and Todd)
7	Workplace problem solving is a learning process. (Eric)
8	Workplace problem solving is an exploration process. (Tony, Bruce, Jason, Mark, and John)

The whole analysis process consisted of five iterations with the last iteration presented in the results section. In the fourth and fifth iteration, when the changes from iteration to iteration became smaller, I started to consider the logical relationship between categories. In the meantime, I discussed the results with my committee members and realized there were two major aspects of variation across categories: 1) students' involvement in problem definition and formulation and 2) students' involvement in solution generation and selection. Therefore, the categories were placed in a two-dimensional space with those two constructs as axes. The final categories of description, the relationship and critical variations between categories are presented in the next chapter.

3.8 Thematic Analysis

Thematic analysis entails searching for repeated patterns or themes across a set of interviews (Braun & Clarke, 2006). The actual analysis process consists of six phases: 1) get familiar with the data by reading transcirpts and taking notes 2) produce initial codes by identifying patterns in the dataset that align with research interest and code data 3) sort and group codes and search for themes among codes 4) refine and review themes 5) define and describe themes 6) generate final results (Braun & Clarke, 2006). In this study, I first inductively generated an initial set of codes by working through the 22 transcripts. After the initial codes were produced, I grouped codes that expressed similar meanings into themes. After all the themes were developed, I reviewed all the codes and themes again in order to refine them. In total, six themes were developed from the thematic analysis of interview transcripts.

3.9 Validity and Reliability

In order to attain rigor in qualitative research, the researcher has to ensure that the study is valid and reliable. Creswell (2007) considers validation in qualitative research as "an attempt to assess the 'accuracy' of the findings" (p. 206). Historically, instead of using the term "validation," other terms such as trustworthiness, authenticity, credibility, and transferability are often used by qualitative researchers (Creswell, 2007). However, Creswell (2007) suggests validation might be a better term to use because it "emphasize[s] a process" (p. 207). In order to validate a study, four primary validation criteria were set forth by Whittemore, Chase and Mandle (2001): "credibility (Are the results an accurate interpretation of the participants' meaning?); authenticity (Are different voices heard?); criticality (Is there a critical appraisal of all aspects of the research?); and integrity (Are the investigators self-critical?)" (Creswell, 2007, p. 206). Many approaches such as peer review, triangulation, and member checking are used by researchers as validation strategies (Creswell, 2007). In qualitative research, reliability can be understood as consistency in results when "repeating or comparing assessments within a study" (Guest, MacQueen & Namey, 2012, p. 81). In practice, it is closely related to intercoder agreement and often refers to “the stability of responses to multiple coders of data sets” (Creswell, 2007, p. 210).

In a phenomenographic study, validity is regarded as “the extent to which a study is seen as investigating what it aimed to investigate, or the degree to which the research findings actually reflect the phenomenon being studied” (Åkerlind, 2005b, p. 330). Two types of validity checks, the communicative validity check and pragmatic validity check, are often used in phenomenography (Åkerlind, 2005b). The communicative validity check requires the researcher to be able to defend his or her interpretation to the research community, people who can represent the interview sample, and those who are interested in the research (Åkerlind, 2005b). The pragmatic validity check requires the researcher to check the extent to which the research findings are perceived to be useful and meaningful by audience (Åkerlind, 2005b). In my case, the communicative validity check is achieved by presenting and defending my study to the engineering education community so that the credibility, criticality, authenticity, and integrity of the study are confirmed by the community members. The pragmatic validity check is achieved by communicating the results with engineering education researchers to find out how the results could be incorporated or applied in their work, therefore allowing the researchers to make the decision on whether the study can be transferred to their circumstances.

Reliability in phenomenography is seen as “reflecting the use of appropriate methodological procedures for ensuring quality and consistency in data interpretations” (Åkerlind, 2005b, p. 331). There are two forms of reliability checks, one is the coder reliability check, where “two researchers independently code all or a sample of interview transcripts and compare categorizations” (Åkerlind, 2005b, p. 331), and the other is the dialogic reliability check, where “agreement between researchers is reached through discussion and mutual critique of the data and of each research’s interpretive hypotheses” (Åkerlind, 2005b, p. 331). In my case, as I am supposed to complete the dissertation study independently, it might not be suitable for me to find another researcher to work on the data. Therefore, I used the alternative reliability check method suggested by Åkerlind (2005b), which is to make my “interpretive steps clear to readers by fully detailing the steps, and presenting examples that illustrate them” (Åkerlind, 2005b, p. 332).

In thematic analysis, validity and reliability can be enhanced in several ways. For example, Guest, MacQueen & Namey (2011) suggest using at least one to two quotes to illustrate each theme and document the process of data analysis in a final report. Other strategies they recommend include: having multiple coders to analyze the data and check intercoder realiability, inviting an external expert to review the results, etc. In my case, I recorded my data analysis process in writing and presented the themes with associated quotes. During the process, I asked my advisor to check those codes and themes to make sure they correctly reflected the meaning of each transcript.

3.10 Role of Researcher

In qualitative research, the background, knowledge, and experience of the researcher might bring biases to the study therefore it is vital for the researcher to be aware of the potential biases he/she might bring into the study (Daly, 2008, p. 66). With this in mind, the following paragraphs describe my background, experiences, and biases in connection with experiential learning and engineering workplace problem solving.

My undergraduate degree is in electrical engineering. Although I began graduate school directly after completing my undergraduate studies and did not actually work as an engineer, my internship and graduation project experience allowed me to work with real world problems. At that time, I felt frustrated that the issues or situations I encountered in the workplace were more complex and difficult than the ones I dealt with in textbooks or classrooms. Compared with engineers or even technical staff working in a power plant who did not attend college, I felt I knew only a little about what happens in the real world. Because my own experience in real world engineering enables me to recognize the differences between workplace problems and classroom problems, as well as my lack of preparation to solve workplace problems, I expect the experiential learning programs, such as Co-Op, would help Purdue engineering undergraduates develop a better understanding of workplace engineering. This is the first bias I brought to this study.

After becoming a Ph.D. student in engineering education, I read literature and conducted research in workplace problem solving and began to understand that workplace problems differ from textbook/classroom problems in a variety of ways. Thus, the second bias I brought to this study is that workplace problems and classroom problems are different and students should be able recognize or identify some of those differences.

CHAPTER 4. RESULTS

In this chapter, I present the results from my study: first the results from the phenomenographic study of the different ways in which students experience workplace problem solving and then the results from the thematic analysis of students' perceptions of 1) the differences between workplace problem solving and classroom problem solving and 2) in what areas are they prepared by college education to solve workplace problems.

4.1 Phenomenographic Analysis: Ways of Experiencing Workplace Problem Solving

4.1.1 Introduction

This section presents findings from the phenomenographic analysis of data, which are the six different ways in which Co-Op students experience and understand workplace problem solving. Previous research that utilized phenomenography as a methodological framework, such as Daly (2008) and Zoltowski (2010)'s work, provided me with structural guidance in this study. The results include six categories of description, generated based on the analysis of 22 interviews with Co-Op engineering students. An additional discussion of the relationships between different categories that further reveals the differences between the six categories is also included.

4.1.2 Outcome Space Overview

The outcome space consists of six categories of description, in which Co-Op students experience and understand workplace problem solving, and descriptions of the differences between categories. The categories of description were generated based on the variations of workplace problem solving experiences shared by 22 Co-Op students. In the data analysis, interviews were viewed and interpreted as wholes; therefore, the categories were created based on the big picture of students' experiences, not the details (Daly, 2008). The type of problems students experienced (e.g. design, trouble shooting) and the different engineering industries students worked in were not considered as factors in determining the categories. Table 4-1 presents those categories of description.

Table 4-1 Categories of Description of Students' Experiences of Engineering Workplace Problem Solving

Category of description (Engineering workplace problem solving is…)	Summary
Category 1: Executing the plan	Workplace problem solving is following orders and executing the plan. The method of solving the problem is known/given in this category and student engineers solve the problem by following the procedures. (Linda)
Category 2: Fulfilling customer needs	Workplace problem solving is implementing customers' ideas and satisfying customer needs. The problem is identified by customers and many constraints/pieces of problem solving related information are given to engineers by customers. (Steve, Roy, James, and Sarah)
Category 3 Technology and math focused	Workplace problem solving is using mathematical and technical knowledge and skills to solve technical problems. (Ethan, Alice, Ryan, and Jennifer)

Table 4-1 Continued.

Category 4: Collecting people's input	Workplace problem solving is consulting different people and collecting their inputs. Those inputs later play a critical role in solution generation and selection. (Greg, Alisa, Todd, and Zack)
Category 5: Using multiple resources to make decisions or draw conclusions	Workplace problem solving is using multiple resources, such as data and people's suggestions to draw conclusions, make decisions, and solve problems. (Clare, Nick, and Kelly)
Category 6: Exploration and freedom	Workplace problem solving is an exploration and research process. Student engineers have the freedom to define parameters in problem solving and generate solutions based on investigation of the problem. (Tony, Bruce, Jason, John, Mark, and Eric)

Each category in the table represents one way of experiencing workplace problem solving and each participant's experience only contributes to one category. The distribution of participants among categories is shown in table 4-2. Again, the categories were generated entirely based on students' experiences, rather than on their major, sex, etc. As we can see, category 2 mainly consists of students who completed five Co-Op sessions and category 4 consists of students who were either working on their first Co-Op session or completed only one Co-Op session. Beyond those there is a fairly even distribution of students in relation to the number of Co-Op sessions completed across the remaining categories.

Table 4-2 Distribution of Participants Across Categories

Category	Pseudonym	Number of Co-Op sessions finished	Academic year	Major	Ethnicity	Sex	Size of Company
Category 1	Linda	4	Fourth year	Chemical engineering	Mixed	Female	Large
Category 2	Steve	5	Fifth year and above	Mechanical engineering	White	Male	Large

Table 4-2 Continued.

	Roy	5	Fifth year and above	Mechanical engineering	White	Male	Small
	James	working on 1st Co-Op	Third year	Mechanical engineering	Asian	Male	Midsized
	Sarah	5	Fifth year and above	Civil engineering	White	Female	Large
Category 3	Ethan	1	Second year	Mechanical engineering	White	Male	Large
	Alice	2	Third year	Electrical and computer engineering	White	Female	Large
	Ryan	5	Fifth year and above	Nuclear engineering	White	Male	Large
	Jennifer	4	Fourth year	Electrical and computer engineering	Mixed	Female	Large
Category 4	Greg	working on 1st Co-Op	Fourth year	Biomedical engineering	Asian	Male	Large
	Alisa	1	Second year	Chemical engineering	White	Female	Large
	Todd	1	Second year	Mechanical engineering	White	Male	Large
	Zack	working on 1st Co-Op	Second year	Mechanical engineering	White	Male	Large
Category 5	Clare	1	Third year	Biomedical engineering	White	Female	Midsized
	Nick	2	Third year	Chemical engineering	White	Male	Large
	Kelly	3	Fourth year	Industrial engineering	White	Female	Small
Category 6	Tony	3	Third year	Chemical engineering	Black or African American	Male	Large
	Bruce	5	Fifth year and above	Electrical and computer engineering	White	Male	Large
	Jason	4	Fourth year	Mechanical engineering	Asian	Male	Large
	John	3	Fourth year	Mechanical engineering	White	Male	Large

Table 4-2 Continued.

	Mark	working on 1st Co-Op	Second year	Electrical and computer engineering	Asian	Male	Large
	Eric	4	Fourth year	Mechanical engineering	White	Male	Large

The relationships between categories were explored in the later phase of data analysis. The critical differences between categories are summarized in table 4-3. A detailed explanation of those differences can be found in section 4.1.4. As mentioned before, a two-dimensional outcome space emerged at the end of the analysis process. The horizontal axis represents an increased involvement in problem definition and formulation, and the vertical axis represents an increased involvement in solution generation and selection. It became evident that the six categories formed a hierarchical relationship based on the extent to which students were involved in problem definition and formulation and solution generation and selection, as it is shown in figure 4.1.

Table 4-3 Category Relationships

Categories	Differences between categories
Category 1 -> 2	The problem solving constraints and general solution direction are usually specified by customers. Student engineers have limited freedom in generating solutions.
Category 2 -> 3&4	No solution is specified in advance. Student engineers generate solutions based on either their technical knowledge and skills (category 3) or other people's input and suggestions (category 4).
Category 4 -> 5	Student engineers have to identify constraints of problem solving and use multiple recourses, including data and other people's inputs, to solve problems
Category 5 ->6	Problem solving includes the exploration of problem space. Student engineers have the freedom to define problem parameters and research the problem to generate solutions.

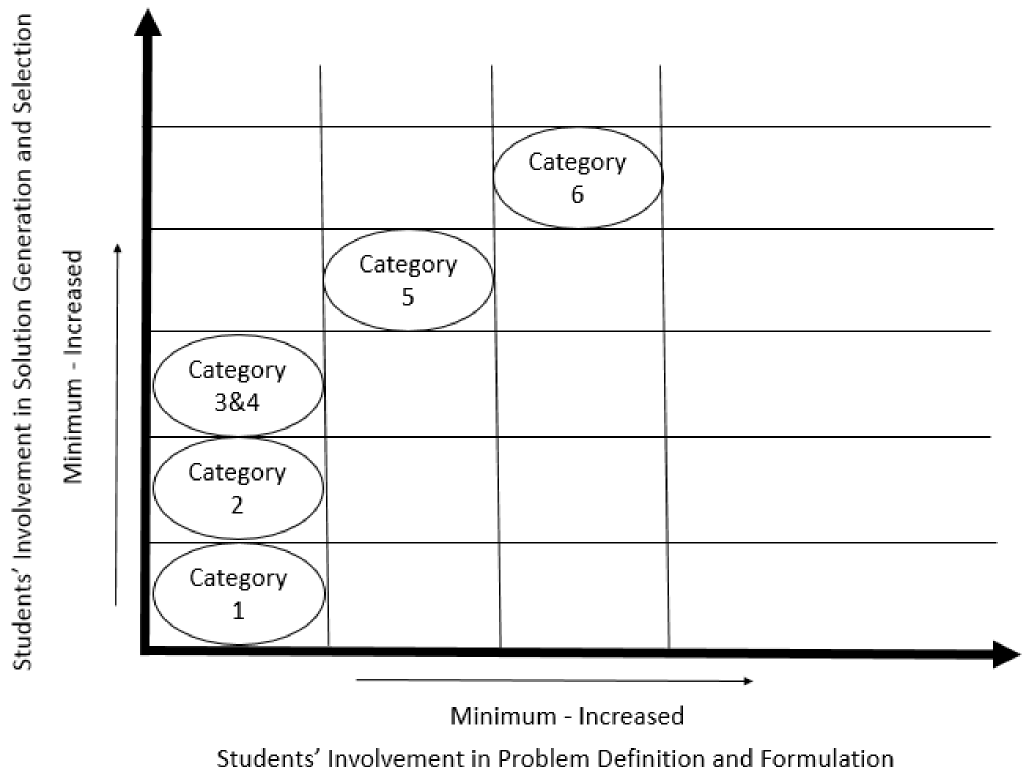

Figure 4-1 Relationship Frame for Six Categories of Experiencing of Workplace Problem Solving

4.1.3 Categories of Description

This section presents the six qualitative ways students experience workplace problem solving. Each category discussed in this section represents a different qualitative way of experiencing engineering workplace problem solving. The categories were generated based on the experiences students discussed in the interviews.

The discussion of each category includes a description of the category supported by quotations from the interviews. The quotations are a small representation of the larger textual basis for the analysis. Although I tried to provide some contextual basis for the quotes, they still cannot convey the whole story contained in the transcripts. In addition, in order to protect the anonymity of participants, any personal information or company/school related information was anonymized.

4.1.3.1 Category 1

Category 1 can be described as such: Workplace problem solving is following orders and executing the plan. The focus of this category is that the way to solve the problem is pre-defined when the problem is assigned to student engineers. Included in this category is the experience of Linda, who illustrated this point in her discussion of how she approached the problem solving task. In her experience, she received clear instructions on how to solve the problem from both her supervisor and company:

> To get started on this one, we started first with the trying to relocate the materials in. A lot of that part of the project was already defined. My supervisor told me “we have this material, we want to move it inside. There's this material there, you gotta move it outside.” I already knew what I needed to do and how, I just worked through–if you're familiar with the management of change process, in Company X management of change it gives a very clear checklist of everything you need to do for any change that you could possibly want to make. That helps you decide what needs to be done.

Later, Linda emphasized again that she followed the process plan documented in her company’s internal system:

> This one required a lot of information. Because there were three parts, and I needed to know all of the different steps required for each part. Company

> X has a lot of systems in place that have information for you. Like, we call it System X, and it has different work documents. It tells you about different processes and what each step needs to be taken for each part of it.

When discussing the solution, Linda further highlighted that since the way to solve the problem was already given, what she did was to execute the original plan:

> For this project, there wasn't a lot of that. The goals were already defined and all I was doing was executing.
>
> In this particular project, there was pretty much a set path that I had to follow. Do all of these things, in this order.
>
> You had to make sure you knew what was on the plan, because I was working on three different parts, and the plans for each part are different. Figure out how, what order all of that needs to be done in. But there's still pretty much a plan.

Linda's interview suggests that she experienced workplace problem solving as executing a given plan. The method of solving the problem is pre-defined, so student engineers do not have to produce alternatives.

4.1.3.2 Category 2

Category 2 can be described as such: Workplace problem solving is implementing customers' ideas and satisfying customer needs. Included in this category are the experiences of Steve, Roy, James and Sarah. In these students' experiences, workplace problems are identified by customers and many constraints/pieces of problem-solving related information are provided to student engineers by customers when the task is assigned. Steve talked about how the customers encountered problems with handles and approached his company for help:

> We were making, they're called cup impactors. It's a handle that threads onto a cup that is used in a hip implant. The handles that were made had two bends in them, and then they had a shaft and gear drive linkage through them that would tighten the screw at the end and attach the handle to the cup. They were forever breaking. The surgeons would hold the handle and hit it with a mallet, and the force would just break the thing, shatter it right through the middle. A lot of times, the handles would break, the threads would break. Pretty much everybody that had to use them, all the doctors that had to use them, hated them. We had doctors that wanted us to make them stronger. They didn't want them to break. We had a couple of different projects, a couple of different attempts, anyway, where we tried to redesign these handles so that they wouldn't break, and a lot of it, just making the walls thicker. That was one that I worked on, trying to figure out how much bigger you'd have to make it before it'll break.

Roy also described how his company received work orders from customers:

> Again, the customer approached us. We had had a longstanding relationship with this customer. Generally, they said when they wanted to try something new, they'd say, "Hey, this is our idea." They only had so many engineers there, and kind of what we provide is kind of a buffer. They have a lot of extra RND money, but they don't have enough

engineers. You're not gonna go out and just hire a bunch of engineers. Essentially, they kind of give us those extra projects, and when they don't have that extra money or whatever, they just don't give anything to us. Like I said, we provide, essentially, a buffer for our customers. They said, "Hey, we wanna show you something different." They were actually doing an electric version, parallel with this in our same company, just different individual working on it. They said, "Hey, make this happen. Let's see what you can come up with."

The project James worked on was to design a new conveyor system for his company's customer:

This was actually a project that the customer needed. They came to us. They came to our company looking for us to build a new system for them and that's how this project came about.

Student engineers whose experiences comprised this category believed that the overall goal of their problem solving activity was to satisfy customer needs:

Steve: I mean, it was a pretty simple objective, really. The overarching objective was to stop having complaints with these instruments. I mean, everybody uses them, so we were trying to figure out what we gotta go to make the complaints stop. The solution to that is make them stronger so they won't break.

Roy: The overall main object was to produce a prototype that fulfilled all the customer's basic requirements, as far as inputs and outputs. Have that

> done in, I'm thinking, I believe it was eight weeks. Cost wasn't a big constraint, but mainly time, and just kinda the final functionality of it.

In those student engineers' experiences, the problem solving requirements and constraints were usually specified by customers when the work was assigned. Steve referred to the product of his work as a custom instrument, and although he indicated that there were safety guidelines and professional standards he had to follow in the design, he felt his customer had a clear picture of every detail. The major constraint of his work was to produce exactly what the customer asked for:

> With customs, it's evolving in the industry too, but when I first started, there was very little that you had to worry about with a custom instrument, because the doctor was the one asking for it, so all the responsibility, more or less, fell on him, cuz he ordered it specifically like that.
>
> With customs, which is mainly what we were doing, because of the nature of the industry, customs didn't have as much strict rules and guidelines. For the project that I was working on, that impactor project, you had to make sure that it was gonna work. I mean, that's the main constraint. It's gotta do what he wants it to do. If it doesn't, then that's not it. A lot of orthopedists, doctors want their instruments to look pretty. That's another design requirement. They want things to look pretty.

In Roy's experience, constraints such as time and packaging came directly from customers and were communicated to him through his manager and senior engineers:

> The overall end goals were just told to me. My manager said, "Hey, this is the project. We have to come up with a surgical tool that does this, this,

> and this when you pull this trigger. It has to be done by this date, cuz they have a show that following week. You'll be working with this person. I'll be talking with you throughout it." Those were just given to me. The packaging constraints, that was mainly just what the customer wanted. They said, "Hey, we wanted this to fit inside of here." That wasn't actually a constraint to start with, but it's kind of one of those unspoken constraints. It's just packaging.
>
> Those two constraints actually were. Being kinda lower on the totem pole, you generally have exact goals and action that was given to you from like the senior engineer and up, saying, "Hey, I need you to do this." All those goals are very well defined. We had an exact date of when they had to have it done, cuz they had to show. We knew exactly what it had to do, what the output had to be, and what the input had to be. Even space claims were given to us. Their internal industrial designers designed the housing for this, and then we had to fit our components inside of that. Within that, those were the main constraints, I guess, for the overall. Anything inside was left up to us.

Sarah pointed out that there were some standards her clients set up and she had to follow them:

> I needed to use Client X's standards. Also, the American Disabilities Association standards, as well as the actual project files that we were using.

James also felt many constraints such as scope and cost were already agreed upon between the customer and his company before he worked on the project:

> We knew exactly what we were doing before we –so when we took on the job, we knew–our scope is defined. It's written, exactly what we're gonna do and what we're not gonna do. Everything's planned out before engineering actually starts working on it. According to what we specify on that scope, a bid is given that this is how much it's gonna cost the customer. If the customer agrees, we do exactly what's said on the scope, so it's very clearly defined.
>
> The final date is specified by the customer, so they tell you – they tell us when they want the project by. On any project, it can be different. Some projects are just really quick. Some of them are maybe five days and some can be three or four months depending on how urgent is the customer's need. Depending on how much the time frame is, the project is given priority. If it's something that's due within the next week or so, it's called a hot job, basically, and those are given priority before taking the long length project.

Because customers usually specify their expectations at the beginning, the goal and constraints of problem solving are clear to student engineers and the way of reaching solutions seems to be straightforward. The focus of engineering work is to implement customers' ideas and meet the requirements. Within this implementation process, student engineers try out different ideas and select the best way to complete work:

> Roy: It was just kind of doing it. We had our constraints fairly well defined. We just kind of had an idea, talked about it a little bit. Just had an idea and just kinda made it happen.
>
> To the overall project, it was just mainly one solution. Again, they had kind of the idea that they wanted to, we just had to implement it. Within that, we ran into plenty of issues during the first prototype, that you had to go back and figure out. Okay, we have too much friction here. Let's put in bearings. This piece is rubbing here. Let's add a little standoff instead. Within there, there was tons of different solutions we had to come up with.
>
> Steve: It was pretty well conveyed to me like, "Okay, this is what needs done," so the solution was pretty easy to come to, pretty quickly, for that. The answers come pretty quick, I mean, it was pretty straightforward work. It wasn't really like research work at all. You didn't really have to take too much time to figure out what you were gonna do. I mean, it was pretty straightforward.
>
> Because, like I said earlier, yeah, they tell you what they want you to do, but then, I was always trying to be like, "Okay, how can we make sure?" How do you really make sure you're doing it right? You make multiple designs, but you really rarely had to do any more than four concepts, maybe, to decide that what you had was about the best you can do.

Students whose experiences comprised this category also discussed how the success of their work was measured by customer satisfaction:

Steve: I mean, as long as the complaints stopped. The doctors and the reps will usually call you back after, though. Usually there's like a surgery that they intend to use it for, and if everything goes well, you usually hear back from the sales rep that it went well or it didn't go well, so you have direct verbal feedback from the customer whether or not what you did was good.

Roy: It was mainly just customer satisfaction, I suppose. Also the fact that either it worked or it didn't. For the most part, it would work. Sometimes, it would hang up. Which, again, would be nice to have another four weeks to figure out why it was doing that. Didn't have it. Mainly just customer satisfaction, feedback, and then just kinda the blatant, yeah it works, or no it doesn't.

Sarah: I'm not exactly sure about criteria, but I know that it will be our client, which is Company X, will be the one to judge the project.

James: Well, if the cust–our company has some–our internal mission in the company is called letters in the lobby. What that basically means is if you do a good job for a customer and if they like your work, they give you a letter which says, "Thank you for doing this for us and we liked it." We display that letter in our main lobby. Getting a letter in the lobby is one of the biggest things that you can ask for at the manufacturer because that gives you an actual evaluation, and that you did well on the project. You did well while you were working on it, and they liked the end result, so the customer comes back to you and says, "I liked your work." We display the

> letter proudly in our lobby, so I guess that would be a measure of success.
>
> Yeah.

In summary, student engineers in category 2 solve problems to satisfy customer need. The goal of problem solving and the majority of the constraints are specified by customers, and usually customers will give specifications on what the final product should look like. The major responsibility of such student engineers is to implement the customer's idea.

4.1.3.3 Category 3

Category 3 can be described as such: workplace problem solving is using mathematical and technical knowledge and skills to solve technical problems. The focus of workplace problem solving is to use hard engineering knowledge and skills to generate solutions to meet technical requirements and constraints. Included in this category are the experiences of Ethan, Alice, Ryan and Jennifer.

The main objective of Ethan's project was to redesign an interface between the connector and module and he felt this objective was well-defined. When talking about the constraints of this project, Ethan went into technical details:

> The main constraint that I had was restriction in a torque direction and in a pullout direction and maintaining the structural integrity of the connector and the module.

When discussing her own responsibility in the project, Jennifer used the word "calculation" and discussed the specific technical constraints she encountered in problem solving:

> My main task was to calculate the overall impedance of the circuit, because it couldn't be above–they wanted it to have really low resistance, so it couldn't be above 0.1 or 0.2 milliohms or something like that. I had to do constant calculations to make sure that our design fit that specification.

Ryan's project required lots of coding and programming skills, and he identified his problem solving constraint as a certain code he had to use:

> I guess my project manager. I could have gone to him, but it was really, as far as like constraints or guidelines it was pretty straightforward. It was, I had to use a certain code, but that was the code that they use for their company wide. There's no reason to go outside of it.

Alice's project was to create an analysis to determine potential issues that would occur on the 69kV line. In her project, she had to make sure the arresters could work in a different power level:

> One of the constraints we had was that the standards that they were giving us didn't match the line that we had because our main company is located in a different location, so they have different power levels than us. When we went and tried to implement those arresters they didn't fit our design, so we had to go back and research and look at our drawings and see which one would work correctly without creating an overvoltage on the line.

In the solution generation and selection phase, student engineers had to use their technical knowledge and skills to come up with ideas and they felt one of the most important criteria to select the final solution was to meet the technical requirements. For example, Jennifer discussed how the constraint on resistance affected her choice of material in her final solution:

> It affected them quite a lot because at first I thought this design project I could just kinda do whatever I wanted and make it work, but I was really limited to the material I was allowed to use, because it had to be–I could only use pieces of copper because that had the lowest resistance. I couldn't really use chains or hooks or–kind of stuff I wanted to use, I learned I wasn't able to use. I was very limited in the material aspect, I guess.

Ryan pointed out that knowledge of coding and schematics played an important role in his problem solving:

> I needed, I used code manuals to kind of make sure I was using the codes correctly and those were readily available to me. I also used schematics of all the assemblies, which were pretty readily available as well.

When Ethan described the information he needed for his project, he mentioned a lot of technical details:

> I needed dimensions of the connector that we currently we using. I needed dimensions in the module to know what kind of room I had to meet up with. I needed to know material properties to know what kind of strength the connector, or the potential strength that it could have.

Then he discussed how he used different technical skills to analyze and solve the problem:

> To measure things what we had done was computer analysis on the connector. We had to make sure there's–or on the connector there were kind of bending tabs, so we had to have those analyzed to make sure that they would be able to bend properly. Also, we had physical connectors made so we could kind of play around with them and see how they interacted and kind of optimized the geometry to help.

Ethan further discussed how he narrowed down multiple solutions to the final one based on the technical constraints:

> Mostly on how well we thought it would meet the constraints of restriction in the areas that it had to meet restriction. Some of the connectors had maybe good restriction in one direction, but not the other, and so that wouldn't really satisfy our goal. We had to really narrow it down to ones that did both and did both well. We narrowed it down to two and it really got narrowed down to one at the end because it was a lot better at restricting both directions.

Student engineers whose experiences comprised this category discussed how their final problem solving product was evaluated based on the technical requirements and performance. For Ethan, the assessment of a final solution was based on how well the solution met the technical constraints:

> We had torque requirements and force requirements that we had to meet. There's also testing requirements. When the module is running in different kinds of conditions it has to make sure that it stays in the module.

Jennifer believed the criterion to evaluate the project was successful calibration:

> I guess they were able to successfully calibrate some of their other models of this product that they make, so I guess that's how.

Alice also commented on how her work was evaluated based on technical performance:

> The success of the project was determined by how much it cost, how much it was able to fix the reliability on the line, how much flashovers it would cause on the line, and how many breaker failures it would cause.

While student engineers whose experiences comprised this category discussed multiple aspects of their problem solving experiences, they put a strong emphasis on the technical aspect of problem solving. Their approach to problem solving is mainly built on their technical knowledge and skills and the main purpose of their problem solving activities is to meet the technical constraints of the problem.

4.1.3.4 Category 4

Category 4 can be described as such: Workplace problem solving is consulting different people and collecting their inputs. Those inputs later play a critical role in solution generation and selection. Included in this category are the experiences of Greg, Alisa, Todd and Zack. Unlike student engineers in category 3, who mainly relied on technical knowledge and skills to solve problems, students in category 4 approached problem solving by collecting and applying feedback from different people. Therefore, their final solutions were largely impacted by other people's inputs.

The main objective of Alisa's project was to make sure all sight glasses were under safety. When talking about her major responsibilities in the project, Alisa emphasized that she had to go through many meetings with people to understand what was going on with the sight glasses:

> I had to do a lot of meetings in order to know what sort of pressures that the sight glasses would be under and exactly what chemicals because it wasn't always clear exactly what was going through these pipes and into the sight glasses. I had to do a lot of meetings to determine that and then determine if the sight glasses were even being used by the operators. If not, we could just get rid of them all together. It was just a lot of getting to know what was actually happening with the sight glasses and then going from there.

The project Greg worked on was to design a remote care system for the pacemaker. His responsibilities in the project also included communications and gathering information:

> I was required to help gather some information from marketing and also help communicate with the software team to see whether a new feature was feasible in the timeline.

Todd's major responsibility in his project was to conduct tests to determine which kind of bolt would meet the thread engagement requirements and company specifications. In the interview, Todd mentioned how the direction of his tests was always driven by people's input:

> It was more, they run these tests, let's see what we got, and so a test that probably should have taken three or four weeks took close to six or seven, because every time we got new data, either the Project Engineer would say, "Well, let's do this test because let's see what happens if you go this direction," or Manufacturing would say, "Oh, I like that. Let's go that way, cuz that kinda supports our point of view on this."

In Zack's interview, he mentioned at the beginning he had to do some design work, but later he recognized his major responsibility was coordinating between people and had different groups of experts to provide verifications on his work:

> I was in charge of the design, so I did the CAD work. I worked with a rep from one of the companies that makes actuating cylinders. I was in charge of, sort of, coordinating when this could take place. I had to go to weekend work meetings cuz this had to go in on weekend. Can't do it during production, so we went in on weekend to install this. A big part of the project was coordinating between many different groups.
>
> The next issue that came up was availability of people, getting everybody together. We had safety people come in and verify that it would be okay. Quality people had to ensure that this would improve the quality, not harm the quality, and a lot of installation was done with maintenance. There's three groups right there, and there were a few other involved, but getting everyone together was tough.

When asked how solutions were generated, Alisa mentioned her company brought experts from an outside company to help them find solutions:

> Well our plant had just been acquired by Company X, it was initially Company Y. We were using Company X standards to follow. We already had sort of a guideline of this is what you need to do. We just kept going until we got to their standards, but then we did bring in the engineering company who were very familiar with what Company X standards were. They definitely guided us in saying when you have this, this is what you need. When you have that, this is what you need. That helped us a lot.
>
> They would offer up solutions, like why don't you just use a rotometer that doesn't have a sight glass on it or just use some sort of level thing that pops up or down and goes to some sort of computer.

In Alisa's case, multiple solutions were generated and the selection of the best solution was based on the operators' preferences:

> Yeah, it was usually the operator who would tell us because they're the ones who use it, who actually like I use this in order to tell this or if we have a problem I troubleshoot from here.
>
> They would usually have the final decision because if they say they definitely need it then we would have to come up with a way to replace it. If they say okay fine I can do without it, then we would say okay good and we could get rid of it. Usually the operators had final say.

In Todd's project, usually the people he worked with in the project, like project engineers and manufacturing people, would determine the choice of test:

> I told you, the test grew every couple weeks. After we conducted one test, they'd say, "Oh, that's an interesting result. Let's do this one as well," which was kind of frustrating for me, because I'm used to a classroom setting where it's kinda like, "Complete this, and you're done." This one was, "End up somewhere around here, and we'll decide whether we're done when we get to that point."

In Greg' problem solving experience, the solutions were generated based on team brainstorming, and the final solution was chosen based on team members' experience:

> It was my team, and they have previous experience. They just followed the previous experience.

In summary, student engineers in this category worked and communicated with different people in the engineering workplace to collect inputs and feedback in order to generate solutions and finalize ideas. Students' personal knowledge and preferences on the solution became insignificant in this category.

4.1.3.5 Category 5

Category 5 can be described as such: Workplace problem solving is using multiple resources such as data and perspectives from other people to draw conclusions or support decision making. Included in this category are the experiences of Clare, Nick and Kelly. The student engineers whose experiences comprised this category discussed using evidence such as data and people's suggestions to draw conclusions and make decisions.

The main objective of the project that Nick worked on was to lower packaging waste. However, it was not clear what factors were contributing to the waste. Therefore, Nick had to analyze the process data to compare findings in the data with information he received from plant engineers and identify factors that impacted the packaging waste:

> I'd say, like I mentioned before, it was–it's a lot of analyzing process data cuz really, we would be in communication with the engineers in the plants a lot and they would–we'd come to them saying, all right, what are you seeing in the plants that's impacting the packaging waste number? They'll say, it's–it could be this or this and then we'd go and look into this data reporting system that tracks all the different manufacturing metrics, how many products are being made per day, where are the products being lost, and try to pinpoint where it's going wrong and try to support their argument with some kind of graphical evidence or statistical evidence.

During the process, Nick consulted with different people to make sure he interpreted data in the correct way:

> We communicated a lot with the person who was kind of responsible for implementing all these different data reports where you can have it tell you all the different statistics and whatever. We talked a lot with the people who develop that to kind of get a better feel for what exactly the data is representing so that we weren't looking at something and trying to say that it was representative of something it wasn't, just kind of wasting our time doing something like that. We talked a lot to the people who were

familiar with that system before we just kind of jumped in making a lot of claims about some set of data.

Nick further explained that data and people's input were two major issues that informed his problem solving:

> I think a lot of it came down to analyzing the data that we got from our– from the database system was the biggest one. Then also you kind of have to get into the plants and talk to the people who are seeing the stuff every day, like the operators and that kind of thing. We relied a lot on their experience to kind of help us along in solving the problems. Then at the same time, we kind of had to look at the data and correlate that somehow to what they're telling us.

Kelly worked on a project aimed at increasing the yield of three mills, and she also recognized she had to take into account both people's inputs and data resources to solve the problem:

> A lot of the resources were like people resources, so we needed like a perspective from both the operator stance and the upper level management stance because they both had different things and saw things from different perspectives. Okay, well, some of the data resources that we needed were like previous yields and like previous like OD/ID wall measurements and stuff like that.

Similarly, her approach to problem solving included the use of statistical analysis as well as communication with operators to identify areas for improvement:

> I mean, it was a method of like making a bunch of like different charts and tables that we could look off of, or making like different diagrams, or just looking at something and seeing hey, why are we doing that and going back and asking the operator is there any way we can–like say, for example, in one part of the event we wanted to cut back less, so like we're taking a foot off of each end every time it goes through a process. Why aren't we taking less? Why aren't we taking a half a foot and saving some of that material? It was a matter of just either going out and doing it or looking at the data we had and trying to draw some sort of conclusion.

Early in the interview, Clare discussed the calculations she needed to perform in order to complete the project:

> That one I had to do some–well in chemical engineering we do a lot of like mass and energy balances, so I had to do some of those around they system to figure out like my flow rates, my pressures, what size of nozzle I would need.

But later, she recognized that talking to people and listening to their suggestions also helped her come up with solutions:

> Yeah I guess I brainstormed. I just looked for all my options, and then just like weighed which options would be better. Talked to people who actually knew what they were doing with the system. Cuz I wasn't very knowledgeable on it yet. I discussed that with them, and saw what their thoughts were. Went from there.

At the end of her problem solving process, Clare relied on both technical criteria and people's preferences to make the final choice of solution:

> I just went through and analyzed the nozzles and saw like which ones had the highest flow rates or the least pluggage, or just like I talked to people and saw what they thought would most likely work for that application just based on their past experiences.

In summary, student engineers in this category used multiple resources including data and people's inputs to complete their work. Engineers talked about how they synthesized and compared information to make decisions and draw conclusions.

4.1.3.6 Category 6

Category 6 can be described as such: Workplace problem solving is an exploration and research process to solve ill-defined problems. Included in this category are the experiences of Tony, Bruce, Jason, John, Mark and Eric. Student engineers whose experiences comprised this category believed that workplace problems are ill-defined and engineers need to take the initiative to explore and define all the parameters and generate solutions based on an investigation of the problem.

The main objective of Tony's work was to monitor all water treatment facilities and figure out how much it cost the company to produce a gallon of ultra-pure water. Tony felt this objective was only a general guideline, and it left him with enough freedom to explore the problem space and define related parameters:

> More money to the cost is the general statement. There are different ways to monitor the cost and there are different parameters to actually guide that cost. Everything is on you as an individual to know define what parameters you feel is relevant enough to make it into the list. The scope is infinitely wide and you have to narrow that scope to say, based on my parameters that I have defined within this scope of work, looking at this tiny segment, while taking the rest of the entire process into account, this is what I think the cost should be. Your answer is all relative. College you're expected to the right answer or wrong answer. The real world no, it's a range of answers that could be correct. Then based on your definition you can say narrow it down to a smaller range.

In Bruce's case, the problem was ambiguous and it depended on him to determine the direction of problem solving:

> It—there was a lot of grey area. It wasn't, okay, this is what you gotta do, go to it. It wasn't that at all. There was a lot of grey area and a lot of free will to kind of do what you want to. There wasn't a yes/no answer. Basically, like I was given the ability to do what I wanted to do on my specific part of the project.

Jason also believed his project was ill-defined and he had to talk to different people to better define the goal and understand the problem:

> It was not well-defined. It was really up to me to speak to whoever was going to be using the elevator or the lift a lot more, or whatever the manager was expecting from me.

John had a similar sense that he needed to work on the problem to make it more well-defined:

> I'd say that it wasn't that well defined. My manager is basically like just stay on top of the disassembly and go over there and look at our parts and see how they did. I definitely had to learn a lot as I went and ask a lot more questions to make it more well-defined.

Eric used the word "vague" to describe his project and recognized both the responsibilities and freedom he had in problem solving:

> The more I think back on it, it was definitely a vague project. I mean my boss basically told me when I walked in the first day, "Here you go. Do this." I probably talked to him maybe four times the entire rotation. His work was so much higher up than what I was doing on my first rotation that–so I kind of got a lot of responsibility and freedom, kind of approached the problem I want. I would say, yeah, it was very loosely defined. I had to define it as I went along. I had to define it myself.

Student engineers in this category believed because workplace problems were not well-defined, part of the problem solving process was to better define and understand the problem:

> John: I just kind of had to sit down and think about it for a while because it was so broad. I sort of had to define it myself, so part of it was just kind of sitting down and thinking about it and the other half–because I really didn't know what I was doing–was just diving in, seeing what happens.

> Eric: Starting high-level, basically I had to define–pretty much I was given a loosely-based, here's this problem. I had to first define what's truly the problem and do some background because I'm fresh out of freshman year of college. It involved a lot of talking with our PA group and figuring out what their needs were, how the tests they currently use, what does it do. I've never even heard of this stuff before and I'm supposed to work on this project. Kind of, at a high-level, defining, for me, the problem, kind of figuring out all the necessary background info and what's going on.

When discussing ways to generate solutions, student engineers talked about how they conducted research in the problem area and came up with solutions after they developed a better understanding of the problem and potential solutions. For example, Bruce emphasized the importance of acquiring knowledge of the problem and possible solutions before determining solutions:

> Mainly what I did was I brainstormed at first and I said okay, what all do I need? What's the possible ways of laying this out? How are the lines coming into the substation? What can I do? Then I researched several possibilities. You always have two solutions in mind, because if one doesn't work you wanna make sure you can fall back on the other one.
>
> Basically the method was, do my research. Ask lots of questions, make sure you know what you're doing. Because if you're spending 20 hours working on something you don't understand, what's the point in even working on it? I'll do that and then I'll also–and then you fill in the details

> and then you tweak it and you basically have other people look it over constantly and always check what' you're doing.

Student engineers such as Jason, John, and Mark talked about conducting research through different means such as looking at previous examples, consulting with people, and collecting information before generating solutions:

> Jason: I kind of just—let me see, I started research with looking up similar lifts, what could be done, or if there's similar situations, and eventually ask around what the people, basically the stakeholders who would be using it, what would they prefer, what is good, what is not. Then I look into different possible options I have.
>
> John: I had to talk to the manufacturing people to see what their schedule was. I had to talk to my team to see what they wanted to look at. Also I had somebody come over and help me out, like to show specific cases of wear, and stuff that I should be looking for, so I know the signs of it. I had to get some tools from the manufacturing people to make the measurements and that sort of thing. I had to write the report at the end.
>
> Yeah, I looked at previous examples of reports to see kind of how other people put that sort of thing together, then a lot of just brainstorming by myself. I had to think about what was the most important things that I found. What do people want to get out of it? I just really thought about that when I was putting it together.
>
> Mark: I was motivated to collect information by myself. My boss would generally give me a direction and say that maybe you should think on

> these lines, consider reading from this book, going to this website. Then he would step back.
>
> Then I would research on it for the next week and come back to him, that now I know pretty much about what we are looking for because I read about pneumatics and I think we would run an air line to turn this valve on and off. When you say information collection, obviously, you don't know right at the top of your head how to go about it, but when you get some supervision or some direction from your colleagues or your supervisors—I went about collecting information from automation books, from websites, from my other colleagues talking about it, and that's how I really shaped up in defining what I really want to do.
>
> The best way to go about doing this is to look at something that has been done previously. I actually looked at a panel that was designed by another co-op in the summer. My boss took me there and he said that the co-op that was here for the summer designed that panel. Then I would go up, inspect that panel, see how it's working, take down the number, go back and look up the documentation and see, okay, that's how he did it, but his situation was different. Mine is different. What is the change that I can make?

These quotes suggest that student engineers whose experiences comprised this category experience workplace problem solving as exploration and freedom. In the problem solving process, they contend with ambiguities and uncertainties in problems space. Usually they begin the problem solving process by defining goals and unknown parameters, and they conduct research to better understand the problem and potential solutions in order to generate their own solutions.

4.1.4 Category Differences and Resulting Hierarchical Structure

4.1.4.1 Introduction

An analysis of the critical differences between categories resulted in the hierarchical structure presented in figure 4.1. It became evident that the six categories formed a hierarchical relationship based on the extent to which students were involved in problem definition and formulation and solution generation and selection. The following sections discuss the differences among those categories in detail.

4.1.4.2 Category 1 -> Category 2

The core idea in category 1 is that there is one pre-defined path to solve workplace problems and what engineers do is to follow the path and execute the plan. Therefore, in category 1 student engineers do not have much freedom in solution generation and selection. Whereas in category 2 the general solution direction is largely determined by customers' requirements and the focus of engineering work is to implement customers' ideas, yet student engineers emphasize that within the implementation process they have to come up with multiple ways to achieve goals and select the best one to meet requirements.

For example, in category 2 Roy talked about how his team followed the customer's instructions to implement the idea, but he also noted how they came up with different solutions to make their prototypes better:

> To the overall project, it was just mainly one solution. Again, they had kind of the idea that they wanted to, we just had to implement it. Within that, we ran into plenty of issues during the first prototype, that you had to go back and figure out. Okay, we have too much friction here. Let's put in bearings. This piece is rubbing here. Let's add a little standoff instead. Within there, there were tons of different solutions we had to come up with.

The previous quotation is an example for the sake of understanding the hierarchical relationship between category 1 and 2. In this regard, I believe students in category 2 have more freedom in solution generation than students in category 1.

4.1.4.3 Category 2 -> Category 3 & 4

The critical variation between category 2 and category 3 & 4 is the freedom students have in the solution generation stage. In category 2, the general solution direction is usually specified by the customers, which leaves student engineers with little room for creative solutions. Whereas in category 3, students often emphasize how they generate and select solutions based on either their technical knowledge and skills (category 3) or other people's suggestions and input (category 4). In other words, students in category 3 and 4 enjoy more freedom in solution generation and selection.

For example, Ethan talked about the detailed technical knowledge he needed to have in order to solve the problem:

> I needed dimensions of the connector that we currently we using. I needed dimensions in the module to know what kind of room I had to meet up with. I needed to know material properties to know what kind of strength the connector, or the potential strength that it could have.

Later, after Ethan came up with multiple solutions based on computer analysis and physical experiments, he chose the final solution based on the technical constraints:

> Mostly on how well we thought it would meet the constraints of restriction in the areas that it had to meet restriction. Some of the connectors had maybe good restriction in one direction, but not the other, and so that wouldn't really satisfy our goal. We had to really narrow it down to ones that did both and did both well. We narrowed it down to two and it really got narrowed down to one at the end because it was a lot better at restricting both directions.

Unlike Ethan (from category 3) who relied on technical knowledge and skills to generate solutions, Alisa (from category 4) admitted that her ideas were largely influenced by other people's inputs and the choice of final solution also depended on the operators' preferences:

> They [Outside Experts] would offer up solutions, like why don't you just use a rotometer that doesn't have a sight glass on it or just use some sort of level thing that pops up or down and goes to some sort of computer.

> They [Operators] would usually have the final decision because if they say they definitely need it then we would have to come up with a way to replace it. If they say okay fine I can do without it, then we would say okay good and we could get rid of it. Usually the operators had final say.

Although students in category 3 and 4 utilize different resources to generate solutions, their ways of solving the problem are similar: rely on one single resource to come up with solutions. Therefore, I put category 3 and category 4 on the same level in the hierarchical structure. Unlike students in category 2 who receive general solution direction from their clients when the projects are assigned, students in both category 3 and 4 emphasize how they come up with solutions either based on their technical knowledge and skills or through consultation.

4.1.4.4 Category 3 & 4 -> Category 5

The critical difference between category 3&4 and category 5 is students in category 5 emphasized how they utilized and synthesized multiple recourses to generate solutions. Unlike students in category 3&4 who mainly relied on a single type of resource to solve problems, students in category 5 used multiple resources such as statistics and people's inputs to help them draw conclusions and make decisions.

Nick provided a good example about how he used both data analysis and feedback from engineers to identify areas for improvement:

> I'd say, like I mentioned before, it was–it's a lot of analyzing process data cuz really, we would be in communication with the engineers in the plants

> a lot and they would–we'd come to them saying, all right, what are you seeing in the plants that's impacting the packaging waste number? They'll say, it's–it could be this or this and then we'd go and look into this data reporting system that tracks all the different manufacturing metrics, how many products are being made per day, where are the products being lost, and try to pinpoint where it's going wrong and try to support their argument with some kind of graphical evidence or statistical evidence.

The experiences of student engineers in category 5 revolved more around using multiple resources to solve the problem, indicating that category 5 is different from category 3&4 where student engineers mainly rely on one type of resource.

In addition to that, students in category 5 felt the constraints of the problems were not given to them and they had to identify those constraints in their problem solving process, as Nick mentioned:

> I guess it–like I said, it kind of–as we progressed with the project, at first, it [constrants] wasn't–it might not have necessarily been clear. Cuz like I said, going in, a lot of the people who just kind of knew about the project, but not necessarily all the details, just kind of had this misconception that it was just a matter of fixing one little thing on one of the pieces of equipment and that's gonna cut your waste in half. It just turned out that wasn't the case.
>
> Really, it just was a matter of gaining familiarity with the problem, communicating a lot with the people close to the problems in the plant, the operators and engineers who work on the problems every day. See, as we

> communicated with them, it kind of became clear that there was–the scope was pretty big and this was just gonna be a long-term goal that necessarily wasn't just gonna have one quick fix where you just buy a new part, slap it on the machine, and that's all you need to do.

4.1.4.5 Category 5 -> Category 6

The critical difference between category 5 and category 6 is students in category 6 recognized workplace problems as ill-defined; therefore, exploring and defining parameters of the problem became part of their problem solving activities. Students in this category emphasized their freedom in defining parameters of the problem space. The solution was usually generated based on student engineers' research on the problem.

For example, in Eric's case, his problem solving process started with defining the problem:

> Starting high-level, basically I had to define–pretty much I was given a loosely-based, here's this problem. I had to first define what's truly the problem and do some background because I'm fresh out of freshman year of college. It involved a lot of talking with our PA group and figuring out what their needs were, how the tests they currently use, what does it do. I've never even heard of this stuff before and I'm supposed to work on this project. Kind of, at a high-level, defining, for me, the problem, kind of figuring out all the necessary background info and what's going on.

Later in his problem solving process, Eric further explored the solution space, by conducting research on the topic and consulting with other people:

> Mainly what I did was I brainstormed at first and I said okay, what all do I need? What's the possible ways of laying this out? How are the lines coming into the substation? What can I do? Then I researched several possibilities.You always have two solutions in mind, because if one doesn't work you wanna make sure you can fall back on the other one.
>
> Basically the method was, do my research. Ask lots of questions, make sure you know what you're doing. Because if you're spending 20 hours working on something you don't understand, what's the point in even working on it? I'll do that and then I'll also–and then you fill in the details and then you tweak it and you basically have other people look it over constantly and always check what you're doing.

John talked in detail how he did his research by looking at previous examples:

> Yeah, I looked at previous examples of reports to see kind of how other people put that sort of thing together, then a lot of just brainstorming by myself. I had to think about what was the most important things that I found. What do people want to get out of it? I just really thought about that when I was putting it together.

In general, students in category 6 emphasized their freedom in problem solving: not only in the solution space (as students in category 5) but also in the problem space.

4.2 Thematic Analysis: Students' Perceptions of the Differences Between Workplace Problem Solving and Classroom Problem Solving

To answer the first part of my second research question, which is how students perceive the differences between workplace problem solving and classroom problem solving, I conducted a thematic analysis. In total, six major themes were developed from the thematic analysis of interview transcripts. In the results section, I presented those six themes, each with supporting quotations.

4.2.1 Theme 1

Theme 1 can be described as workplace problems are different from classroom problems in that they have less given information and different types of constraints. Many participants pointed out that in workplace problem solving, they often received less information than they did in class and they relied on their own ability to identify critical information and solve the problem. In this respect, Tony said:

> You are given a heat exchanger. Your heat exchanger has not been performing right. In a classroom usually they will give you input temperature, output temperature, input pressure. This is what I mean. Every single parameter that you need to solve that problem is provided. Input temperature, pressure, volume, you're told what type of steam it is. You're given some assumptions. Assume that the transfer across the entire heat exchanger is uniform. You go to the real world you find out in some cases they don't even have flow meters. You can't determine the flow rate. You can't determine temperature. There are no devices to measure any of

> those parameters. Now you have to come up with creative ways on how to solve this problem.

Steve also deemed scarcity of information to be the major difference between workplace problem solving and classroom problem solving:

> I think, the biggest difference is the—I can't think of the right word to describe it–like, workplace problems from class, they give you all the things. You have all but one of the things you need to know, and you solve a problem for that last missing piece, typically. It's kind of got like, it's this equation, this equation, and this equation, and your assumptions are—and it's like this really organized, procedural thing. Then you go to work, and your problem is a sticky note with a drawing on it.

Similarly, Jennifer found workplace problems more difficult to solve because they had less given constraints:

> Actually–okay, the co-op one was harder to do, because it didn't have as many constraints as my circuit problem in the classroom did. In this one, I wasn't given the material I was allowed to use like I was for that one, so I kinda had to figure that all out on my own. I guess that was part of the challenge.

Several participants further noticed that the constraints they encountered in the workplace were different from the ones they usually met in solving classroom problems. For instance, Jennifer mentioned that money was an important constraint that seemed only to appear in the engineering workplace:

> They (students without real world experience) might not know–they might not consider money ever being an issue, the way it is in the workplace, because that's never something that comes up in school. At work, it's like "Well, how much money is this project gonna cost us? Is it gonna cost anything?" I guess money is a constraint that comes into play at work that doesn't at school so much. I guess senior design, but probably not most sophomores or juniors know about it.

4.2.2 Theme 2

Theme 2 can be described as workplace problems diverge from classroom problems in that they are more practical and solutions are more realistic. Many participants felt that workplace problems were more practical and solutions had a real impact, while classroom problems had the opposite attributes. Some of the words that participants used to describe classroom problems include: "theoretical," "experimental," "ideal," "simple," and "shallow." For example, Eric commented:

> With the classroom approach, it feels shallow. It feels like you're just faking it the entire time. At the end of the day, here you go, here's your B. Here's your A. You're done. You move on. My projects from work are still being used. They're contributing back to the company like it was an investment for them. They invested money and materials for me to build it and they're gonna use it. There's a reason they invest in money, 'cause they knew that it would pay off.

Another student, Mark, expressed similar ideas:

> After my experience with X Company it's a completely, completely different outlook. Majorly because now, when I look at engineering in school, it is all theoretical. When my friends with a 4.0 are solving questions, I'm actually finding a solution because I tell them that in the real world, you never get a chance to put all your theoretical knowledge into use. You do use your theoretical knowledge, but I would say 90 percent would be your practical experience you gain by working and understanding how things work rather than just solving them on paper. There's a world of difference. Calculation and design on paper, and calculation and design in the real world, in the factory, on the pilot plant floor, very different.

He further argued that while the focus of classroom problem solving was calculation and reaching the answer, in workplace problem solving the physical implementation of the idea would help students look beyond the surface of the problem:

> The classroom project, if I compare it to the co-op, was very similar, and yet, restricted to a simulation environment. If I'm in a classroom and my teacher says that today we will learn how to install a Festo pneumatic manifold to automate two valves, even though you are visualizing, you are not physically doing it. You are not facing the challenges of different mindsets putting their brains together and working together. When it is a project in class, all you need to do is take out your calculator, punch in the values, calculate the pressure, and submit your answer. You get a five out of five and you're done. You don't really apply your mind to really seeing

> that manifold in a factory, and you really can't do that. That is where this practical experience really comes into play. A teacher would explain the principle of a law in physics and give you a question or a project to deal with it. You would just work on the surface of the project and never go into so much of detail that I went with this project in the co-op.

Mark then pointed out the importance of coming up with a practical solution in the workplace:

> When you're in a classroom, you don't have a deadline to meet in order to come up with an idea. You can come up with an idea that is just a bad idea, but you really don't care about it because you don't have any pressure of finishing the project. When you're in the real field, your idea better be good because a lot of people are counting on it. Tomorrow, if that manifold fails, they would go back and see that this design was made by Mark, so he's the one who came up with the bad idea. I will let down a lot of people. There is a lot more pressure, constructive pressure.

Kelly had the same feeling that in the workplace, the solution needs to be feasible and realistic:

> I guess the difference between the Co-Op and class is that when you're in a work setting your solutions actually have to be feasible and realistic, and in class you can just say whatever you need to say to get the grade.

4.2.3 Theme 3

Theme 3 can be described as workplace problem solving is distinct from classroom problem solving in that it requires different knowledge and skills. A number of students mentioned that while classroom problem solving required solid technical knowledge, success in workplace problem solving often depended on other factors, like the ability to work with people, as Alice summarized:

> I think that the major difference between co-op and classroom problems is that co-op problems, like, seem a little bit more detailed, just because it's not just, like, technical knowledge. You always have to, like, talk to people that have been doing, like, your type of work for a long time. So you'll have differences, like, in people that are experts at a certain subject but will still disagree on, like, certain things, and then you have to decide for yourself about what you're going to do to approach that.

Linda also believed that while in the classroom students had to possess technical knowledge to succeed in problem solving, in the workplace the ability to take initiative and talk to people was more critical:

> The difference is classroom problems are usually a lack of technical knowledge that prevent you from solving a problem. Whereas when you're at work, the thing that's going to prevent you from solving a problem is your lack of initiative. Like, every problem is going to require information from different sources, and so you have to talk to as many people as possible.

Several students also commented that although the classroom prepares students with a broad set of knowledge and skills, in workplace problem solving you only need to be an expert in your area of specialization. Correspondingly, Steve said:

> I mean, college tries to teach you everything engineering: The real world and reality is that, an engineering job, you're gonna have a really, really specific kind of engineering that you're gonna do, where 90 percent of what you learn, you're not gonna use at all, and the other 10 percent, you're gonna need to really refine and really understand exactly what parts of that engineering, the technical aspect that you've learned in school.

Ryan had similar feelings:

> Also I feel like the school environment is kinda coming from all over at the same time with all your different classes. Where at work it's kind of you're learning about one thing at one point in time. There's really an emphasis on making sure you learn it. Cuz at work you actually need to know how this stuff works, so not only did you wanna learn it because it's like, "This is important and I'm gonna use this," but you feel like the whole environment at workplace needed you to know it so you could do your work.

4.2.4 Theme 4

Theme 4 can be described as workplace problem solving is unlike classroom problem solving in that the professional environment engineers work in is different from the classroom setting. In the interviews, many students mentioned that the people they interacted with in the workplace and the social environment were different from what they were used to in classroom problem solving. For example, a couple of students noticed the professionalism in the workplace. Roy described it as such:

> To me, at least, working with college students and working in industry, it's just a different feel. You have professionals versus students who have varying degrees of what they call success, versus professionalism. Professionals generally have, you kinda know what the bar is in your company.

Roy further explained why he liked to work with professionals, “As far as time management goes, co-op you're working with professionals. Deadlines generally never get blown. That's actually really nice, to work with that instead of constantly having to bug people to get their stuff to me.”

In many cases in the workplace, students have the opportunity to work with experienced people, and those “experts” play a key role in helping students solve problems. On the other hand, in the classroom everybody is a novice to new problems. Bruce stated:

> In classroom learning, it's a brand new problem for everyone. There's no one person who knows the answer right away, so there's a lot of involvement with your classmates. I'd say that's, if you're looking for one main difference, I'd probably say that is the main difference is, at the workplace, when you've got a problem there's always someone who can help you know the answer. In the classroom, that's not the case, because you're all trying to solve the same problem.

Todd also felt that he was working with experts in the workplace:

> The peer group you work with in a job environment, on average, typically have more experience than you do, at this level of my career. In the classroom setting, my project groups–everyone had the same general level of experience, but at work, there are people who had been there for 40 years, and then there was me, who had been there for ten weeks.

4.2.5 Theme 5

Theme 5 can be described as workplace problem solving differs from classroom problem solving in that workplace problem solving has less guidance. Several participants suggested that while in classroom problem solving the process is often planned out beforehand, in the workplace students have less guidance and have to make plans and choices by themselves. For example, Sarah mentioned:

> Classroom problems are more–they're specifically designed for the students to achieve a certain outcome and there's steps they can follow along the way and they can achieve these–they can accomplish these steps by referring to a textbook or something like that. You're in the real world and you may not even know what steps are gonna be necessary along the way. There's nothing to refer to.

Steve had a similar sense that in classroom problem solving students had an organized procedure to follow:

> It's kind of got like, it's this equation, this equation, and this equation, and your assumptions are–and it's like this really organized, procedural thing. Then you go to work, and your problem is a sticky note with a drawing on

> it, and you need it done in four weeks. You have all these open-ended things. It's not as straightforward. You don't have all of the variables given to you upfront. You have to decided how you're gonna find them and where you're gonna go.

Tony also pointed out that less guidance was provided in workplace problem solving:

> You're on your own. They have someone there who is there to help you occasionally, but you do not get the level of supervision you get in class, where you're forced to go to recitation. The entire process is you, once you are given the problem statement or general idea of the statement.

Because of the lack of guidance in workplace problem solving, students had opportunities to experience failures and learn from them. For example, Eric remarked:

> I guess the way I could best describe it is, on my co-op projects, you gain experience by just doing it and you fail a lot. You make a lot of mistakes. In class X, you get one or two bad grades, whatever. They give you where you should have been, then you start fresh from there and then go on again.

Roy also believed that in the workplace people identified errors, learned from failure and produced better results:

> Unless you're actually getting your hands dirty doing extracurriculars, learning how to fail. You don't get to fail in your academics. If you do, you get a failing grade. Formula SAE, for example, if you fail or if something doesn't work the first time, okay, you go back, you figure out why it doesn't work. You fix it, and then you have something better. That's what you're actually gonna experience once you hit industry. It's not, it

> was a failure, no more. I get the same thing with that project I worked on. It didn't work the first time. Nothing I know of ever works the first time, really. You go back, you fix the stuff that you know. You learn from your failures, and you have sometimes even better the second time around.

4.2.6 Theme 6

Theme 6 can be described as workplace problem solving is distinct from classroom problem solving in that it has open-ended solutions. A number of participants indicated that workplace problems were more open-ended and had more than one solution, compared with classroom problem solving. For example, Alice commented: "I feel like when you're doing your classroom when you're doing a classroom problem, you're, like, going towards one solution, but when you're doing a workplace problem, there are multiple divergent solutions." Ethan pointed out that in real world engineering there were only better solutions, not correct solutions: "In the engineering workplace there's not necessarily always a right answer. You have to kind of weigh the pros and cons of everything and determine what would be better in the end." A similar opinion was expressed by Tony: "College you're expected to the right answer or wrong answer. The real world no, it's a range of answers that could be correct. Then based on your definition you can say narrow it down to a smaller range."

4.3 Thematic Analysis: Students' Perceptions of the Areas They are Prepared by College Education to Solve Workplace Problems

Thematic analysis was performed again to answer the second part of my second research question: What are students' perceptions of the areas they are prepared by college education to solve workplace problems? In general, students felt their college education prepared them for workplace problem solving in four major aspects: knowledge of how to work and communicate with people, knowledge of the problem solving process, software and computer skills, and technical knowledge.

4.3.1 Knowledge of How to Work and Communicate with People in a Team Environment

During college education, students have opportunities to work with peers to solve problems, and many participants felt they benefited from those experiences. For instance, Mark commented:

> Definitely if I was to take this Co-Op right after high school without taking these important courses of team building here, I would probably panic. I would probably be exposed to something that I was not prepared for. Class A, Class B, engineering classes, introduction to teamwork, was really something that laid the base, the foundation for what I was expecting at a co-op. It was a cushioning. It was a soft padding for me to really launch myself in a Co-Op so that when I went to the office, I had the - I had a design in mind as to what I'm expected to do as a team

> member because this is what I learned from class. That experience of taking that class really paid off.

Jennifer also felt she was able to apply her teamwork skills in the workplace:

> I guess in the freshman engineering class, we had to work in teams, so I had to be very used to dividing up work evenly and scheduling meetings and kind of goals of when we would wanna get stuff done.

4.3.2 Knowledge of the Problem Solving Process

A number of students felt that the problem solving process they learned in school education prepared them to solve workplace problems. Todd elaborated on this idea:

> The biggest thing in school that prepared me for this Co-Op thing was a– for the Co-Op program was kind of the problem-solving techniques you get from First-Year Engineering. Those were–helped me approach a problem from an engineering standpoint rather than a non-engineering standpoint.

Steve held a similar position:

> Whether it's technical problem solving or as a manager, people problem solving, you learn how to handle situations, and I think that's the biggest way that college engineering education plays into the kind of work that I did as a co-op.

Alice felt the problem solving skills she learned in class were applicable in the workplace setting: “Yeah, I thought I was able to apply problem-solving skills I've learned in school.

I thought, like, school prepared me a lot to problem-solve and try to, like, communicate to find data."

4.3.3 Software and Computer Skills

Several students noted how software skills acquired in college education benefited their workplace problem solving abilities. For example, Ethan said, "The CAD was definitely a help. If I had not had CAD it would have been more difficult." In Sarah's case, she was able to apply her Excel skills to workplace problem solving:

> Excel. I keep coming back to Excel, but it's just—it's an invaluable tool. If I didn't know how to use Excel, I can't imagine how lost I would been during the course of my co-op. I don't know how common that is for other Co-Ops. I'd imagine it's a pretty useful tool, but not just Excel. I'd say being able to organize a calendar in Outlook and being able to use Microsoft Outlook is a big one cuz you need to be able to set up meetings, appointments, that kind of thing, coordinate between people all over the country and that kind of thing is—was pretty tough. Again, Excel. Microsoft Office in general, like Word, PowerPoint, Excel. Those are the big ones that I'm really glad I was familiar with.

4.3.4 Technical Knowledge

In the interviews, several students mentioned how technical knowledge they learned from their classes helped them with projects in the workplace. For example, Ryan stated: "As well as a course at school here, neutronics, where you actually talk about how different materials affect neutrons and where they're gonna go was big for me knowing what was gonna happen in my project." Linda also commented:

> All the skills you're doing when, a lot of the work that I do at Company X, contractors actually do engineering designs, and then as interns we implement the designs that they've created. But at the same time, the chemical engineering knowledge that you had lets you understand what they've provided and know that it makes sense, or even ask questions if it doesn't.

4.3.5 Areas for Improvements

In terms of areas to improve in engineering education, students suggested that they need more instruction in communication skills, computer and software knowledge, as well as practical work preparation. In addition, some students doubted whether classroom education could prepare them for the workplace. Several of them felt that what they learned in school was not applicable in the workplace. Regarding this issue, Zack said:

> Well, I mean, school gives you an opportunity to work and improve that skill, but as far as the actual coursework that I learned, I found that a lot of it really didn't apply to my job. For example, the physics courses I'd taken and thermodynamics, it's just, I'm glad I know it, but my job there didn't really have much to do with it, to be honest.

There were also students who believed school education and workplace experience were complementary and prepared them to solve real world problems in different ways. Although students stressed the importance of their classroom learning experience, they believed there was no substitute for the real world work experience. For example, Mark explained his point of view:

> Classroom problem solving develops your academic mindset. It just makes you a more hardworking, diligent–I'm not getting the right word. It just makes you a more disciplined person. It just gives you more capability to tackle different varieties of problems on paper. Being a Co-Op gives you the confidence to get up from your desk, go out in the field, solve problems in real. Being a smart kid in a classroom means that you know how to solve all of the problems in the book, but being an excellent co-op is the trust that you really give everybody else, the faith in you and if they assign a problem to you, you will take care of them.

Eric also remarked on this subject:

> I think by its very nature the classroom prepares you for more classroom stuff. It makes sense. I can't say that all of my time in high school, going to class, did not help prepare me for class here at Purdue. Going to class prepares you to go to class. Going to work prepares you for going to work. A build-up of experience. When I look at my fellow graduates who are not co-op students and I've put in 140 credit hours' worth of experience for classroom work and I've also put in, I think it's like 20 months, maybe, for five-term co-op, around 20 months of work experience, not only am I prepared for the classroom environment, I'm also prepared for the work environment. Work prepares you for work. Class prepares you for class and you learn skills, and knowledge, and toolsets valuable in the

classroom that you can apply to work later, but you're not gonna learn how to work. By its very nature, you're basically doing something different hoping to–it's like if I'm training to run a marathon yet I never get off my couch. You're saying one thing and doing something different, which, I mean, it's by its very nature–we're comin' to college to do classroom things. Should we expect to be trained in documenting and being an engineer? There's a higher level of concepts that you learn in the classroom that, coupled with work experience, is what takes you to the next level at work. That's where the classroom experience is very valuable.

CHAPTER 5. DISCUSSION

5.1 Introduction

In this study, I used phenomenographic analysis to explore the different ways students experience workplace problem solving and conducted thematic analysis to identify students' perceptions of the differences between workplace problem solving and classroom problem solving, as well as areas they are prepared by their college education to solve workplace problems. The categories of description resulting from the phenomenographic study and themes generated from thematic analysis contribute to the current knowledge of workplace problem solving and have implications for engineering education and engineering practice. The following sections provide a discussion of results obtained from both phenomenographic analysis and thematic analysis.

5.2 Discussion of the Outcome Space

This section discusses the outcome space resulting from the phenomenographic study. In the outcome space, six different ways of experiencing workplace problem solving were identified and presented in a hierarchical form, which contribute to the current knowledge of workplace problem solving by providing insight into how student engineers experience problem solving in the real world. Unlike previous research in workplace problem solving, the primary focus of which is on the exploration of the nature of workplace problems and how they are different from classroom problems, this study investigated student engineers' actual experience in workplace problem solving.

In total, six different ways in which Co-Op students experience and understand workplace problem solving were discovered in this study. The first category can be described as workplace problem solving is executing the plan. Co-Op students, who can be considered as novice engineers in the workplace, experienced workplace problems as well-defined with one pre-determined solution. This finding corroborates previous research on newly hired engineers, which indicated that "new engineers typically received first assignments in which others had defined the problem and their task was to finish the process or provide assistance to a coworker assigned to the problem." (Korte, Sheppard and Jordan, 2008, p. 6). Because earlier studies point out that classroom problems often possess similar characteristics: they have well-defined specifications and a preferred/known solution (Thomas, Azman, Sandekian and Amadei, 2006; Regev, Gause, and Wegmann, 2008) — it can be inferred that in category 1 students' experiences, workplace problem solving is not substantially different from classroom problem solving.

Starting from category 2, the differences between workplace problem solving and classroom problem solving begin to come into view. Although student engineers in category 2 still do not have much freedom in solution generation and selection, in their experiences customers as stakeholders played a significant role in determining their problem solving requirements and solution direction. Compared with classroom problem solving, the success of which is usually measured by engineering standards (Jonassen, Strobel and Lee, 2006), solutions to workplace problems were mainly evaluated based on customer satisfactions, according to students' experiences that comprised category 2.

Similar idea was brought up by professional engineers, who believed that the central part of engineering work is to understand and satisfy customer needs (Anderson, Courter, McGlamery, Nathans-Kelly and Nicometo, 2009; Trevelyan, 2008).

One major difference between students' workplace problem solving experiences in category 3&4 and classroom problem solving is the freedom students have in solution generation and selection. In classroom problem solving, there is usually a preferred path/solution to solve the problem (Jonassen, Strobel and Lee, 2006) and students often receive hints on how to solve the problem (Regev, Gause, and Wegmann, 2008). However, students in category 3&4 received minimum instructions on solutions and problem solving methods so they relied on either their technical knowledge (category 3) or other people, such as coworkers, operators, external experts' feedback and inputs (category 4) to generate solutions. This finding confirms that the ability to apply prior math and science knowledge into problem solving (Winters et al., 2013) is important for engineers to remain successful in workplace engineering, especially when the problems they solve are technical ones. In addition, the fact that student engineers sometimes had to rely on other people's suggestions to solve problems is consistent with previous research on new engineers, which shows that those engineers often seek for help from their managers and coworkers, in order to better understand expectations and accomplish work (Brunhaver, Korte, Lande and Sheppard, 2010). Furthermore, this study shows that student engineers in the Co-Op program had to talk to different people to collect ideas and suggestions, which might explain why previous research indicates students' communication skills improve significantly during their Co-Op work (Pierrakos, Borrego, & Lo, 2008; Johrendt et al., 2010). To summarize, students from category 1-4 all experience workplace problems as well-defined ones and they don't mention problem definition as part of their problem solving experience. This finding is supported by Yin (2009)'s work, which pointed out that fewer students experienced problem definition when solving well-structured problems than when solving ill-structured problems. One explanation provided by Yin was students were more familiar with well-structured problems therefore they could solve problems without explicitly defining the problem space (Yin, 2009).

In category 5, students not only have to use multiple resources to come up with solutions to solve open-ended problems, but also need to identify the constraints of the problems that are usually given in classroom problem solving. This lack of information on problems is identified in previous studies as one of the major differences between classroom problems and workplace problems (Korte, Sheppard and Jordan, 2008; Regev, Gause, and Wegmann, 2008). In category 6, students experienced workplace problems as ill-defined and open-ended problems, and they felt that problem solving is an exploratory process. In their experiences, workplace problem solving is vastly different from classroom problem solving because the characteristics of problems are the opposite of how the literature described classroom problems: well-defined with much given information and preferred solutions (Regev, Gause, and Wegmann, 2008). Students' problem solving experiences in category 6 share many similarities with new engineers' problem solving experience, which can be characterized by four themes: "organize, define, and understand a problem; gather, analyze, and interpret data; document and present the results; and project-manage the overall problem-solving process" (Korte, Sheppard and Jordan, 2008, p. 6). Compared with students in the first five categories, students in category 6 emphasized that the problems they solved were ill defined and part of their problem solving process was to better define the parameters in problem space. This finding resonates with results from previous studies on Co-Op students, which suggest that students found participation in Co-Op helped them learn not only how to develop solutions but also how to identify and formulate engineering problems (Parsons, Caylor, & Simmons, 2005; Pierrakos, Borrego, & Lo, 2008). This ability to identify and formulate problems is essential to success in workplace problem solving, according to research with engineers and engineering managers (Lang, Cruse, McVey, & McMasters, 1999; Banik, 2008). However, because new engineers are used to classroom problems, which are usually less complex and ambiguous compared with workplace problems, they often find it difficult to define problems and identify important parameters (Korte, Sheppard and Jordan, 2008).

The categories of description reveal that there are different types of problems in engineering workplace. For example, some students experienced workplace problems as well-defined with given constraints, while others experienced workplace problems as ill-defined with unknown constraints. In previous studies, researchers (Jonassen, Strobel and Lee, 2006; Regev, Gause, and Wegmann, 2008) indicated that workplace problems are different from textbook or classroom problems in many aspects, such as workplace problems are ill-defined and can be solved in a variety of ways. However, the results of this study suggest that there might be well-defined problems in the engineering workplace and sometimes there is a set path to solve the problem. The two conclusions may sound contradictory, but are actually not. Several possible reasons are listed and discussed here. First, the purpose of previous studies is to identify universal characteristics of workplace problems. In other words, authors tried to encapsulate what the majority of workplace problems have in common. For example, in Jonassen, Strobel and Lee (2006)'s work, the authors used analytic induction to identify common themes of workplace problem solving within engineering stories to discover shared experiences or patterns. In contrast, in my study I looked for variations in experiences through the lens of phenomenography. Therefore, I had the opportunity to discern the nuances of each individual case. The second reason could be the difference in participants. The participants of Jonassen, Strobel and Lee (2006)'s study were all professional engineers, and the participants in my study were all engineering students. As previous research indicates that new engineers are often given well-defined problems to solve (Korte, Sheppard & Jordan, 2008), it is possible that students were deliberately given those well-defined problems because employers felt students might not have the knowledge and skills to solve ill-defined ones. In order to better understand workplace problem solving, further research is needed to investigate how professional engineers experience workplace problem solving and how engineers who supervise Co-Op students choose the projects and problems they provide to the students.

The model of domain learning describes students' expertise development in an academic field. In other words, the MDL explains what knowledge and skills students possess and what students are capable of in different phases of progress. According to MDL, students' expertise in workplace problem solving develops as they become more involved in the Co-Op program. So I speculate that students with little real world problem solving experience, such as first time co-op students, are more capable of solving well-structured problems, which are similar to the ones they usually encounter in engineering classrooms.

Gradually, with their knowledge and skills of workplace problem solving developing, students can start working on problems that are more ill-structured. However, most Co-Op students don't have the privilege to choose their projects in the workplace and usually they have to work on problems which are assigned to them by their supervisors/managers. For example, if one student receives a well-defined problem and clear instructions on problem solving procedures, he or she might not have much freedom in generating alternatives and would thus experience workplace problem solving as executing the plan. In contrast, if one student receives an ill-defined problem and few instructions on problem solving procedures, he or she might experience workplace problem solving as exploration and freedom. Therefore, in those cases, students' level of expertise shouldn't be judged based on what problem he/she is assigned to solve or the type of problem solving experience he/she has, although in an ideal world, based on MDL, students should be given problems that match their expertise. In addition, the results of this study don't imply that a problem from an upper level category is more difficult to solve, compared with the one from a lower level, but it is possible that the different experiences students have might relate to their level of expertise in some degree. For instance, as was shown earlier, it appears that category 4 (collecting people's input) consists of students who were either working on their first Co-Op session or had completed only one Co-Op session. The possible reason could be that students who were first time Co-Op participants had little knowledge of problem solving and relied on other people's feedback and assistance to solve problems, as previous research indicates that new engineers have to seek for help from their managers and coworkers to solve problems (Brunhaver, Korte, Lande and Sheppard, 2010). Moreover, majority of the students in category 2 had completed all five Co-Op sessions. The reason could be that students were assigned those customer driven projects because the company felt they were experienced and reliable.

The results of this study share some similarities with Daly (2008) and Zoltowski (2010)'s work. In Daly (2008)'s research, she studied how designers experience design and some of her findings, such as design is "a series of evidence-based decision-making" (p. 64) and design is "freedom" (p. 65) are similar to what I have found in my study. For example, in category 5, I found problem solving is "using multiple resources to make decisions or draw conclusions" and in category 6, I concluded that problem solving is "freedom and exploration". Zoltowski (2010) explored the different ways students experience human centered design and part of her results, such as "[h]uman-centered design is keeping the users' needs and how design will be used in mind while designing" (p. 67), is similar to category 2 of my outcome space. These resemblances are not surprising because some of the problems student engineers face in the workplace are design problems/human centered design problems. These similarities actually confirms the validity and reliability of my study by providing additional evidences on how students/designers solve design problems.

5.3 Discussion of Themes

In this study, students discussed the differences between workplace problem solving and classroom problem solving from six major aspects: 1) Workplace problems are different from classroom problems in that they have less given information and different types of constraints. 2) Workplace problems are different from classroom problems in that they are more practical and the solutions are more realistic. 3) Workplace problem solving is different from classroom problem solving in that it requires different knowledge and skills. 4) Workplace problem solving is different from classroom problem solving in that the professional engineering environment is different from the classroom setting. 5) Workplace problem solving is different from classroom problem solving in that workplace problem solving has less guidance. 6) Workplace problem solving is different from classroom problem solving in that it has open-ended solutions. The results show that many differences students identified mapped with what researchers have discovered in previous studies; for example, workplace problems have less given information and guidance, and they can be solved in different ways (Regev, Gause, and Wegmann, 2008; Jonassen, Strobel and Lee, 2006). Some characteristics of workplace problems that researchers have identified from studying professional engineers, such as "engineers primarily rely on experiential knowledge" and "engineering problems often encounter unanticipated problems" (Jonassen, Strobel and Lee, 2006, p. 145), did not appear as common themes in this study. The reason could be the limited number of students included in this study (22 interviews in total) and the gap between the experience and expertise of professional engineers and students. It is highly possible that professional engineers have more opportunities to work on engineering projects that are more challenging and unstable, which means their chances of encountering unanticipated problems are much higher. In addition, this study also found that several differences identified by students are not emphasized in the literature. For example, students recognized that workplace problem solving was more practice focused with realistic solutions, while classroom problems were more theoretical. They also felt that the professional environment in the engineering workplace was something they never experienced in classroom problem solving. Further research with a larger number of students is needed to confirm these findings.

Although previous research with undergraduates indicates that students might not have a clear sense of what engineers do and what the engineering workplace looks like (Matusovich , Streveler, Miller, and Olds, 2009; Jocuns, Stevens, Garrison, and Amos, 2008), students in this study demonstrated that they were aware of the differences between workplace problem solving and classroom problem solving to a certain degree. Based on this fact, I believe students developed a better understanding of engineering workplace in their Co-Op work.

In general, students felt that their college engineering education prepared them for workplace problem solving in four major areas: knowledge of how to work and communicate with people, knowledge of the problem solving process, software and computer skills, and technical knowledge. These results are consistent with findings from previous research with engineering graduates who had already entered the engineering industry and felt that they were well-prepared in “technical background, problem solving skills, formal communication skills and life-long learning abilities” (Martin, Maytham, Case, and Fraser, 2005, p. 167).

In the interviews, students pointed out that more education in communication skills, computer and software knowledge, as well as practical work preparation would benefit them in the long term. Those findings resonate with previous studies conducted with industry employers that suggest that employers expect students to be better prepared in areas such as problem solving knowledge and skills, team work and communication skills, and engineering fundamentals (Grubbs and Ostheimer, 2001; Tuncer, 2003). This again underscores the importance of communication and practical knowledge in real world problem solving.

Finally, students expressed their concerns with engineering education in the interviews. Some of them felt the knowledge and skills they acquired in the classroom were not applicable in the workplace, and several of them believed that workplace knowledge and skills can only be obtained through real world experience. This poses questions for future research: Can workplace problem solving knowledge and skills be learned in a classroom setting? What is the best way to teach those skills?

In my dissertation, I explored students' experiences of workplace problem solving using a phenomenographic study and investigated students' perceptions of the differences between classroom problem solving and workplace problem solving as well as their preparedness using thematic analysis. It should be noted that, the phenomenographic analysis and thematic analysis were conducted separately and it might not be appropriate to map those themes identified in the thematic analysis back to the individual experience I analyzed in phenomenography. Because in the interviews, I asked students to give me one typical example of their problem solving experience in the workplace and the results of the phenomenographic analysis were generated based on analyzing those experiences. It is highly possible that students might have other problem solving experiences in the workplace that influenced their perceptions of the differences between workplace problem solving and classroom problem solving and their preparedness.

CHAPTER 6. CONCLUSION

6.1 Implication for Engineering Education

The results of this study have implications for engineering education. Many students enter the university without much knowledge of the engineering workplace and problem solving, so the courses they take in college may influence their perceptions of what engineering is and what engineers do. Therefore, undergraduate engineering education has the best opportunity to help students develop a comprehensive understanding of engineering workplace problem solving. However, despite the fact that many efforts have been made to bridge classroom education and real world engineering practice, in the interviews students identified differences between classroom problem solving and workplace problem solving. This indicates that there is still a gap between classroom engineering and workplace engineering. For engineering educators who aspire to prepare students to be future engineers, it is imperative for them to understand the nature of workplace problem solving and engage students in solving complex, open-ended problems with real impact.

The results of this study suggest that there are different types of problems present in engineering workplace, and students experience workplace problem solving in different ways. Because there are variations in the ways of experiencing workplace problem solving, it is reasonable to assume each type of problem solving experience will prepare students with a different set of engineering problem solving knowledge and skills. For example, if students experience workplace problem solving as executing the plan, it is possible that no significant engineering knowledge, creativity, and leadership skills are garnered from that experience. Those who prefer receiving clear instructions in work and are good at execution might enjoy this type of experience. If students experience workplace problem solving as fulfilling customer needs, they might learn how to understand customers' needs and expectations very well and how to transform customers' ideas into products. If students experience workplace problem solving as utilizing technical knowledge and skills to generate solutions, they have opportunities to practice advanced mathematical and engineering technical knowledge and skills. If students experience workplace problem solving as consulting with people and collecting inputs, students might develop better communication skills. If students experience workplace problem solving as using multiple resources to draw conclusions, make decisions, and generate solutions, they are probably good at organizing and synthesizing information. Last of all, if students experience workplace solving as exploration and freedom, they might enjoy dealing with ambiguity and taking initiatives in defining and solving problems. Therefore, the findings of this study may be used by engineering educators to design different learning experiences in the classroom to better prepare students with the knowledge and skills required in the workplace. For example, by purposefully engaging students in problem solving activities that require extensive collaboration, engineering educators can help students develop better communication and teamwork skills.

In the interviews, many students also pointed out the differences between workplace problem solving and classroom problem solving and several of them noted that they did not feel the knowledge and skills they learned in class were applicable in the engineering workplace. While engineering educators should reflect on the current engineering curriculum and identify gaps between what is taught in class and what engineers need in the workplace, it is equally important to help students understand the connections between classroom learning and workplace problem solving to become aware of the many ways that classroom prepares them to work in the industry. For example, instructors could incorporate real world examples into teaching and illustrate how knowledge and skills learnt in the classroom can be applied into real world. Instructors could invite Co-Op students or professional engineers to come to engineering classrooms and share their real world problem solving experience with fellow students and discuss the connection between engineering education and engineering workplace practice and how classroom learning can prepare students for their future jobs.

6.2 Implication for the Co-Op Program

In the interviews, many students believed that college education and workplace experience were complementary and prepared them for work in different ways. While students stressed the importance of their classroom learning experience, they strongly believed there was no substitute for the real world work experience. Although the point of this study is not to advertise the Co-Op program and make it mandatory for every engineering student, it is clear that students in the Co-Op program benefit significantly from involvement in real world engineering. Therefore, I recommend that engineering educators encourage students to participate in real world engineering practice such as the

Co-Op program and acquire firsthand knowledge and experience of workplace problem solving.

The study also reveals that engineering students experience workplace problem solving differently in the Co-Op program, depending on what problem their supervisors assign to them. In other words, engineering employers in the workplace have the power to determine students' workplace experience and influence students' perceptions of problem solving. Because Co-Op is an educational program for students to get a taste of real world engineering, I recommend Co-Op employers to involve students in as many different kinds of problem solving experiences as possible in order to help students develop a comprehensive understanding of workplace engineering and acquire a broader base of knowledge and skills required in the workplace. For instance, Co-Op employers could allow students to rotate in different roles among multiple departments when they are Co-Ops in the company. It is equally important for the employers to realize the current gap between classroom engineering and workplace engineering and design relevant training programs to help students adapt to the work environment. For example, employers might want to remind students that there is less guidance in workplace problem solving and they should search for different resources and talk to people to get the information they need in order to solve problems.

Moreover, an advising session to facilitate a conversation between employers and students before students choose which Co-Op company they want to join is recommended, because this could give students an opportunity to learn what type of problem solving opportunities different companies offer and then decide which position would match their personal interest in engineering. For example, if one student is interested in becoming an expert in a particular technical field, he/she might want to work for a company that is more likely to provide them with opportunities to solve technical problems.

6.3 Implication for Purdue's First Year Engineering Program

As a graduate teaching assistant, I have been working in Purdue's first year engineering program for three consecutive semesters and thus possess the firsthand knowledge of how engineering is taught and learnt in the classroom setting. Based on the findings of this study, I have made several suggestions of improvement to the first year engineering program.

First, most students come to engineering with some previous problem solving experiences they gained from high school education and the first year engineering program should help students build on those experiences to acquire additional problem solving knowledge and skills. In order to achieve this goal, it is recommended that the instructional team design a survey to get an insight into students' prior problem solving experiences and require all first year engineering students to complete the survey at the beginning of the semester. Based on the results obtained from the survey, the instructional team could develop and incorporate problems that students don't have much experience with into homework, in-class activities and exams, with the purpose of exposing students to a broader range of problem solving experiences. For example, if most students experience problem solving as mathematical calculation in their high school, the instructional team might want to create some problems that will encourage students to interact and consult with people to find solutions. If students don't have experience in solving ill-defined problems, they should be given more opportunities to work on problems that are not well-defined and require them to collect information to better define problems. During the semester, the instructors and TAs should carefully observe students' progress and ask students questions such as: which type of problems are you mostly comfortable with? Which type of problems do you feel most challenging to deal with and why? Then based on students' answers, the instructional team could adjust homework problems and in class activities to meet student needs and develop corresponding teaching strategies to help students overcome difficulties in problem solving.

Second, it is recommended that current homework problems, in class activities and exam problems could be mapped into the two dimensional space and classified into different types: e.g. technical/mathematical problems, problems that require collecting other people's ideas. By calculating the frequency and summarizing the information, the instructional team would have a better idea of the different types of problems students solve in the first year engineering program. This allows the instructional team to easily identify areas for improvement: e.g. which types of problem appear less frequently in the classroom but should be given more attention? To make sure students can experience different types of problem solving in a progressive way, homework problems and in class activities should be designed in a manner that first encourages students to solve some well-defined problems and gradually move to ill-defined ones.

Third, during the lecture, instructors could introduce the different kinds of workplace problems to students and explain to students that there are different ways to solve problems. To help students develop a better understanding of engineering workplace, the instructors could incorporate examples of real world problems into teaching and invite professional engineers to come to the classroom and share their problem solving experiences with the class.

Fourth, in the interviews, many students mentioned that classroom problems were more "theoretical" and "experimental" and they couldn't see the impact of their work. One way to change students' perceptions and experiences is to provide students with opportunities to collaborate with local communities to help people solve a real problem in the semester design project. This will benefit students in many ways: e.g. students will be able to interact with a variety of stakeholders and understand real world constraints and limitations that they won't be aware of if they are just sitting in the classroom.

6.4 Implication for Engineering Practice

The results of this study have implications for engineering practice. For novice engineers who are just entering the engineering workplace, an awareness of the fact that there are different types of problems in the engineering workplace and a variety of ways engineers experience problem solving might help them become more reflective in their engineering practice and make better decisions when approaching problems.

For engineering employers, understanding that there are different types of problems in the workplace and that engineers experience problem solving in different ways might help them to make better choices when assigning projects to engineers. For example, when a recent engineering graduate first joins the company, it might be better to assign him/her projects that are similar to classroom problems in the beginning and then later offer loosely structured and open-ended projects, as this might help them make a smooth transition from the role of student to practicing engineer. Knowing the gap between classroom education and real world engineering practice could also help companies to predict what novice engineers might not know about the workplace and design effective training programs for novice engineers. For example, helping novice engineers get familiar with the workplace and recognize their sources of information (knowing who they can ask for help) could be one way to help them relieve their stress and adapt themselves to workplace problem solving fast.

In addition, knowing there are different ways of solving problems in the workplace might help the company select the best candidates for their opening positions. For instance, if the company works a lot with clients, it might want to hire someone who is good at communicating with customers. If the company is a high-tech one, a person who has a strong technical background might be suitable for the job.

6.5 Limitations

There are several limitations in this study. First, this study has a limited sample size. It is possible that additional ways of experiencing workplace problems would be discovered if a larger number of students were studied. A larger sample size would also benefit the thematic analysis as more themes might be identified and existing themes could be supported and verified by more participants. Another limitation of this study is the lack of comparison groups. If I could work with students without any engineering workplace experiences and study their perceptions of the differences between workplace problem solving and classroom problem solving and compare the findings with the results from this study, I would have a better idea of whether the Co-Op program helps students get a clearer sense of the engineering workplace. Including perspectives from practicing engineers would also help me triangulate findings from the phenomenograhic study and validate the different ways to solve problems in the workplace.

6.6 Future Research

This study explored the ways that student engineers experience workplace problem solving and their perceptions of the differences between workplace problem solving and classroom problem solving, as well as areas they are prepared by their college education to solve workplace problems. The findings contribute to the current knowledge of problem solving and have implications for engineering education and engineering practice. At the same time, it leaves several questions for future study:

1) The results of this study reveal the different ways in which students experience workplace problem solving. So how does that compare to the different ways that practicing engineers experience workplace problem solving? Furthermore, how does that compare to the different ways students solve classroom problems?
2) In this study, students identified several differences between workplace problem solving and classroom problem solving. How about students without workplace problem solving experience? Will they be able to identify the same differences?
3) Are problem solving knowledge and skills transferrable? What would be the best way to help students transfer knowledge and skills learned in the classroom to real world problem solving?

4) How do we incorporate real world problem solving in the classroom setting to enrich the student learning experience?
5) What is the most effective way to prepare students with workplace competencies in undergraduate engineering education?

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APPENDICES

Appendix A Recruitment Survey

Please indicate your age:
a) 18 b) 19 c) 20 d) 21 e) 22 and above

Please tell us your gender:
a) Female b) Male

Please tell us your year at Purdue:
a) First year b) Second year c)Third year d) Forth year e)Fifth year and above

Which Engineering department are you in?

a) Aeronautics and astronautics engineering
b) Agricultural and biological engineering
c) Biomedical engineering
d) Chemical engineering
e) Civil engineering
f) Construction engineering and management
g) Electrical and computer engineering
h) Engineering professional education
i) Environmental and ecological engineering
j) Industrial engineering
k) Material engineering
l) Mechanical engineering
m) Nuclear engineering

Please indicate the times you have participated in the Co-Op program.

Program	Number of times you have participated in Co-Op program
Co-op program	

You ethnicity is:

a) American Indian or Alaskan Native
b) Black or African American
c) Native Hawaiian or other Islander
d) White
e) Asian
f) Others, please indicates:

Please indicate the size of company you have worked for:

a) Large (more than 500 employees)
b) Midsized (201-500 employees)
c) Small (50-200 employees)
d) Mini/Start-up (less than 50 employees)

Appendix B Interview Questions

1. First, thank you very much for agreeing to participate in my study. Could you tell me why you decided to participate in the Co-Op program?

2. Tell me briefly about your work experience, including your position, how long you worked at that position, which company (companies) or which type of company (companies) you worked for, what your responsibilities were, and what projects/tasks you have worked on.

3. Tell me how you thought about engineering workplace before you participated in the Co-Op program, in terms of the types of problems, the way to solve them, people you work with, etc.

4. Where did your knowledge of engineering workplace come from before participating in the Co-Op program? (How did you know that?)

5. Think about an example of the problem you worked on in your Co-Op program, which you think would be representative of your work place experience. In the next set of questions, I want you to compare this example with a typical problem you solved in classrooms/school.

a) What was the main objective of this project or the task? Was it specified and well-defined or not? Were there any sub-goals? Have you met/worked on similar tasks before? How does it compare to the problems you met in classrooms/school?

b) What was the scope of the project/task and how was it determined (e.g. time frame, constraints)? How did you know that? What were the major constraints of this project? How does it compare to your problem solving experience in classrooms/school?

c) How did you know how to approach this project/task? How does it compare to your problem solving experience in classrooms/school?

d) What was the social environment in your workplace? Did you work in teams or work alone in this project? If working in teams, who did you work with, what was the division of work, and did you work with the same group of people from the beginning to the end? How does it compare to your problem solving experience in classrooms/school?

e) What kind of information (resources) was needed to complete this project/task? Where did you get that information? And how did you know where to get that information? How does it compare to your problem solving experience in classrooms/school?

f) How did you/your team figure out the solution? Was it something totally new or something you have met/used before? How many solutions did you figure out? If more than one, how did you pick up the best solution? How does it compare to your problem solving experience in classrooms/school?

g) Was your solution successful? What criteria were used to determine the success? How does it compare to your problem solving experience in classrooms/school?

h) What's the final product of your project/task? How does it compare to your problem solving experience in classrooms/school?

i) Compared with the goal you set up at the beginning of this project/task, was your goal modified or changed during the problem solving process? (If yes, why and how?) Were there any other elements (e.g. time frame, constraints) that changed during this process or did any unanticipated problems happen during the process? How does it compare to your problem solving experience in classrooms/school?

j) How was information conveyed between people/group members? (Email? Telephone?) How does it compare to your problem solving experience in classrooms/school?

k) Did any conflicts happen/exist when you or your team worked on the project/task? How did you resolve them? How does it compare to your problem solving experience in classrooms/school?

l) What kind of tools did you use to complete this project/task? Have you ever used them before? How does it compare to your problem solving experience in classrooms/school?

m) What kind of knowledge and skills did you use to complete this project/task? Did you learn that from school or somewhere else? Among those knowledge and skills, what do you think are the critical ones? How does it compare to your problem solving experience in classrooms/school?

6) What were the major challenges you met in your Co-Op program? How does it compare to your problem solving experience in classrooms/school?

7) Were you able to apply knowledge and skills you learnt from classrooms/school to problem solving in the Co-Op program? What are those knowledge and skills?

8) How well do you feel you were prepared by your classroom/school learning to work in the Co-Op program?

9) Did you have a chance to reflect on and summarize what you had learnt from your Co-Op work? Were you asked to write a reflective journal or something similar?

10) Based on your experience, describe the major differences between workplace problems and classroom problems.

11) What knowledge and skills are critical for solving workplace problems?

12) How well are you prepared to solve workplace problems? In what areas do you feel your classroom/school learning might help? In what areas do you believe your Co-Op engineering experience might help?

13) Compared with students who don't have such engineering workplace related experiences, what are the things you think they might not know about workplace problems?

14) Compared with students who do not have such experience, what advantages do you think you have in terms of understanding engineering workplace problems? In terms of practicing engineering, in what areas will you perform better than them? Why?

15) How does your Co-Op engineering experience influence your classroom problem solving?

16) For students with multiple experiences: how did your first experience influence your second experience? For students without multiple experiences: how might your experience influence your next experience?

Appendix C Iterations on Categories of Description

Table C 1 First Iteration

Categories	Categories of Descriptions
1	Workplace problem solving is following orders and executing the plan. The method of how to solve problems is known/given in this category and engineers solve problems by following the procedures.(Alisa and Linda)
2	Workplace problem solving is improving current solution and satisfying customer needs. The problem is identified by customers and many constraints/problem solving related information is given to engineers by customers. The aim of problem solving is to satisfy customer needs. (James, Jason, Roy, and Steve)
3	Workplace problem solving is using technical knowledge to meet the requirements and achieve goals. This way of experiencing workplace problem solving is about coming up with technical solutions within constraints. (Jennifer, Ethan, Sarah, and Ryan)
4	Workplace problem solving is finding evidence to make decisions. Engineers in this category have to use data or other information to support their engineering decisions. (Nick and Kelly)
5	Workplace problem solving is working with different people to find out the solution. In those cases, engineers need to consult the problem with different people and people's opinions/schedule/input become critical for engineers in finding solutions. (Clare and Zack)
6	Workplace problem solving is exploration. It involves a lot of trial and error. (Todd)
7	Workplace problem solving is defining the problem and then coming up with solutions. Workplace problems are usually ill-defined and the first step of problem solving is defining the problem. (Eric, John, Alice, Greg)
8	Workplace problem solving is freedom. The majority of the parameters in the problem solving process are defined by engineers. (Tony and Bruce)
9	Workplace problem solving is a learning process. (Mark)

Table C 2 Second Iteration

Categories	Categories of Description
1	Workplace engineering problem solving is following orders and executing the plan. The method of solving problems is known and engineers solve problems by following the given procedures. (Alisa and Linda)

Table C 3 Continued.

2	Workplace engineering problem solving is satisfying customer needs. The problem is identified by customers and many constraints/pieces of problem solving related information are given to engineers by customers. The aim of problem solving is satisfying customer needs. (Steve, Roy, Sarah, and James)
3	Workplace problem solving is using technical knowledge to generate solutions to achieve the goal. (Eason, Jennifer, and Ryan)
4	Workplace problem solving is consulting or coordinating with people. (Clare and Zack)
5	Workplace problem solving is using evidences to draw conclusions or support decisions. (Nick, Kelly, Alice, Greg, Todd, and Jason)
6	Workplace problem solving is an exploration and learning process. (Bruce, Tony, Mark, Eric, and John)

Table C 4 Third Iteration

Categories	Categories of Descriptions
1	Workplace engineering problem solving is following orders and executing the plan. The method of solving problems is known and engineers solve problems by following the given procedures. (Linda)
2	Workplace engineering problem solving is satisfying customer needs. The problem is identified by customers and many constraints/pieces of problem solving related information are given to engineers by customers. The aim of problem solving is satisfying customer needs. (Steve, Roy, Sarah, and James)
3	Workplace problem solving is using technical knowledge to generate solutions to achieve the goal. (Alice, Jennifer, Ethan, Ryan, and Clare)
4	Workplace problem solving is consulting with people and using others' suggestions to solve the problem.(Alisa and Greg)
5	Workplace problem solving is coordinating with people and finishing work. (Zack)
6	Workplace problem solving is using evidence to draw conclusions or support decisions. (Kelly, Nick, and Todd)
7	Workplace problem solving is a learning process. (Eric)
8	Workplace problem solving is an exploration process. (Tony, Bruce, Jason, Mark, and John)

Table C 5 Fourth Iteration

Categories	Categories of Descriptions
1	Workplace engineering problem solving is following orders and executing the plan. The method of solving problems is known and engineers solve problems by following the given procedures. (Linda)
2	Workplace engineering problem solving is satisfying customer needs. The problem is identified by customers and many constraints/pieces of problem solving related information are given to engineers by customers. The aim of problem solving is to satisfy customer need. (Steve, Roy, Sarah and James)
3	Workplace problem solving is using technical knowledge to generate solutions to achieve the goal. (Alice, Jennifer, Ethan and Ryan)
4	Workplace problem solving is consulting with people and using other's suggestions to solve problems.(Alisa and Greg)
5	Workplace problem solving is coordinating people and finishing work. (Zack)
6	Workplace problem solving is using evidences to draw conclusions or support decisions. (Kelly, Nick, Todd and Clare)
7	Workplace problem solving is freedom. (Tony, Bruce, Jason, Mark, John, and Eric)

Table C 6 Fifth Iteration

Category of description (Engineering workplace problem solving is…)	Summary
Category 1: Executing the plan	Workplace problem solving is following orders and executing the plan. The method of solving the problem is known/given in this category and engineers solve the problem by following the procedures. (Linda)
Category 2: Customer	Workplace problem solving is implementing customers' ideas and satisfying customer needs. The problem is identified by customers and many constraints/pieces of problem solving related information are given to engineers by customers. (Steve, Roy, James, and Sarah)
Category 3 Technology and math focused	Workplace problem solving is using mathematical and technical knowledge and skills to solve technical problems. (Ethan, Alice, Ryan, and Jennifer)
Category 4: Collecting people's input	Workplace problem solving is consulting different people and collecting their inputs. Those inputs later play a critical role in solution generation and selection. (Greg, Alisa, Todd, and Zack)

Table C 6 Continued.

Category 5: Using multiple resources to make decisions or draw conclusions	Workplace problem solving is using multiple resources, such as data and people's suggestions to draw conclusions, make decisions, and solve problems. (Clare, Nick, and Kelly)
Category 6: Exploration and freedom	Workplace problem solving is an exploration and research process. Student engineers have the freedom to define parameters in problem solving and generate solutions based on investigation of the problem. (Tony, Bruce, Jason, John, Mark, and Eric)

VITA

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