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# Engineering Students' Experiences of Workplace Problem Solving

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# Engineering Students' Experiences of Workplace Problem Solving


## Abstract

Workplace problems are different from traditional textbook or classroom problems because they are ill-structured and complex in nature. Research shows that engineers need a wide range of knowledge and skills in order to succeed in workplace problem solving. However, it is unclear how engineering students, who will become professionals in the workplace after graduation, experience real world engineering problem solving. Motivated by a desire to better understand engineering problems and prepare students for engineering practice, this study aims to explore students’ experiences of workplace problems solving. As previous research points out that educational programs such as the Co-Op program provide opportunities for students to observe and experience engineering in the workplace and prepare them with workplace competencies, in this study, we interviewed 22 engineering Co-Op students about their problem solving experiences and explored: what are the different ways in which Co-Op students experience workplace problem solving? In order to answer this question, we conducted a phenomenographic analysis on our interview transcripts to capture the variation in students’ experiences. 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.


## Introduction

Problem solving is the central part of engineering work and engineering students are expected to be problem solvers after graduation[1]. For instance, ABET (2013) specifies the “ability to identify, formulate, and solve engineering problems”[2](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”[3](p. 1).

Previous research indicates that workplace problems are different from traditional textbook or classroom problems in many different aspects and engineers need a wide range of knowledge and skills in order to succeed in workplace problem solving[4]. However, it is unclear how engineering students, who will become professionals in the workplace after graduation, experience workplace problem solving. Motivated by a desire to better understand students and prepare them for real world engineering practice, this study aims to explore the different ways in which students experience workplace problems solving.

In this study, we interviewed 22 engineering Co-Op students who experienced real world engineering problem solving and explored: Of Co-Op students who participated in workplace problem solving, what are the different ways in which students experience workplace problem solving?

Literature review

Workplace problems are different from traditional textbook or classroom problems. In literature, researchers have described workplace problems as "ill-structured problems"[4] or "wicked problems"[5]. By interviewing over one hundred professional engineers, Jonassen, Strobel, and Lee (2006) found that workplace problems are ill-structured because they have, among other things, conflicting goals, various solutions, and different types of constraints; they then pointed out that solving workplace problems requires comprehensive collaboration and teamwork[4]. 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"[6](p. 6). Buckingham Shum, MacLean, Bellotti and Hammond (1997) listed some important features of wicked problems, noting that they:

- 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[7] (p. 274).

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) and shown in table 1[5] (p. 87).

Table 1 Comparison between Workplace Problems and Classroom Problems[5] (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. |

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|---|---|---|
| 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. |
| 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. |
| 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. |

Although much research has been conducted regarding workplace problems, how students experience workplace problem solving is still largely unknown. Since students are expected to be problem-solvers within the engineering workplace after graduation, it is important that they understand the nature of those problems that they will encounter and the specific challenges they are going to face in the real world.

Not many researchers have investigated students' perceptions of engineering workplace problem solving. Some of the existing studies we have found suggest that students might not have a good understanding of engineering workplace. For example, Jocuns, Stevens, Garrison, and Amos (2008)'s study indicates some students graduated from engineering without a clear idea of what the actual workplace will look like[8]. Similar findings are shared in the work presented by Matusovich, Streveler, Miller, and Olds (2009). Their qualitative study over a four year period found three out of ten participants were not sure about what engineering is and what it would mean to be an engineer at their third or fourth year in undergraduate study[9].

Because workplace problems vary from classroom problems and engineers need a 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. Brumm, Hanneman, and Mickelson (2005) proposed that one of the best ways to prepare students with workplace competencies is experiential education[10]. 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" [10] (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" [10] (p. 2) and suggested that "Engineering experiential education programs, such as cooperative education and internships, present the best place to directly observe and measure students developing and demonstrating competencies while engaged in the practice of engineering at the professional level" [10] (p. 2).

One typical experiential learning program is the Co-Op program. Garavan and Murphy (2001) defined cooperative education as "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" [11] (p. 281). They summarized previous literature and listed five outcomes of cooperative education program that employers think would be valuable to students: "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" [11] (p. 282).

In this study, we worked with engineering Co-Op students and explored: Of Co-Op students who participated in workplace problem solving, what are the different ways in which students experience workplace problem solving?

## Methodological framework

The methodological framework guiding our research is termed "phenomenography". It is believed[12, 13] that each phenomenon can be understood or experienced "in a limited number of qualitatively different ways"[14](p. 4). Therefore, the aim of phenomenography is to "uncover the variation in ways of experiencing a particular aspect of the world"[15](p. 39). In order to explore such variations, researchers conduct in-depth interviews to elicit the understanding or experience that an individual has of a phenomenon[14]. The result of a phenomenographic study is known as the "outcome space"[14, 15], constituted by the "categories of description"[12](p. 263), a term that describes the differing ways in which people may experience and understand the phenomenon[14]. These categories are often organized in a hierarchical form, from "a less complete understanding" to "a more complete understanding"[14] (p. 4).

## Participant selection and data collection

Data of this study were collected through semi-structured interviews with 22 engineering Co-Op students. The interview questions were designed in a way that encourages students to discuss and reflect on their Co-Op experience. The interview protocol can be found in Appendix A. To recruit participants, an invitation email was sent to students currently enrolled in the Co-Op program requesting participation in this study. A recruitment survey was included in the email, designed to help us collect students' background information. The survey questions can be found in appendix B. Because the aim of the phenomenographic study is to explore variation in experience and understanding, the selection of participants was guided by "an attempt to gain the largest diversity in experiences"[15](p. 41)[16]. This entails "the use of a purposeful sampling method"[14](p. 5). From those who agreed to participate, we selected the final 22 students based on the following criteria: number of times of experience, major, academic year, sex, ethnicity, and size of the company the student worked for (see Table 2).

Table 2 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 |
| 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 | Femal e | 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 |
| Sarah | 5 | Fifth year and above | Civil engineering | White | Femal e | 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 |

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"[17](p. 324) and further emphasizes 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"[17](p. 323). 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"[17](p. 324).

Based on those guidelines, the data were analyzed in the following way: after the interviews were recorded and professionally transcribed, the first author listened to the interviews once more to check the accuracy of each transcript. This process also helped her to become more familiar with each interview transcript. Because of the large amount of data, the first author re-read each transcript two to three times, made notes on the transcripts and summarized the main ideas presented. 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. The whole process was iterative, as the author 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 the first author felt the groups became stable and each group represented a distinct way of experiencing workplace problem solving, she discussed the result with the second and third authors and attempted to generate a description for each group. After the descriptions of how students experience workplace problem solving were generated, the first author read all the transcripts again, which resulted in another iteration of grouping and generating of categories of description. The iterations ended when the first author 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. This process is described by Marton (1986) as one in which "[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"[13](p. 43).

## Results

In total, six different ways in which Co-Op students experience workplace problem solving were identified from data analysis (see table 3). The categories of description were generated based on the critical 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[15]. 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 3 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) |
| 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) |

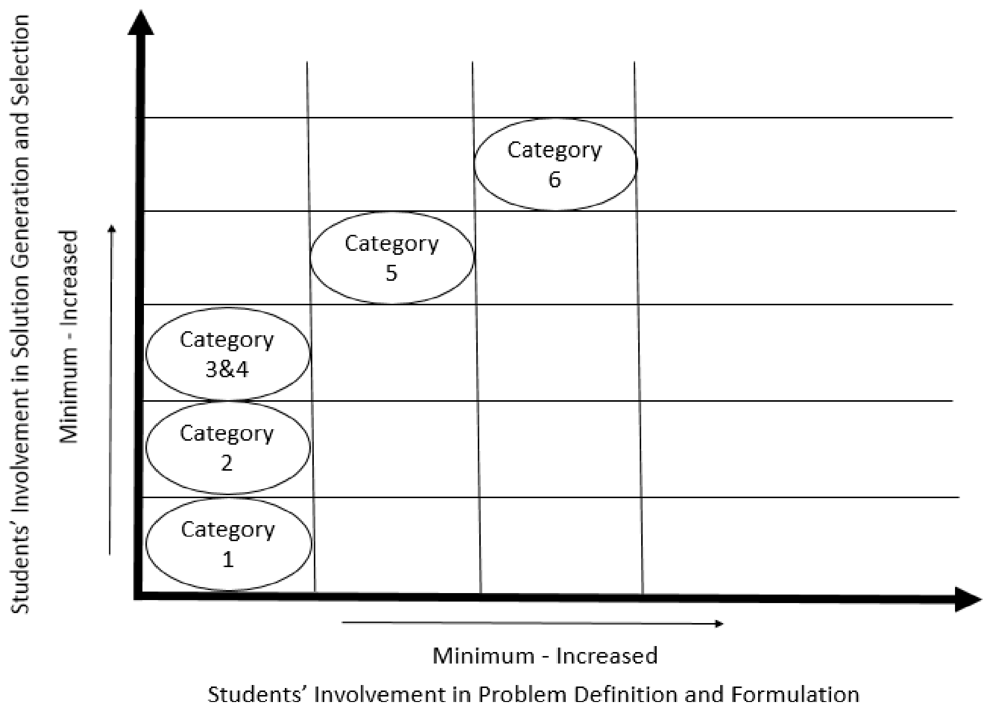
The relationships between categories were explored in the later phase of data analysis. The critical differences between categories are summarized in table 4.

Table 4 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 inputs 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. |

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 1. The following part discusses the differences among those categories in detail.

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




<u>Category 1 -> Category 2</u>

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. Linda illustrated this point in her discussion of how she approached the problem solving task:

> 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.

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 emphasized that within the implementation process they had 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:

> 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.

> 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, we believe students in category 2 have more freedom in solution generation than students in category 1.

<u>Category 2 -> Category 3 & 4</u>

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&4, 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 inputs (category 4). In other words, students in category 3 and 4 enjoy more freedom in solution generation and selection.

For example, 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.

Ethan also 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: mainly rely on one single resource to come up with solutions. Therefore, we put category 3 and category 4 on the same level in the hierarchical structure. Unlike students in category 2 who received general solution direction from their clients when the projects were assigned, students in both category 3 and 4 emphasized how they came up with solutions either based on their technical knowledge and skills or through consultation.

<u>Category 3 & 4 -> Category 5</u>

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 relied 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 [constraints] 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.

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.

## Discussion

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"[6](p. 6). Because earlier studies point out that classroom problems often possess similar characteristics: they have well-defined specifications and a preferred/known solution[18, 5] — it can be inferred that in category 1, students' experience of 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[4], 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[19, 20].

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[4] and students often receive hints on how to solve the problem[5]. 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 and 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[21] 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[22]. 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[23, 24].

In category 5, students not only have to use multiple resources to come up with solutions to solve open-ended problems, they also need to identify the constraints of the problems that are given. This lack of information on problems is identified in previous studies as one of the major differences between classroom problems and workplace problems[5, 6]. In category 6, students experienced workplace problems as ill-defined and open-ended problems, and they felt that problem solving was 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[5]. 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"[6] (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[23, 25]. This ability to identify and formulate problems is essential to success in workplace problem solving, according to research with engineers and engineering managers[26, 27]. 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[6].

## Conclusion and implications

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. 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 team work skills.

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 make better choices when assigning projects to engineers and design reasonable training programs to train new 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. Helping novices understand the nature of workplace problem solving might help them make a smooth transition from the role of student to practicing engineer.

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Appendix A 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 B 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)