AC 2010-165: EXAMINING PROBLEM-SOLVING SKILLS BETWEEN STUDENTS WITH AND WITHOUT ENGINEERING WORK EXPERIENCE

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Examining Problem-Solving Skills between Students with and without Engineering Work Experience

Abstract

Cooperative education (co-op) and internships are forms of experiential education that allows students to complement their classroom experiences with work experience. This qualitative study addresses the following research question: "How do students with cooperative education or internship experience differ in their perception and understanding of their engineering problem-solving skills as compared to students with no experience?" For this study, I interviewed three groups of senior electrical engineering students at a single research I university: 1) students who completed three rotations in the co-op program, 2) students who completed at least one internship, and 3) students who did neither co-op nor internship. In total, I interviewed 17 undergraduate engineering students.

The analysis suggested three types of knowledge were differentially influenced by students' classroom and work (co-op/internship) experiences: theoretical, practical, and procedural knowledge. "Theoretical knowledge" refers to the theories, laws and principles of the field. The majority of the students reported that classroom experiences in solving textbook problems helped them develop this type of knowledge. "Practical knowledge" encouraged students to consider factors besides technical issues when solving problems. Students with work experience described how their work assignments often required them to consider contextual factors beyond technical issues. These contextual factors were not always prominent in classroom assignments or homework problems. Finally, "procedural knowledge" can be defined as knowledge of how to solve problems. When comparing the groups, students with co-op and internship experiences were more likely to understand the importance of this kind of knowledge than students without work experience.

Introduction

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

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

Cooperative Education

Cooperative education has been in existence since 1906 and approximately 100 engineering schools in the United States currently have a co-op program[iii]. Much of the engineering education research on cooperative education focuses on benefits such as higher salaries[iv, v, vi],the number of job interviews obtained[vii] , and academic achievement (grade-point-average) [viii, ix] among students who do and do not participate. Other studies of cooperative education have shown that employers perceive students with co-op experiences as having better problem-solving skills than those who do not[x], and that students perceive their cooperative education experience in aiding their development of problem-solving skills[xi].

Research Question

Still, little is known about how these work experiences influence the development of problem-solving skills. The current study moves beyond previous research by answering the following research question: How do students with cooperative education or internship experience differ in their perception and understanding of their engineering problem-solving skills as compared to students with no experience?

Methodology

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

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

The interview protocol asked students about their short- and long-term career and educational plans, confidence in solving ill-structured and well-structured problems, problem-solving experience, learning experience, and their development of problem-solving skills. As part of the protocol, students were asked to describe how they would solve two think-aloud problems (a well-structured and ill-structured problem) as well as their approaches to problems solving. All student names in this paper have been changed to pseudonyms.

Findings

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

Theoretical Knowledge

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

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

> You're always kind of figuring out new ways to look at something. And in particular, like with that problem [the think-aloud textbook problem], you could, if you're a novice at electrical engineering, just coming in your junior year, you would probably solve that problem the long way. You would just go through it entirely. You would write out all the differential equations basically and try and solve back and figure out how it would work. But since you kind of do those problems a lot, you can just kind of look at it and the professors -- I think they do this on purpose -- they don't tell you the short cuts that you can take. So, you do it the long way. And then, you know, after you do it a little bit you figure out the short cuts and then later on, they kind of tell you that "well you can just do this."

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

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

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

> How it changed, when I got into the EE [electrical engineering] coursework, is I guess you learn to think like an electrical engineer would think in terms of real and imaginary pieces of things. … We consider stuff with imaginary numbers and sinusoids, but you do get that from math and physics. That is important, but I guess you learn … what stuff from those classes is going to be important. … And there is going to be stuff that you never see again that you have in math class, and there is going to be stuff that you see every day, so when you start your major course work, you get more familiar with these aspects and how to solve problems that involve these things.

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

Practical Knowledge

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

The non-co-op/internship students often felt they did not have enough opportunities to learn how to apply or apply the discipline knowledge to real-world problems in their coursework. Brian, who had neither co-op nor internship experience, felt he understood, for example, how antennas worked, but did not know how to apply this knowledge.

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

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

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

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

> There's this concept called skin depth and basically it's how electromagnetic waves propagate into a medium. How far they go down is classified as the skin depth. We spent maybe a day going over it [in class] and I just thought, this is kind of stupid, I don't know where you'd ever use this. Then when I went to my internship, of course, it was all about that. It was all about how far the EM [Electromagnetic] waves propagate into the material

> that is below what they call micro strip line, which is based in the wires. So it was a big problem, but I just thought at the time that this is kind of useless. I don't see how you would ever use it because I had no understanding of communications circuits at the time.

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

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

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

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

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

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

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

> For my power company, I designed a relay system for a distribution on a power grid. I had to look back on all my design classes and be like, OK this is how I would do this, and this is why I would do it this way. I was obviously critiqued in different methods [by people at my internship], and saying this works in theory, but this isn't practical because you know this part, they don't make this part anymore, we have to move on to try something different. A lot of the systems were going from analog to digital, we focused a lot at least sophomore year on analog systems. I mean I had seen the basics before, but I had never actually applied them to a real-world problem.

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

Determining the Scope of the Problem.

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

> At school you don't even [consider] some things. For instance, at school you see the circuit and the voltage is there and it's perfect every single time, it's all theoretical. And then in the workforce almost 90 percent of your problems are noise. Why is there noise in my circuit? Everywhere you go there's noise. Well maybe you should wrap the wires around each other so there's less noise, maybe you should twist them so there's less noise. And then, at school it's like, "Oh yeah, just assume the noise is zero, and then here is your final result" … So at one point you feel like they're teaching you wrong at school, and then the other side of it is well, "now I've got all this experience at my job," I come back to school like the hotshot and then at my classroom I'm going to be the man and just do it well because I see the big picture.

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

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

> Building circuits, sometimes it is hard because there are so many things. That is maybe why I say it [building circuits] is more practical, because you need a lot of practice figuring out what is wrong because there are so many things. You might have something not powered correctly, you might not see what you are supposed to see because there is

not a big enough load and you are not drawing enough current. There are so many different things.

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

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

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

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

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

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

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

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

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

Procedural Knowledge

When asked to identify the two most important components of problem-solving and how they developed those skills, three students (Jim, Isaac, and Kevin) identified knowledge as important. To these students, knowledge was needed to solve problems. Even though a few students (Vanessa, Keith and Larry) mentioned behaviors characteristics (such as diligence or "don't freak out") as important components, all the students mentioned at least one problem-solving skill (e.g., understanding the problem, breaking the problem down, checking the solution). Thus, students often recognized that solving problems went beyond content knowledge to the utilization of problem-solving skills. Isaac, who had neither co-op nor internship experience said:

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

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

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

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

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

Common Problem-solving Skills

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

> If you don't understand what the problem is asking for, you are going out somewhere else. That actually happens to a lot of people, probably me in some classes. I think that is the first key [component] I try to focus on, what it is exactly asking me to do. So right away, you know where to start.

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

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

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

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

Development of Problem-Solving Skills

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

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

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

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

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

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

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

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

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

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

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

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

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

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

> I just watched them [her engineering co-workers], we would have meetings every week, saying this is what I did this week, and people would elaborate if necessarily, other people would ask them questions, how did you come about this idea, and they would explain it was like, wow, that was really interesting. And I would remember things like that, using that hopefully in the future.

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

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

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

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

Conclusion

The main objective of the qualitative analysis was to answer the second research question, “How do students with cooperative education or internship experience differ in their perceptions and understanding of their engineering problem-solving skills as compared to students with no experience?,” by comparing and contrasting academic experiences of students who completed the co-op program, students with at least one internship experience, and students with neither co-op nor internship experience.

My analysis suggested three types of knowledge were differentially influenced by students’ classroom and work (co-op or internship) experiences: theoretical, practical, and procedural knowledge. “Theoretical knowledge” refers to the theories, laws and principles of the field. The majority of the students reported that classroom experiences in solving textbook problems helped them develop this type of knowledge. Participants reported that they learned that there were limitations to the theories, laws, and principles they learned in the courses through the application of theoretical knowledge. “Practical knowledge” encouraged them to consider factors besides technical issues when solving problems. Some of the students without work experience commented that a lack of hands-on learning opportunities in the engineering curriculum prevented them from gaining practical knowledge in the field. In contrast, students with work experience described how their work assignments often required them to consider contextual factors beyond technical issues. These contextual factors were not always prominent in classroom assignments or homework problems.

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

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

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