Synergies between Experience and Study in Graduate Engineering Education

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Abstract

Various programs and research initiatives seek to support the success of master's students in engineering. However, as programs can have diverse groups of students, supporting their success may not be a one-size fits all. Our work focuses on a group we define as Returners, who spent five or more years in industry before returning to university for a master's degree. As part of a larger survey with approximately 300 engineering student participants who were pursuing master's degrees, we asked them to evaluate the influence of their prior work experiences on their learning experiences in their Master's program using two open-ended questions. Participants cited that their work experiences supported their technical skill development, and also their professional skill development, which participants believed contributed positively to their ability to work in groups in school. Participants who were in industry the longest also indicated that their work experiences helped them to think critically about coursework in terms of best benefits for their career needs and interests.

Introduction and Background

For the purposes of this study, work experience is defined as time spent at a job in the participant's field, whether paid or unpaid. This can also include internships or co-op work experience. Educational experience is defined as academic time spent in coursework, not the internships or other work experiences students may obtain as part of their undergraduate program. Students in Master's programs may or may not bring with them prior work experiences. However, not all students have the same amount of engineering work experience. Some programs allow students to obtain a master's degree in engineering as they also complete their undergraduate degree. Other students may work for a time, perhaps a year or two, before deciding to enroll in a master's program. There are others who decide to return after many years.

As differences in prior work experiences may influence how students approach various aspects in their Master's programs, our study focused on the perspectives of two groups: 1) Direct Pathway students, who enroll in a graduate program either directly after their undergraduate program or within five years of undergraduate graduation and 2) returning students who have a gap of five or more years between their undergraduate and graduate programs [1, 2]. The five-year mark was chosen as the cutoff because other benchmarks are set in that general time frame (GRE scores are only good for five years, the PE exam can only be taken after four years, and ABET accreditation is renewed every six years, for example). In addition, the types of problems Returners have faced tend to have multiple solutions or difficult ones, and are real-world situations [3, 4].

Work experiences may have also been akin to cognitive apprenticeships for Returners, allowing them to gradually take on responsibilities as their knowledge and understanding increases [5, 6] and learning to engage in a community of practice [7]. These types of experiences in the workplace likely shape how they learn [8, 9]. Additionally, experienced engineers have a rich knowledge of the discipline in which they work and upon which they build their understanding of the practice. They build new knowledge on their existing schema to create a deeper, richer understanding of practice and theory. Novice engineers, because of the lesser amount of

exposure to the work, do not have this rich knowledge [7, 10, 11]. Experts also have had experiences that have allowed them to automatize their actions. This notion of automatic processing uses what is known as chunking [12] and allows for more effective retrieval and application of knowledge [13].

The goal of our research was to explore Master's students' perceptions of the ways that they perceive connections between prior work experiences and their study of engineering in their master's program, both theory and in application. The aim is to get a better understanding of two particular groups of students and the ways in which they interact with and understand the material in their coursework. Specifically, in this work, we were searching for student descriptions of synergies across their prior work experiences and their Master's education where they believed the combined effect of both work and educational experiences was greater than either individually [14]. Problem-solving in industry is different from closed-ended problem sets with solutions at the back of the book. While this may seem obvious to practitioners, students may not have the experience of open-ended problems with many potential solutions. Employers have called for workers who can think critically about problems, are innovative and highly skilled, and act as team players [15].

Methodology

The participants in this study were 293 domestic engineering students pursuing master's degrees from approximately 80 schools of engineering in the United States. Participants were recruited by rolling recruitment over a period of four months and anonymized surveys were sent to them. The median age of Returners was 30, and for Direct Pathway students the median age was 24. The overall median was 25. Table 1 includes ethnicity information reported by participants.

Table 1: Ethnicity of Participants.

Ethnicity	R	DP
American Indian/white	4	1
Asian	5	38
Asian/White	0	6
Black or African American	4	6
Black or African American/Latino/a	0	1
Hispanic/Latino/a	4	7
Hispanic/Latino/a, White	1	5
Other	1	3
White	59	148
No Response	10	27
Totals	88	242

To achieve the goal of this study, we analyzed data from two open-ended questions from a larger survey.

1. How do you think your work experience (including any internships and co-op experience) has contributed to your success in your coursework?
2. How do you think your work experience (including any internships and co-op experience) has influenced or impacted your approach to learning in general?

The data were analyzed using an open coding method to allow themes to emerge, and triangulated to ensure validity [16]. Once coded, Returner and Direct Pathway student answers to these questions were grouped separately so that any differences in perception might emerge. A variety of themes were seen. Some of these themes were equally visible in both Returners and Direct Pathway students, while others weighted more heavily towards one group.

Findings

There were three main themes throughout the responses of these participants for both questions. These themes had components that will be addressed later in the paper. The first theme was that work experience helped students recognize the importance of the ability to collaborate with others. There was an increased appreciation of the importance of the ability to explain ideas to co-workers who might have a different or no technical background. Students also felt that work experience contributed to their boldness in stating opinions and asking questions about aspects of group work as well as of professors. This differed from their undergraduate experience, where they did not ask for clarification from either fellow students or professors. Work also taught the difference between teamwork as experienced in the workplace and group work in school. Students who had not had work experience tended to approach projects which were meant to be a group effort as they had always done, rather than as in industry, where people are responsible for the success of the project rather than to get a grade.

A second theme of student responses was that students could see how their experiences allowed them to quickly see how engineering principles learned in the classroom applied to actual engineering problems. For Returners, techniques or concepts that were going to benefit their professional practice were easier to identify than for Direct Pathway students. Conversely, skills learned at work could also be transferred to coursework. Real-world problems gave context to theory being learned in class.

A final theme was that the importance of lifelong learning became a fundamental worldview. Students understood not only the need for lifelong learning, but also found excitement as well as direct application for learning throughout their lifetimes. They had mastered the techniques intrinsic to learning, and work experience had also helped them learn to prioritize their work and manage their time more efficiently.

The responses for both Returners and Direct Pathway students indicated that work experience contributed to better understanding of application of the coursework and allowed for contextual application of what they learned in class.

Responses across all participants related to their estimation of particular job skills that translated to success in school and learning in general are represented in the following tables. Table 2 shows the percentage of student responses for the question, “How do you think your work experience (including any internships and co-op experience) has contributed to your success in your coursework?”

Table 2: Responses to Question 1: “How do you think your work experience (including any internships and co-op experience) has contributed to your success in your coursework?”.

Responses	DP	R
No Change or Hurt Success	25%	9%
Relate Theory to Practice	20%	30%
Knowledge Acquisition and maintenance	28%	37%
Teamwork	6%	12%
Project Management	4%	11%
Professional Skills	18%	28%
Helpful Generally	15%	18%

The second question involved the impact or change work may have had on learning in general. Table 3 shows percentages of responses that were grouped into similar answers to the question: “How do you think your work experience (including any internships and co-op experience) has influenced or impacted your approach to learning in general?”

Table 3: Responses to Question 2: “How do you think your work experience (including any internships and co-op experience) has influenced or impacted your approach to learning in general?”.

Responses	DP	R
Professional Skills	18%	22%
Importance and Fun of Learning	6%	10%
Motivation	16%	9%
Connection Between Theory and Practice	25%	27%
Helped with Engineering Problem-solving Skills	13%	8%
Learning More Important than Reputation or Grade	8%	11%
More “Driven”	8%	17%

Responses to Question 1 showed that responses differed between Direct Pathway and Returner. More of the Direct Pathway students felt that work experience had not changed or had hurt their chances for success in coursework than Returners. A sizable minority of both Returners and Direct Pathway students said that the impact of work experience supported knowledge

acquisition and maintenance. More Returners than Direct Pathway students felt that their professional skills had been increased because of work experiences, but did not explicitly state that work was helpful in class generally. Some of the answers were very brief, while others were considerably more extensive. It seems that professional skills, lifelong learning, and ability to apply real-world experiences contributed to the students' success in coursework. The following are some responses that highlight perception of these skills. These first comments reflect the utility of professional skills and how work helps learners to learn them:

> DP1: "I am only a few weeks into my first course in my degree so the GPA is not reflective of my current progress. However, I do believe that having some experience in the work force has given me perspective on what I'm learning as well as having professionalism in emails and speaking with my professor. I also think that after working for a year, I have a better understanding in working with other people in a group setting."
>
> DP2: "More comfortable asking questions; improved leadership and communication skills."
>
> R1: "I am familiar with some of the course content from my work experience. I have a level of maturity and experience from working as part of a team that enables me to succeed on team projects. Also, I recognize when I need help and feel that effectively find sources to provide to help."

The experiences obtained at work solving real problems offer students an ability to apply learning to real-world experiences:

> DP3: "My learning has become much more applied. I'm constantly asking, 'How can I use this? Where does this apply?' and 'How does this fit in with what I currently know?'"
>
> DP4: "I think I look for more connections to real life now than before."
>
> R2: "Yes, Professional experience has given me a strong since (sic) of the how to for completing projects and practical development that was absent from my academic training."
>
> R3: "I have spent over 22 years building and refining my software engineering skills as well as managing a fairly complex data center. Many of the skills developed over those decades are directly related to the coursework and project/thesis development."
>
> R4: "Course is more relevant to my field of work, and applies to a higher degree than what undergraduate course work had. GPA reflects engagement."
>
> R5: "Engineering is all about the application of theoretical principles. Working in industry has strengthened this skill in a way that school never could. As a result, school is more meaningful in the areas where the material correlates to practical aspects encountered in one's career."

In responses to Question 1, students related ways that learning has become a lifelong activity:

> DP5: "I believe that my work experience has caused me to view learning as an asset to my development. I now view the topics we address as a way to build my understanding of the field, and not just something I need to learn for a grade."
>
> DP6: "Yes. My work experience has helped me pick up new concepts and techniques quickly.
>
> DP7: It is my programming experience at work that led me to decide to pursue a Masters in Computer Science."
>
> R6: "I have been able to use my experience to better understand the tools that I have learned vs. just theory."
>
> R7: "Just being out of school helped me realize that I have ADHD. Work experience/life has taught me how to find a method of determining what is important. This helps me read problems and figure out what is actually being asked, and not being distracted by other equations or what if scenarios."

In general, the effect of work on coursework success was positive. The negative answers seemed mainly to be either that the work experience the student had was in another field (i.e., not engineering), or that the student had had no work experience at all.

Question 2 explored the more global question about how work influenced the learner in terms of new habits or attitudes, for example, or other changes he or she could identify. Students responded that work helped them make sense of what they were learning in coursework.

> DP8: "My co-op experience helped me understand the industry before I formally entered after graduating. Co-op allowed me to alternate school and work for 3 rotating semesters that helped me apply what I've learned in class and apply them on the job."
>
> DP9: "My work experience has allowed me to develop a deeper understanding of the subjects by seeing the practical applications in the industry."
>
> DP10: "Working in the industry has given a lot more context to problems that you just don't have in the classroom. It gives you the why and the background for the problems that you are working through in the courses. I have also become more independent and able to apply myself to solve problems more by working, which helps in coursework because you allow yourself to struggle more, to look at different solutions and possibilities before going to an instructor for help."
>
> DP11: "Group dynamic experience will prove to be my greatest strength."

DP12: “The Professional Engineer I work under has instilled in me the importance of continued education. Although I already had getting a master's degree as a goal, my work and people I work with have encouraged me to go through with getting my degree.”

Lifelong learning was again noted as being part of how work experiences have changed the learner.

DP13: “An interesting 2-way struggle:
1. Because I have a full-time job already at a company I love in the field I want to work in, the requirement for reimbursement at my company is a C or better for each class, so I feel like I don't need to excel at every test/problem set/report, since I don't need an A+ to show to future employers.
2. On the other hand, because I love what I do, I really do want to learn more about anything potentially relevant and apply it to my job, and conversely, because I have more hands-on experience in some of the topics of these classes, I find it a bit easier to catch on and push myself to really understand and internalize the material so that I can call upon it if it's necessary at work.”

These comments reflect the effect of the experience of work and how that changes attitudes toward what one is learning.

R8: “I relate my learning to my job constantly and try to think of ways to apply what I'm learning. That has likely helped me to retain information. I also think more critically of certain aspects of coursework, such as Marketing, because I have already understood some major business-related advantages and disadvantages within the marketing environment.”

R9: “I am a nuclear trained navy submarine officer and the experience of going through nuclear power school and the entire nuclear pipeline made me a MUCH better student. I thought I knew how to study at the Naval Academy, but being a "nuke" really made me a much better student: I finished with a 2.89 at USNA and have a 5.0 at MIT currently.”

R10: “I've become much more cognizant about how my time is utilized, and in turn value my time better. I used to have a more frivolous mindset when it came to time spent learning. Of course, I think I may have developed an unhealthy habit of setting expectations of my learning returns too high. I stress myself unnecessarily when I could surely get just as good a grades (sic) without putting so much effort into my coursework. Perhaps you could call that passion. Work experience has made me more passionate.”

R11: “Very Significant. My work experience has taught me not only professional approach to understanding concepts and theories but also as an engineer of our society who sees things in a bigger picture.”

R12: “… being honest, it has not impacted my approach to learning. That approach was honed at UIUC's engineering program and has pretty much stayed the same, i.e. hard work, paying attention, sitting at the front of class, attending office hours, trying not to

> get discouraged by the difficulty of it all. Working has made me more intellectually curious, but that is not the same as 'approach to learning.'"

It is interesting to note that percentages of students who believed that work experience contributed to making the connection between theory and practice are close, even though there were many more Direct Pathway respondents than Returners. While both groups responded regarding the topics in Table 3, the percentage of Returners was greater than for Direct Pathway students in every category except two. *Motivation* and *Help with Engineering Problem-Solving Skills* were the two areas in which Returners reported work experience had less influence than for Direct Pathway. This suggests that Returners feel confident in their engineering skills and are motivated by something other than work to go to graduate school.

In Question 1, students referenced the notion of theory and how learning it was more productive now than in undergraduate work. They were able to make sense of engineering theory and could see how theory related to engineering practice. While the answers to Question 1 were mostly benign or somewhat positive toward the learning of theory, answers to Question 2 were more demanding of the rationale for the study of theory. Many students stated they chose graduate school precisely because they needed to understand the theory involved in engineering processes. However, the importance of theory was emphasized more than its ultimate utility in everyday work problems. They wanted to learn theory to become better engineers, not to be knowledgeable theorists. The comments below show this common theme from Question 2:

> DP14: "I believe that doing the work in the field and the idea of what you want as your job are things that have separated themselves. I may have a fascination with learning theory on an item in the classroom, but see it as unhelpful in the real world."

> DP15: "Working in industry exposed me to topics and skills that are valued in the work place and has influenced me to focus on these skills. From my experience, school work is mainly focused on theory and it's hard to tell what's actually going to be useful in professional practice…"

> DP16: "I learned that only the highest positions need theory. Most positions rely on empirical practices."

> R13: "Yes, I focus on the practical application; often times the instruction will stop short by just discussing theory."

> R14: "Yes. I place more importance on application than theory."

One student even felt that all of graduate work could be seen as the study of theory:

> R15: "I think of my coursework as learning the 'theory', which I can attempt to apply to practical workflows at my workplace."

The theme here is one of utility and practicality. Students want to learn theory only as long as there is a practical application that will facilitate their jobs as engineers.

Finally, in Question 2, students talked about how work has changed their worldview as regards learning, curiosity, and grades. They felt that learning for understanding and for the sake of curiosity were more important than for grades, and seemed to want the result of their graduate work to make them better engineers rather than for any other extrinsic rewards. Work experience gave students a sense of responsibility and maturity that carried over into their studies. It also gave them a different attitude toward asking questions and getting help when they needed it. Graduate school, for many, was the opportunity to have questions answered and to provide a deeper understanding of their work as well as their own discipline and ability.

> DP17: "It has made me realize that there is a lot that I don't understand, but that I am capable to an extent on my own to learn as long as I am persistent and patient."
>
> DP18: "Has made me more concerned with the overarching concepts and general understanding."
>
> R16: "It hasn't really. If anything, I have less time to spend worrying about getting the perfect solution to a homework problem because I have real world problems to deal with that are more important."
>
> R17: "Again, being honest, it has not impacted my approach to learning. That approach was honed at UIUC's engineering program and has pretty much stayed the same, i.e. hard work, paying attention, sitting at the front of class, attending office hours, trying not to get discouraged by the difficulty of it all. Working has made me more intellectually curious, but that is not the same as 'approach to learning.'"

The study of work experience and how it contributes to success in school as well as learning in general is two-fold: first, students with experience in industry have an exposure to application on which to build understanding of theory. A few students regarded the study of theory to be a necessary evil, not useful in terms of immediate educational value:

> DP19: "My work experience has contributed to only two (2) courses so far. Typically, material related to theory does not contribute directly to my work at my job."
>
> R18: "It is helpful to see how the theory works with the practical application, but at time[s] the theory is just that. Work has helped me focus on the need."

However, the students who were able to find the *why* had a better understanding of the material as well as applications of it. Direct pathway students seemed less enthusiastic about theory. Returners had a much richer store of experience on which to draw that helped them focus on important theory that would help them in their work immediately, and could identify with minimal effort what theory that was. Students who did not have this experience seemed frustrated because everything seemed of equal value. See the comment of DP9, above. This is a trait of novice behavior [17, 18]. Those students who have spent time in industry in deliberate practice may have formulated benchmarks to identify information of relevance and importance to their goals and needs.

Overall, the students who had practical experience, whether Direct Pathway or Returners, were alert to ways to apply theory or find concrete examples either in past work experiences or current projects. The many responses regarding theory and work were evidence that students were able to make connections and gain greater understanding of the theory they learned in class, in ways that became even more powerful than the work experience or course content alone could do.

> DP20: "My professional experience has given me a real-world understanding that helps me interpret the theory we learn in class."

> R19: "It has given me a practical framework to understand the theory, and has built a base of the concepts discussed."

Students who had practical experience in industry repeatedly cited the immediacy of coursework to specific applications. Others said that they went back to school to better understand the theory behind specific engineering principles. Working in the field helps solidify theoretical understanding and give practical applications for theory. This ability of Returners to relate coursework back to their work experiences helps them retain the information better, which seems to suggest that the implicit knowledge and informal learning that happens in the workplace may actually be the solidification of conceptual knowledge, and the subsequent coursework is more of a reiteration than completely new information.

In undergraduate engineering, students are encouraged, and in some cases required, to incorporate some sort of co-operative educational experience. This intentional shift in the use of real-world experiences to learn the principals of engineering as well as providing students with experiences so that they are ready for the workforce is a product of the notion that engineers must not only be technically proficient but also able to help solve the complicated problems of a multi-faceted society with divergent needs [19]. The notion of a well-rounded engineer includes not only engineering proficiency, but also the ability to communicate, ask questions, and function successfully within a team of problem-solvers. The comments of one Returner in our study embody this attitude:

> R20: "…My work experience has taught me not only professional approach to understanding concepts and theories but also as an engineer of our society who sees things in a bigger picture."

The contributions of work experiences to coursework and the ability to understand content seem greater for Returners than for Direct Pathway students. However, both groups acknowledge the importance of professional skills, social and emotional intelligence in communicating with fellow workers, the customer, and the enterprise. The ability to ask questions and to not feel as though one needed to "know it all" beforehand was also a function of work. Since engineering challenges are open-ended and there are no pre-determined answers, students seemed to understand that asking questions was an application they learned from working with other engineers.

Discussion

Three major themes were noted within the responses from both Returners and Direct Pathway students. First of all, acquisition and application of professional skills were cited as critical to success in both graduate school and work. Secondly, work experiences contribute significantly to building understanding of application of engineering principles and the context for using them. Finally, students reiterated the importance of an attitude of lifelong learning in order to continue to grow as professionals and equip themselves to solve engineering problems.

Professional skills include abilities such as "communicating, making decisions, showing commitment, flexibility, time management, leadership skills, creativity and problem-solving skills, being a team player, accepting responsibility and having the ability to work under pressure" [20]. Research participants stated that professional skills have an impact not only in success in industry, but also with studies. This notion is supported in other research [21]. Time management, teamwork, and prioritization were explicitly cited as skills learned at work and applied in school. It seems from this research that even minimal work experience helps students with their ability to plan and produce. In other words, internships have an impact on these students' ability to learn. Experience at work seems to have taught students how they focus best and how to prioritize as well as concentrate on the work. They seemed to have learned how to learn in order to best understand the material to suit their own particular needs.

Specific applications of engineering concepts were important for all students, but Direct Pathway students seemed to explicitly need to have an application to go with the theory in order to understand it, while Returners with their richer experience could find examples from real life that would help them understand the topics at hand through the context of their work. This seems to underscore Dewey's notion that reflection on practice is how people solidify what they are learning [22]. Both Direct Pathway and Returner students continuously cited real-world examples (or not) as their way to reflect on meaning and build understanding of concepts, theory, and application. Returners seemed to have a better understanding of which topics and concepts on which to focus, while some Direct Pathway students did not feel confident in this ability. In fact, they could not always tell which topics and concepts were important. This situation reflects Dreyfus' stages of novices and experts [11, 18]. Novices tend to judge everything of equal importance, while experts have a better understanding of which concepts are more critical than others. As well, Returners tend to have a broader picture of the field of practice in general and may also have the experience of managing larger projects. They may therefore be able see critical areas where more information is needed while Direct Pathway do not [23]. Returners found work experience to be more helpful in this regard than Direct Pathway. This may be because they feel the professional skills they have learned were directly as a result of years of experience, where Direct Pathway students did not make that connection as readily.

Finally, both Direct Pathway and Returners commented positively on the notion of lifelong learning. In order to stay current in their fields, engineers of all disciplines need opportunities to increase their knowledge base. The notion of obsolescence may be very real for some more experienced engineers, who have witnessed it first hand and know they need more technical knowledge in order to be current in the field and marketable in eras of downsizing [24]. Direct Pathway students may not have had as immediate an experience; however, both groups showed

their love of and commitment to learning and to the belief that one must always strive to understand and gain new knowledge in the field.

Limitations of the study

Convenience sampling was used to obtain respondents for the survey. These responses cannot be relied on as a representative sample of the population. It would have been helpful to follow up on these responses or to clarify what was intended with the answers, which is a limitation of anonymized studies such as this. Some respondents looked only at how their job did or did not relate specifically in topic to their graduate degree, while others looked at the overarching job skills they obtained through work and talked about these skills instead.

Conclusion

Students' knowledge construction was influenced by whether they have spent time in industry because of the connections they were able to make between application, theory, and coursework. Those with more experience understood theory through the lens of application more readily and were able to focus on what would have the greatest impact for their work. Many students indicated that their understanding of the needs of business, and their industry experience contributed to their understanding of how their learning fits within it. Students with less industry experience do not as easily see connections between applications and coursework, and may need more examples to help them make those connections.

Returners have a rich, broad schema to which they make connections. Many of the comments showed that they were able to apply theoretical knowledge to real-world applications. Direct pathway students were focused on finding these applications and at times seemed frustrated by the amount of theory in their master's courses. This seems to be a difference for Returners and Direct Pathway students. As well, many of the returning engineering students approached the courses from the standpoint of what it would add to their understanding of their work, while Direct Pathway students were creating understanding not only of the course content, but possible applications to real-world problem-solving without real-world experiences to help solidify their understanding.

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