Investigating the ways prior experience informs the research approaches of returning and direct-pathway students in engineering PhD programs

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Abstract

Purpose – The purpose of this paper is to explore the ways engineering doctoral students draw on prior experiences to inform their doctoral research. This study includes the experiences of "returners" – those who have worked as practitioners for five or more years before entering a PhD program – who have distinct experiences from "direct-pathway students," which may inform how they engage in doctoral research. This study also explores the traits that distinguish varying levels of sophistication in the ways PhD students think about the research process and how prior experience may contribute.

Design/methodology/approach – This study draws on interview data from 52 returning and direct-pathway engineering doctoral students. A thematic analysis of this interview data highlights the primary ways participants' prior professional, academic and life experiences inform their doctoral research. In addition, the authors conducted an iterative analysis process to sort participants' responses about their management of a hypothetical research scenario into emergent categories of research thinking sophistication to understand what characterizes varying levels of sophistication in research thinking and explore how experience may contribute.

Findings – Participants identified past experiences as shaping their research, related to how they identify a research problem, considering what needs to and can be done to address the problem, identifying an appropriate research approach, managing unexpected challenges, responding to critical feedback, determining their comfort taking risks and using intuition to lead a project.

Originality/value – Outcomes of this research can inform how graduate education supports students throughout their degree by identifying key experiences that may contribute to students' research approaches.

Keywords Engineering, Pre-PhD experiences, Research thinking, Returning students

Paper type Research paper

Introduction

Engineering PhD graduates are employed in a number of sectors of industry, government and academia. Doctorate programs in engineering are tasked with preparing graduates as

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independent researchers and problem-solvers. Specifically, engineering PhD students need to be able to consider the broader context and potential impacts of their research, identify and frame an appropriate research question, develop an approach to studying their topic of interest and use experience and intuition to steer their projects and navigate challenges that may arise. While the development of such skills is a chief goal of doctoral training, the nature of this training is highly variable across and within fields, departments and institutions. In addition, students enroll in engineering graduate programs with vastly different prior educational and professional experiences and skills, which likely shape their doctoral experiences and performance. However, further study is needed to understand how students draw on these prior experiences within their research work and the ways such experiences contribute to students' development as independent researchers.

Based on national data on age at PhD graduation (NSF, NIH, USED, USDA, NEH and NASA, 2014), within engineering, many students pursue a PhD immediately after completing their undergraduate studies, or possibly a master's degree, while a small, but noteworthy, proportion of engineering doctoral students have extensive (five or more years) of professional work experience prior to enrolling in their PhD programs – a group we refer to as returners. In addition to representing an under-researched pathway through advanced engineering training, returners are an important population because their prior work experiences likely influence their approaches to research and problem-solving (Mosyjowski *et al.*, 2017; Peters and Daly, 2011).

In this study, we leveraged interview data from 52 participants about their past professional, academic and personal experiences and how those experiences interfaced with their PhD research. This study includes the experiences of returners and students who pursued an engineering PhD more immediately after their undergraduate work (who we refer to as direct-pathway students), as both groups offer potentially important insights into the ways students' past experiences are leveraged in their independent research in their doctoral programs. We look to the diversity of pre-PhD experiences of returners and direct-pathway students alike to understand the experiences that support students' research work and skill development and explore how such experiences may inform interventions to aid the development of students' independent research skills, regardless of their background.

Background and conceptual foundation

Though the specifics of doctoral research in engineering vary widely by project, student and discipline, there have been some efforts to describe the general research skills students may be expected to develop by the end of their training. For instance, the Carnegie Foundation (Golde and Walker, 2006, as cited in Rogers and Goktas, 2010) calls for PhD graduates to be able to conduct research investigations, analyze and interpret findings, understand existing work in a field to contextualize new work and communicate in both written and oral forms. In their article exploring engineering graduate students' research proficiency, Rogers and Goktas (2010) named a variety of research skills, including statistical ability, written and oral communication, critically analyzing information, analyzing and interpreting data, conducting experiments and locating and learning from literature. A study by Berdanier *et al.* (2014) examined the knowledge, skills and attributes engineering PhD students intending to pursue work in academia and industry identified as important. Both groups of students emphasized problem-solving, meeting deadlines, communicating with a particular audience (both orally and in writing), strong analytical ability, managing multiple projects, working in teams and meeting deadlines. Skills and knowledge emphasized exclusively by students intending to pursue industry careers tended to be industry-specific, such as writing technical reports and learning new technologies. Those graduate engineers entering

academia also emphasized skills that related to their future roles as advisors and researchers. Research skills emphasized by these students included those related to bringing in and managing research funding and managing a research team.

While the assessment of doctoral students' research skills tends to be highly individualized, several studies that examine graduate student outcomes across a range of fields suggest that many students to do not feel adequately prepared to conduct independent research (Golde and Dore, 2001; Rogers and Goktas, 2010), even for some students who have successfully completed their doctoral study (Walker *et al.*, 2009). Studies suggest that undergraduate, or even graduate coursework, may not adequately prepare students as independent researchers and problem-solvers capable of conducting doctoral level research (Council of Graduate Schools, 1990; Lovitts, 2002; Walker *et al.*, 2009 as cited in Rogers and Goktas, 2010). However, little is known about the factors that do positively contribute to engineering doctoral students' research ability, both upon entering the program and throughout the course of their degree.

Engineering graduate students who are returners are not only likely to possess more experience in the field of engineering that can lend itself to expertise but, given their unique combination of applied engineering experience and advanced engineering training, may be particularly well-positioned to do innovative work with real-world implications. Our team's earlier work suggests that engineering returners draw on their rich prior work experiences in approaching their doctoral research (Peters and Daly, 2011). Direct-pathway students may also have experiences beyond their undergraduate degree courses that direct their approaches toward research, such as co-ops, internships and undergraduate research experiences. Research supports that these types of experiences are influential in students' post-undergraduate pathways (Kuh, 2008; O'Donnell *et al.*, 2015).

Multiple theories acknowledge the key role of prior experience in learning or the development of new skills. For example, in Dreyfus and Dreyfus's (1980) five-stage model of adult skill acquisition, the authors emphasize the critical role of "concrete experience" in achieving mastery in a particular domain. They explain that, while instruction in general principles of a domain may provide an essential foundation, relating that task to prior experiences or the opportunity to gain concrete experience with the task is key for higher levels of performance. Ericsson (1996, 2011) similarly acknowledges the key role of experience in developing expertise in a particular domain, though he argues reflection, intentional focused practice and expert feedback are also essential for higher levels of skill development, such as that which may be expected for PhD recipients.

Research design

Research goals

This study investigated types of prior experiences engineering doctoral students identified as key influences in their research, guided by the following research questions:

RQ1. How do returning and direct-pathway students draw on prior professional, educational or life experiences in their doctoral research?

RQ2. What differentiates students' relative sophistication in how they think about research and how might students' prior experiences may contribute to their thinking?

Participants

Participants included 52 graduate students who were recruited for interviews from a survey we distributed for a project focused on graduate students' choices and engagement in engineering PhD programs (Mosyjowski *et al.*, 2013). From those who volunteered for an interview, we selected participants to achieve diversity of the sample concerning returner status, institution, major, gender and racial/ethnic background. Participants were enrolled in PhD programs at 19 different universities studying aerospace engineering, bioengineering, civil engineering, computer science, electrical engineering, engineering education, industrial engineering, materials engineering, mechanical engineering, multidisciplinary engineering or systems engineering. In total, 26 participants were classified as returners and 26 as direct-pathway students. In total, 21 participants were female and 8 were from populations underrepresented in engineering. Given variation in "typical" paths through undergraduate and graduate degree programs across countries (including compulsory military service requirements, varying interpretations of the purpose of a PhD and visa processes that might influence students' time to degree and choices during and after their degree programs) and our larger study's focus of characterizing the trajectories of returning students, only US domestic students attending universities in the USA were recruited to participate in this study.

Data collection

Interviews were conducted for the larger project focused on doctoral engineering students' experiences prior to and during their PhD programs, where a subset of questions focused on participants' research processes. The protocol used for the interview was developed following best practice guidelines, including pilot testing (Boyce and Neale, 2006; Brenner, 2006; Roulston *et al.*, 2003), in which we iterated on the questions based on interviews with several individuals who were either in the process of completing or who had recently completed a PhD in engineering and had some work experience prior to their PhD.

The questions within the protocol that were focused on students' research approaches were prompted by posing a hypothetical scenario: "Imagine you have completed your PhD and are an independent researcher, and have the opportunity to receive funding for a five-year project." We then asked participants about their approaches within the context of the scenario using the following questions:

Q1. How would you determine what is an important problem?

Q2. How would you figure out what needs to be done and what can be done?

Q3. Imagine you have selected a problem to work on; how would you figure out possible approaches and methods to studying it? Once you have explored possible approaches and methods, how would you select one of those to move forward with?

Q4. How confident would you feel in your intuition when it came to steering the project?

Q5. To what extent would you feel comfortable taking risks in your proposed project? What factors influence your willingness to take or not take risks?

Q6. How would you respond to unexpected challenges?

Q7. How would you respond if you got negative feedback on your ideas?

After participants responded to each question, we asked them to describe any specific activities or experiences they had, both during and prior to their PhD, in which they

completed a similar task or drew on a similar skill as the one described. The hypothetical questions allowed us to investigate how participants would describe their general research approaches, and the follow-up questions allowed us to gather specific information about their general research approaches connected to their prior experiences.

One member of the research team conducted the interviews, 38 in person and 14 via Skype. Interviews lasted between 35 min and 2 h in length and were audio recorded. Participants were given $20 Visa gift cards as compensation for participating.

Data analysis

Our primary analysis examined the ways participants felt their past work and educational experiences contributed to their thinking about how to approach a research project. For this portion of the analysis, one member of our team reviewed each participant's transcript for any mentions of past experiences that they felt informed their research approach and the ways these experiences shaped that approach. The researcher then compiled these excerpts into a spreadsheet and identified the broad dimension of research to which each excerpt pertained. These dimensions largely aligned with the questions asked of participants – how they identified a research problem, how they thought about problem needs and possibilities, how they selected a particular approach to solving the problem, how they would manage challenges that arise, their responses to negative feedback, their comfort with risk-taking and their confidence in their intuition to lead a project. Then, looking at all the excerpts that pertained to each of these dimensions of research, the researcher identified themes about the ways different types of experiences informed participants' thinking about each dimension.

An additional analysis included a holistic sort and inductive categorization of participants' descriptions of the ways they would approach the hypothetical research scenario that we posed to them during the interview. We analyzed responses to these questions separately from the rest of the interview so that we did not have other information to influence our analysis, including if the participant was a returner or direct-pathway student. We collected each participant's responses to all questions about the hypothetical research scenario, allowing our unit of analysis to be on the participant level rather than by question. As a first analysis pass, we read the collection of responses for each participant to inform our next analysis pass with regard to what constituted an important difference in the description of research approach. In this next analysis pass, one researcher inductively sorted each participant's collection of responses based on perceived differences. Characteristics of research thinking for each group were articulated. After all participant responses were grouped, the researcher re-read each group as a set refining the descriptions of the grouping as necessary. These refined categories were used by a second coder to independently sort participants' responses to investigate reliability of the category descriptions. Comparing the two coders' categorizations demonstrated a high level of agreement (44/52 categorized the same). For the eight cases in which ratings differed, the PI reviewed the transcripts and made the final determination. More information about these analyses can be found in Mosyjowski *et al.* (2016). For the purposes of this paper, we highlight the features that characterize the responses that make up the most and least sophisticated descriptions of research thinking and note defining characteristics of these categories, as they relate to our findings on the ways students draw on prior experiences to inform their research work.

Findings

Our findings section is divided into two subsections. The first subsection addresses our primary research question related to the ways returning and direct-pathway students draw

on their prior experiences in their PhD work. The second subsection explores the characteristics that differentiated students' relative sophistication in how they thought about research and the ways prior experiences may contribute to students' thinking.

How prior experiences inform research approaches

Both returning and direct-pathway students cited a number of ways their prior experiences (or lack thereof, in some instances) informed various aspects of their research approaches. While there were few differences in the *number* of returning and direct-pathway students who identified ways that their experiences may inform aspects of their research, students in the two groups varied in the *nature* and *influence* of the experiences described. Table 1 provides a summary of the numbers of returning and direct-pathway students who described influential experiences related to seven aspects of their PhD research and is followed by in-depth descriptions and examples of each.

Identifying a research topic. A total of 31 participants, including 16 returners and 15 direct-pathway students, cited ways that their past experiences informed their current or future selection of a research topic or problem to study. For some, past personal or life experiences shaped their topics of interest. Seven returning students named their personal experiences and relationships as informing what they considered to be important problems and motivating them to select problems that will help people. For example, one participant described how seeing the way coming from a low-income background constricted the opportunities for many of her friends shaped her research agenda in engineering education:

> Seeing where my friends are and where they are in their lives and being able to do something that even though it can't impact them directly would impact people that are very much like them or that in the future could be like them.

Conversely, several direct-pathway participants noted their relative lack of exposure to particular social or health issues that restricted their awareness of important problems that they would like to address in their work. One participant explained:

> Honestly, kind of growing up in a bubble in [suburban location], I don't think I can give a good answer to that. [. . .] I can't think of any specific experiences again other than this vague sense of occasionally reading about global warming in the news and that alternative energy is important.

Other participants named previous professional experiences that exposed them to potential problems in their field that they might address in their work. Some participants described particularly striking experiences that shaped the type of problem they identified as

Table 1.
Count of returning and direct-pathway students citing prior experiences informing aspects of approaches to PhD research

Research approach aspect	No. of participants citing experiences informing their approaches to a particular aspect of research		
	Total ($N = 52$)	Returners ($N = 26$)	Direct-pathway ($N = 26$)
Identifying a research topic	31	16	15
Understanding what needs to be and can be done	14	8	6
Identifying approach or method	19	11	8
Managing unexpected challenges	8	4	4
Responding to negative feedback	11	5	6
Comfort with risk-taking	9	4	5
Intuition to steer a project	24	10	14

important and motivated their future work. A returning student described one such experience that informed her research topic selection:

> I consider this environmental remediation to be really important. One kind of life-changing experience, in that regard, was that on this one project I had been working on [. . .] there was a large homeless population in [city] who relied on the fish in this particular river for sustenance. All of these fish were essentially giving them cancer. People were just dying because they had no other food source other than this really contaminated river full of mutated fish. It was really sad. So, I think something like that is exactly the kind of problem that I would hope to address.

Other participants expressed that they gained awareness of the strengths and weaknesses of their field through their professional experiences, which allowed them to identify problems they may be able to address in their research. Some participants felt these past professional experiences were essential in informing their present research agenda. One returner even argued: "Recognition of what's an important problem comes from your workplace, it doesn't come from the PhD".

In contrast, other returning and direct-pathway participants identified their educational experiences, both prior to and during their PhD, as informing their research topic selection. Participants described both how they developed an understanding of a particular research area during their studies that they would build on in future work and how their experience with particular methods or research approaches from their academic work may prompt them to select a topic in which they could draw on these skills. One returning student described that methodological expertise is a common driver of topic selection among members of her lab:

> Well, I think, at least in my lab in particular, we have a handful of methods that we try to apply to every problem. [. . .] you become kind of experts in a certain set of analyses, and then you tackle problems on which you think those analyses will work and also that you're interested in.

Identifying what needs to and can be done. For 14 participants, previous experiences also played in understanding what needs to be and can be done in a research project after selecting a topic to address. Participants who described influential prior experiences in this area included eight returners and six direct-pathway students. Both returning and direct-pathway students described their prior experiences solving other problems, either in their careers or earlier academic work, as influential in this regard. One participant, working in bioinformatics, described how years of experience in the field gave her a good understanding of the types of techniques that would likely work best for identifying particular diseases, explaining:

> I've just been working on it for so long, that I kind of know what will work and what won't work. [. . .] Based on my experience [. . .] like I said previously, I can tell somebody, depending on what disease they're working on, you know, how noisy their data will probably be and therefore how many samples they'll probably need.

Another returning student explained that there is a lot of overlap in the type of work he did in his career prior to graduate school and his academic research, which informed his understanding of what was feasible:

> This is the same kind of data that I dealt with the entire time in my career before I was a scientist, before I went back to graduate school. In a certain sense I'm pretty knowledgeable about what its limitations are and what you can do with it. That's definitely how I can try to decide what you can and can't get away with doing.

In addition to previous work solving similar problems, several participants cited experience receiving explicit instruction from or relationships with experts in the field that they felt they could draw on in determining what would need to be done for a particular project. One returning student emphasized the importance of knowing the literature related to a problem, which was something his advisor had emphasized in his PhD training, something he had not really understood prior to beginning his degree. Another student felt that relationships with top people in the field was key in figuring out what could and should be done and that she has developed such contacts through her work in the field that could help her, explaining:

> I've got pretty good contacts or know who some of these people are now at the national labs and some of the industry sort of partners. I think that that would actually be pretty easy for me at this point.

Identifying approach or method. Participants described types of educational and professional experiences that informed their abilities to explore and select appropriate approaches or methods for addressing a research problem as for understanding what needs to be and can be done in a research project. These participants included 11 returning and 8 direct-pathway students. One direct-pathway student cited her experiences conducting research as an undergraduate student, in which she worked with a graduate student and examined the literature carefully to understand and critique existing methods to addressing a problem as a way of understanding how she might "bring something new to the table in terms of methodology".

Several returning students credited their prior work experiences as key in shaping their process for figuring out an appropriate problem approach. One returning student described his PhD supervisor as very disengaged from his research but explained that he instead relied on his industry experiences to guide him in his PhD work:

> What I did here to succeed, what I just explained, I learned in industry. That's what I do in industry. I go to the lab, see what I can see, mess with things, go back to simulation. I wasn't really aware of the literature as much as the industry, but I basically go with the lab, simulation, going back and forth to try to figure out a problem.

Many returning and direct-pathway students cited direct instruction or advice from others as the most important experiences informing the way they would identify approaches or methods for solving a problem. One student explained he would always look to what had been done previously, an approach encouraged by his advisor. He described being instructed by his advisor to follow the methods his former advisees used, with explanations from his advisor about each step of the process:

> Since our problems were very open-ended at first, this was my first advisor, we very, very often had to go back to what previous students within his lab had done because that's the formula that he liked. He explained to us why every step was important and then we made sure to follow.

Others described less formal learning from others, such as one returning student who explained he would seek out expertise from others in the environment, something that was a "fairly common" approach in his past work experiences.

Managing unexpected challenges. A smaller number of participants, including four returners and four direct-pathway students, described the ways their past professional and academic experiences prepared them to face unexpected challenges that might arise during the research process. Many of these participants felt that their experiences successfully responding to earlier challenges in their academic or professional careers helped them develop necessary skills or confidence to deal with future challenges. One returning student

said that responding to challenges was something she got "much, much better at over the years," crediting her past experience working as a consultant, explaining:

> I've encountered that a lot in my previous work. It was like almost a daily occurrence, in consulting, when things change up last minute. Regardless of what you think about it or how much time you had, you'd just have to adapt instantaneously. So, I think I got really good at doing that.

Another student explained that facing challenges regularly as a graduate student made her confident that she could handle any new challenges that might arise:

> I think [facing new challenges is] so common for a graduate student. Everything is a challenge, nothing goes the way you want it. [. . .] you could throw something at me that I've never seen before but I'm sure I could talk to people, do some research, figure out some way to handle it.

Other participants described learning from others about how to respond to unexpected challenges. For one returning student, he explained that keeping a level head and not directing his frustrations at others was a key for responding to challenges, an approach he explained was in response to witnessing how badly the opposite approach went for others during his time in industry. In contrast, another student described the positive example set by his advisor that informed his approach to steadily work through setbacks and challenges. He explained:

> I was told early on, every week you don't have to make progress every week, you have to do something every week. So, if you go backwards that's OK. Just not panicking and keep doing stuff, and write up what you did.

Responding to negative feedback. In total, 11 participants, including six returners and five direct-pathway students, described prior experiences that informed how they dealt with negative feedback in their PhD research. Some of these participants explained that receiving negative feedback in the past has helped them to develop a "thick skin," or feel less hurt by negative feedback over time. One returning student who worked as a consultant explained that he was less likely to take negative feedback personally at this point in his career owing to his experiences in his past workplace, stating:

> That's one of the things that having worked in industry has given me a very thick skin. The fact that where I do work is informal, sometimes that makes it a little bit worse because people may not be as restrained with giving their negative feedback.

For other participants, their past experiences helped them to interpret negative feedback differently, or come to see it as a potentially useful or constructive tool. One direct-pathway student said he took the majority of negative feedback to be constructive and something that could be used to improve his work. He described being influenced by several instances in which negative feedback improved his end product, including the following example:

> At a conference I presented and this woman, a professor from [University] got up and just grilled the heck out of me. It was really, really hard. I was kind of distraught because it was my first major conference, national conference. It was tough. But I listened to her. I responded to her questions the best I could and I definitely see her point of view and it caused me to revise the discussion section of the manuscript that I was preparing at that time and ended up submitting and it got published right off the bat. So, I think that her feedback probably improved that paper.

Other participants described their experiences serving as reviewers for conferences or grants as shaping both how they gave and interpreted negative feedback, understanding it was often given in the spirit of improving the work. Several participants described the

importance of trying to understand where negative feedback was coming from and past experiences that helped them discern between constructive feedback and feedback with another motive. For example, one returning student with extensive industry experience described being challenged publicly on his work by an individual whose earlier work was being challenged by newer research methods.

Comfort with risk-taking. Many participants in our study explained that their comfort with risk-taking was contingent upon a number of project-specific factors, for which prior experiences might not necessarily translate. However, nine participants (four returners and five direct-pathway students) did describe past personal or professional experiences that shaped their risk-taking approaches in several ways. For some of these participants, prior experiences informed their views of risk-taking as context-dependent. For example, one returning student contrasted her increased comfort with risk-taking as she moved from a resource-strained startup to academic research:

> [I'm working to] to take more risks and realize like actually we're not in a high stakes environment with death, or we're not going to lose a whole bunch of money at a company if we try an experiment and it goes wrong.

In other cases, participants cited examples of watching others take risks and fail as experiences that made them more risk-averse in their own work. Speaking specifically about the role of risk-taking in the academic job market, one direct-pathway student nearing the end of his doctorate program said the following:

> I've seen more situations where people take risks and it doesn't pay off than those where it does. Now those people are looking for other jobs, and they seem to be tremendously qualified, and yet just taking that risk, it didn't work out for them.

A returning student who considered risk-taking a necessary element of his research work explained that this approach stemmed from his socioeconomic background:

> I don't have any other choice - I think that people can have a lot of upsides in life, based on who they are, what their connections are, what their economic status is. So, for someone like myself who maybe didn't have those conveniences, I have to push a little bit harder, I have to take riskier moves, not safe ones.

Another participant explained that he works to strategically reduce the risk of failure in the eyes of funders by being strategic in what he promised – a skill he credits to his experience working with lawyers:

> One of the things I've learned is how to say a lot and say nothing at the same time. Especially working with those patent lawyers. They're tricky people. And so, if you word it correctly, you can address the same problem, but not necessarily say how you're going to get there. So leaves room to take risks without being disingenuous to your funding source.

Intuition to steer a project. Nearly half of our study participants (24, including 10 returners and 14 direct-pathway students) described their confidence to rely on their intuition to steer an independent research project as something that was heavily dependent on their prior research, professional and life experiences and knowledge base. For Some direct-pathway students explained that having little to no prior experience conducting independent research led them to question their present ability to steer a project. One direct-pathway student explained:

> I think right now at the moment I'm in, just because I'm mostly given things to work on, I don't have enough experience to feel really confident in doing this project on my own.

Other participants explained that they felt that they were developing confidence in their ability to steer a project through their experiences in their PhD program. One returning student cited her recent experiences making decisions for her own research project as key in developing her intuition and explained:

> You know my intuition, that's one of the things that's really improved with the PhD, my confidence and therefore my intuition. I think they're very tightly tied. I actually feel like as long as it was a project that was in my general area, I would be pretty confident in my intuition at this point.

For some returning students and more senior direct-pathway students, having substantial experience in a particular field led them to be quite confident in their ability to rely on their intuition to steer a project. One returning student explained that, while he had more difficulty reliably directing work on a project earlier in his career, he was quite confident at this stage in his career. He explained:

> At this point, with all the experience, I'm pretty confident about what to do. I guess at this point, it almost comes natural to just know exactly what you have to do and it's rare for you to miss a step. You've already seen it so many times. You understand the logic. Once you understand the logic behind it, it'll make sense.

Sophistication of students' research thinking and the role of experience

Though prior experience was explicitly not a criterion for our inductive categorization of participants by the sophistication of their research thinking, there are several key connections between the types of things participants gained from their prior academic, professional and personal experiences and the traits that define varying levels of sophistication in the ways doctoral students think about independent research. Further, while the majority of all participants' research thinking was rated in a middle category, we saw a much higher proportion (9 of 12 responses) of returning students' responses in the highest category, suggesting extensive prior experience, even if not in a directly analogous role, may provide useful context or skill development for doctoral students to build on in their research work. This section begins with a description of the responses that make up the least sophisticated (Category 1) and most sophisticated (Category 3) categories of research thinking, followed by a discussion of the linkages between the distinguishing characteristics of these emergent levels of research thinking and the prior experiences of returning and direct-pathway students that may contribute. The descriptions of each category come from our team's previous work (Mosyjowski *et al.*, 2016), which also provides examples of participant responses in each category.

Category 1. Participants whose responses fell in Category 1 were most likely to struggle to answer questions related to the independent research scenario. Their responses were typically somewhat vague, with little detail about the specific elements they would consider in engaging in an independent research task. Answering the first question of how they would identify an important problem proved to be a particular challenge for students in this category. Students in this category expressed a lot of doubt in their responses and uncertainty about the "right" answer to these questions. When asked about their likely responses to negative feedback on their research, participants in this category were most likely to express difficulty with or avoidance of receiving critiques of their research work.

Responses in Category 1 also frequently suggested a reliance on external guidance and expertise. Students referred to what they were taught in their coursework or an advisor's

rules or suggested best practices for research. Category 1 responses and associated examples often highlighted the importance of others' input on guiding a project. Students explained that they would consult with expert researchers to "check" their work or look to a more experienced individual for support.

Responses that fell in Category 1 represented a more concrete, black-and-white understanding of how to best address an engineering research project. One student, when asked how he might determine what needs to be done and what can be done, responded that there was "probably an equation" to address this issue. Participants in this category often provided relatively simple answers for the best ways to explore a particular research area and guide a study. Their responses did not explore more nuanced, complex issues of steering a research project.

Category 3. Category 3 responses were characterized by clarity, detail, strategic thinking and consideration of potential contextual influences on a research project. Participants in this category provided detailed responses that covered multiple elements of the process of designing and steering and independent research project. This consideration included an emphasis on the importance of long-term planning to account for the influence of funding agencies, stakeholders and needs and resources associated with team management and the responses broadly reflected an understanding of the complexity of independent engineering research. Responses in Category 3 suggested knowledge about the needs and practices of participants' specific area of engineering. These students demonstrated comfort with the specifics of conducting independent research while discussing the hypothetical research scenario in a way that suggested they were able to abstract to explain their research process more broadly, demonstrating their ability to apply core principles or knowledge across multiple settings.

As a whole, participants in Category 3 expressed not only greater confidence in their own ability to lead an independent engineering research project but also a sense of ownership of a particular approach or area of work. Students whose responses fell in this category expressed a strong sense of purpose and had a clear path or area of focus when asked to consider how they would identify an important research problem, clarity that was also evident in the way they discussed their research process. Some participants in Category 3 responded to the questions beginning with "What I always do is [. . .]" referencing a personally held approach to guiding a research project, as opposed to an approach that is largely dependent on the guidance of others. However, taking ownership over one's research does not necessarily mean ignoring the perspectives and expertise of others. While participants in Category 3 expressed confidence, direction and security in their own topic and process for research, they expressed openness to the perspectives of others, even negative feedback from others, to inform their thinking. A distinguishing factor of participants in Category 3 related to their use of feedback from others was that they did not give all external opinions equal weight but rather considered and evaluated all external input for its merit.

Sophistication of research thinking and experiences of returning and direct-pathway students. Our findings point to the role of experience in developing research-thinking skills. Participants whose responses were sorted into Category 1 often self-identified as inexperienced, as students who were still learning. Additionally, when prompted for examples of relevant past experiences with various elements of the research process, participants at times struggled to cite examples of instances in which they had experienced or engaged in these particular practices. When students were able to provide examples of past experiences, they often lacked in detail. In contrast, many participants in Category 3 provided detailed examples of rich experiences in their past work and educational

experiences related to multiple aspects of the research process. Their responses indicating an ownership over their personal approaches to research also suggested past experiences, in which they were able to develop a "typical" approach. Some students in this category explicitly cited their past research experiences as influential in informing and shaping their current research process.

Several differentiating features of these two categories of research thinking were closely related to the ways both returning and direct-pathway students described prior experiences as contributing to their research thinking. One key differentiator was the extent to which participants were aware of or personally drawn to particular research problems in their field – the aspect of research participants most frequently cited as being informed by past professional or life experiences. Similarly, participants who demonstrated the most sophisticated research thinking typically described a high degree of comfort with their personal approach and ability to solve a problem, while Category 1 participants described reliance on external guidance or vague "rules" to guide their project. This is closely related to participants' descriptions of the ways prior work or research experience, or similar experiences having responsibility for an academic or professional project, positively contributed to their comfort directing a project and understanding how best to approach a problem.

While our data suggest that both returners and direct-pathway students cited the influence of prior experiences in their research thinking, roughly in equal proportion, differences in the nature and outcome of these experiences are evident. As reflected in some Category 1 responses, some direct-pathway students described the influence of a lack of prior exposure or experience in a particular domain of research as informing their approaches. For example, several direct-pathway students described difficulty identifying a research topic owing to a lack of exposure or personal experience with potential problems in their research domain, while both returners and other direct-pathway students with more experience recounted the key role such experience played in the process of selecting a topic. Similarly, several direct-pathway students cited a relative lack of experience as negatively affecting their confidence in their ability to direct an independent research project. While a subset of participants classified as direct-pathway students in our study had some work experience in a non-academic context, returners, by definition, had more work experience in a context beyond academic study. Further, while both returning and direct-pathway students had academic experiences they named as influential in their research thinking, it is possible that returners had more varied academic experiences on which to draw. For instance, in a comparison of undergraduate to doctoral degrees for participants in this study, over three-quarters of returning students (20 of 26) pursued a PhD in a field at least somewhat different from their undergraduate degree field, while only half of direct-pathway students changed their paths in this way.

Returners' distinct experiences appeared to be associated with differences in their research thinking, compared to direct-pathway students. While returning and direct-pathway students were equally represented in this study, returners represented a disproportionate number of Category 3 responses, making up 9 of the 12 participants in this highest category. Of the three direct-pathway students categorized as displaying the highest levels of sophistication of research thinking, two had several years of professional work experience before pursuing a PhD. In contrast, among the seven responses that composed the lowest category of research thinking sophistication, Category 1, only one was from a returning student.

Discussion

This study described a number of ways both returning and direct-pathway students' academic, professional and life experiences informed their research thinking and highlighted the ways students may draw on experiences from a range of contexts to inform their research approaches. Figure 1, below, represents a summary of our findings, which highlight the ways both returning and direct-pathway students drew on prior experiences, whether those were from personal, professional or academic experiences, and the ways these experiences informed their approaches to various aspects of the research process. While both returners and direct-pathway students cited influential prior experiences, the ways such experiences informed students' research processes varied based on the nature of the experience and students' reflection on and integration of these experiences. Our emergent findings suggest that returners' experiences may be particularly helpful related to contextualizing and identifying important problems in their field and greater levels of confidence in their ability to steer an independent project. Finally, a holistic analysis of the research thinking skill demonstrated by participants suggested that distinguishing features of most sophisticated research thinking (Category 3) and least sophisticated research thinking (Category 1) responses reflected differences in students' approaches to different aspects of the research process. Returning students appeared to be disproportionately represented within the most sophisticated research-thinking category.

While it is the norm in engineering for students to pursue a PhD shortly after their undergraduate degrees (NSF, NIH, USED, USDA, NEH and NASA, 2014), our findings suggest that returning students' extensive prior work experience may be an asset in their development of research skills, particularly for their understanding of the disciplinary context and familiarity and comfort with leading a project independently. Even in cases where returners' prior work experience was not research-oriented, it still proved valuable in informing students' perspectives, skills and confidence related to conducting doctoral research. This finding stands in contrast with the common expectation that students with prior professional experiences put aside their professional identities and expertise and assume the role of novices (Austin *et al.*, 2009; Pifer and Baker, 2016; Gardner, 2009; Sweitzer, 2009). Regardless of prior work experience, our findings highlight the value of

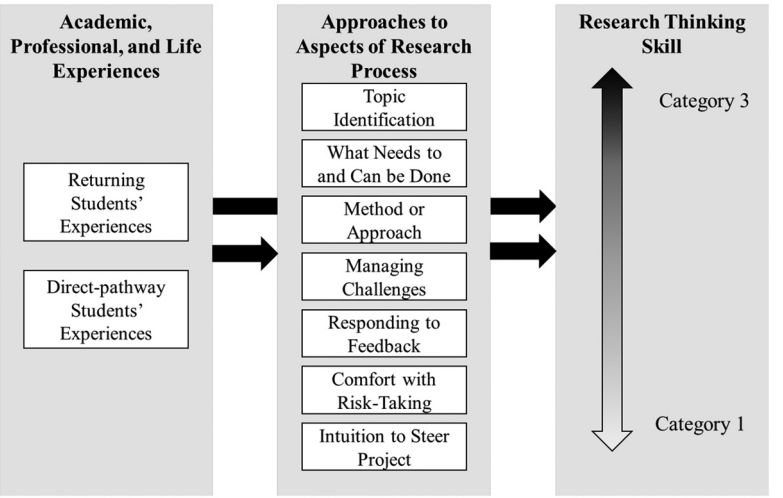

Figure 1.
Summary of findings

experiences across multiple contexts, whether it is prior undergraduate research experience, professional work, travel or problem-solving in one's personal life. Such experiences may help individuals develop contextual knowledge and build skills that can be applied to their academic research work.

Our findings point to several educational and conceptual implications. In education, it is important for faculty and advisors working with doctoral students to be aware of both returning and direct-pathway students' prior experiences and consider how the skills and perspectives students have developed through such experiences might be leveraged in their research work. Conceptually consistent with Dreyfus and Dreyfus (1980) work on the development of expertise, situating the introduction of new skills in the context of prior experiences may help students better develop research skills. Further, despite the distinct experiences that returning students may bring with them into their doctoral studies, returning student status is not widely acknowledged or tracked as a demographic in engineering doctoral programs. Implementing such tracking may help raise awareness among faculty about the experiences of returning students and how these experiences may be leveraged for the benefit of returning students and the work the produce.

Relatedly, this study further highlights the importance of providing students with hands on or applied experiences, described by both Dreyfus and Dreyfus and Ericsson (1996), throughout their undergraduate and graduate careers. Students cited a number of instances in which prior practice conducting research or engaging in a related task contributed positively to their ability to conduct independent research. While not all students will or should be expected to have extensive prior professional experience before pursuing a PhD, finding ways to build in exposure to a range of topics or approaches to research early on in graduate training or even undergraduate study, such as brief rotations through different research labs or short industry-linked research projects, may supplement coursework experiences that may not fully prepare students for research work (Council of Graduate Schools, 1990; Lovitts, 2002; Rogers and Goktas, 2010; Walker *et al.*, 2009).

Finally, several students cited the role of feedback or focused instruction from their advisor or another expert in the field as contributing to their development of research skills, mirroring Ericsson's (1996) argument that such expert feedback is critical for the development of expertise. The involvement of research supervisors, providing carefully targeted feedback, can and should play a key role in students' development of research skills. Such feedback may also facilitate students' reflections on the knowledge, skills and assumptions they bring with them into the research setting and how these might inform their research work.

Conclusion

Both returning and direct-pathway students have experiences that inform their approaches to engineering research. While students' non-academic professional experience is often not seen as asset in research-oriented doctoral study, this study's findings highlight the ways this prior work experience can positively contribute to students' research skills and understanding of the field. The study also describes a number of other educational and life experiences that contributed to the ways both returning and direct-pathway students thought about and approached research. Awareness of these influences can direct how graduate education environments support all students, including returning students who may be able to leverage learning from their work experiences to support their development of research skills.

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Further reading

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