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Drivers of research topic selection for engineering doctoral students

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Drivers of Research Topic Selection for Engineering Doctoral Students*

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In this study, we explored engineering doctoral students' motivations for selecting their research topic. The extent to which individuals are intrinsically or extrinsically motivated and the autonomy they have to make their own decisions has implications for their enjoyment of and success at a particular task. Given the importance of motivation, we sought to address a gap in the understanding of how doctoral students in engineering decide on a particular problem to study. Our findings are based on interviews with students with varying past educational and professional experiences that enable us to capture a wide range of motivations for engineering PhD students' research subject decisions. We found that the majority of students interviewed reported some form of extrinsic motivation guiding their decision, though these students varied in their autonomy to select their own topic. Of the students who reported intrinsic motivations for their research topic selection, many had extensive prior work experience that informed their topic choice. Funding played a major role in shaping students' project decisions, which is reflective of the scale and expense of much of engineering work. However, our findings suggest there are a number of opportunities for students to identify research topics in which they personally perceive as important and interesting.

Keywords: returning students; doctoral research; motivation; self-determination theory

1. Introduction

Selecting an individual research focus is a critical part of engineering doctoral students' experience in their PhD programs. Students must choose a research topic that is sufficiently rich to satisfy their program requirements, and to which they are sufficiently committed, so as to persist in that area through the completion of their degree. Beyond meeting the requirements of their doctoral programs, for many students, a line of research they begin in their doctoral program will position them for a career of research related to that area. Understanding students' decision processes and motivations for selecting a particular research area is key in identifying ways to better support students' success in their academic research work.

There has been little empirical work aimed at understanding PhD students' motivation and decision processes for selecting their research topics, particularly within engineering. There have been several studies that examine students' motivation for pursuing research [1, 2], but do not examine students' choice of a particular topic. Other non-empirical literature provides advice to doctoral students about research topic selection, emphasizing that students should select a topic that aligns with their interests or passions [3–5]. While some students may have the experience and resources to identify a successful research topic based on their personal interests, such advice does not account for a number of other factors that may constrain, shape, or encourage students' decisions to pursue a particular line of research. This perhaps reflects a need to understand students' research topic selection within particular disciplinary contexts, as doctoral programs and funding are structured differently between fields. In engineering, particularly given the expense and scale of many engineering research projects, students may have to consider a variety of factors beyond their own interests in the feasibility of pursuing a particular line of study during their PhD.

Within engineering, students' selection of a research project may reflect a consideration of project funding sources, technological resources, and students' own skills or knowledge. Students may have broad areas of interest upon entering a PhD, but find the specifics of their project selection are shaped by other factors beyond interest. Stu-

dents' pre-PhD experiences may also shape research topic selection. Research suggests that students with undergraduate research experience are more likely to go to graduate school and to conduct research [6, 7], and it is likely that some students' prior research informs the topics they pursue in this later research. And, students with extensive industry experience, a group we refer to as returners, may draw on their past work in selecting a topic [8]. While few studies within engineering education specifically consider returning students in data collection and analysis, intentionally including the perspectives of these returning students may provide a broader understanding of the range of students' motivations for selecting a research topic.

Given that engineering PhD students must conduct research as part of the requirements to earn a degree, it is important to more fully understand students' varied motivations for choosing a research area. Students' motivations for selecting a particular line of research may influence their commitment to, engagement with, and ultimate success in their research area. Informed by Deci and Ryan's self-determination theory and conceptualization of different forms of motivation, this paper explores the research topic selection process of 53 engineering PhD students with varying levels of prior work experience to understand their processes of and motivations for selecting the focus of their doctoral work.

2. Background

Though there is little empirical work on why doctoral students select a particular topic of research, particularly within engineering, several studies provide insight into what motivates students to pursue research more broadly. Deemer, Martens, and Buboltz [1] developed a "research motivation" scale based on responses from graduate students in STEM fields. Using factor analysis, the authors identified three broad types of research motivation: intrinsic reward, extrinsic reward, and failure avoidance. Their conception of intrinsic reward related to students' enjoyment of being involved in research and finding satisfaction in their work. Students' extrinsic reward related to their desires to be recognized and respected for their research accomplishments, while failure avoidance included items related to students' aversion to difficult tasks, a desire to walk away from potentially unsuccessful tasks, and a fear of negative outcomes. Their work helps characterize distinct patterns of research motivation emphasizing both intrinsic and extrinsic forms of motivation.

Similarly, Roach and Sauermann [2] studied STEM PhD students' decisions to pursue research-oriented careers. The authors found a positive relationship between students' taste for science, which included "preferences for upstream research, for freedom in choosing research projects, publishing, and interactions with the scientific community," [2, p. 2] and students' likelihood of pursuing a research-oriented academic career over a career in industry. Like much of the research on individuals' decisions related to their pursuit of research, Roach and Sauremann's [2] work focused on the choice to do research broadly rather than a choice to pursue research on a particular topic and emphasized students' internal beliefs and values rather than elements (internal and external) of their decision making process.

Most resources that address the selection of a research topic are instructive rather than empirical. Several scholars have authored articles offering advice to doctoral students about the selection of research projects. Luse, Mennecke, and Townsend [9] offered a framework for selecting a research project that draws on Kuhn's work on scientific revolutions. They emphasized the importance of changing one's mindset and questioning previously held beliefs, and suggested tools for expanding one's thinking, including brainstorming, making visual models, and discussing ideas with others. They also emphasized the importance of personal interest in a research topic for perseverance when the research process becomes difficult or discouraging. Many university websites offer similar advice to students, emphasizing the importance of interest in the topic, as well as providing suggestions about considering the scope and focus of one's research question [3, 5].

The emphasis on personal interest in articles providing advice on how to select a research topic (and perhaps even reflected by the lack of an empirical investigation of students' research topic selection motivations) seems to belie an assumption that, at least at the graduate level, individuals' research pathways are primarily driven by their preferences and interests, as opposed to any potential external influences or constraints. However, graduate students often interact with a variety of other individuals and organizations in selecting a research project: their advisor, members of their dissertation committee, their peers and labmates, external employers, funding agencies, potential stakeholders in and consumers of their research, and even their partners and families. These factors likely play a role in the ultimate decision of research focus area.

While there is limited research related to students' research motivation and topic selection and graduate student academic motivation more generally, engineering education research at the undergraduate level provides some additional insight into what

motivates students to engage in academic engineering tasks. One study by Economy, Sharp, Martin, & Kennedy [10] suggested that students' decisions to select a particular summer research opportunity were motivated primarily by their interest in a project, though they also cited external factors such as funding and location as important in their decisions. Though not focused on research motivation, several other studies of undergraduate engineering students provided insight into their motivation within a classroom. Kolari, Viskari, & Savander-Ranne [11] examined characteristics of an undergraduate engineering learning environment that fostered academic motivation and success. They found that helping students recognize the personal relevance of the curriculum to their individual career interests and goals and students' enjoyment of the learning activities helped with their motivation and success. In another study of undergraduate students' motivation within a particular classroom context, Trenshaw, Revelo, Earl, & Herman [12] found that relatedness, a sense of connection and community with other students, was key for students' intrinsic motivation to succeed within a second-year computer engineering course. These studies at the undergraduate level further illustrate how engineering students are likely to draw on a number of both intrinsic and extrinsic motivating factors in their academic decision making.

Building on the existing literature of student research topic selection and academic motivation within engineering, we draw on self-determination theory to explore engineering doctoral students' motivations for pursuing a particular research topic. While our initial analysis involved an inductive examination of the data, the findings of our inductive analysis suggested self-determination theory, with an emphasis on intrinsic and extrinsic motivation, and proved to be a useful lens for understanding students' motivation for pursuing a specific research agenda.

3. Guiding theoretical framework

Individuals' motivation for engaging in a variety of academic and achievement-oriented tasks has been an important focus of educational research. However, while Deemer, Martens, and Buboltz [1] used the concept of motivation to explore students' choices to engage in research, little has been done exploring students' motivations for selecting a particular topic or area of research. Deci and Ryan's [13] foundational work on self-determination theory builds on the notion of two primary types of motivation, intrinsic and extrinsic. *Intrinsic motivation* refers to an individual engaging in a parti-

cular activity for its own sake, out of an inherent interest in or enjoyment of that activity. In contrast, *extrinsic motivation* reflects an individual's decision to engage in a task because it leads to an outcome separable from the task itself, like a reward or the influence of others [14].

Subsequent works by Deci, Ryan, and others [14–16] complicated the notion of an intrinsic/extrinsic motivation dichotomy, exploring different types and elements of intrinsic and extrinsic motivation and the way these types of motivation relate to one another. Later works emphasized the role of autonomy in differentiating different types of extrinsic motivation. Deci and Ryan [13] proposed the notion of autonomous versus controlled motivation, in which autonomous motivation is characterized by individual volition or choice and controlled motivation involves external pressure or coercion. Intrinsic motivation and some more internalized forms of extrinsic motivation can be characterized as autonomous, while less internalized types of extrinsic motivation are characterized as controlled [17].

Ryan and Deci [14] outline different forms of extrinsic motivation. The least autonomous of these, short of amotivation, or an absolute lack on an intent to act, is external regulation, in which individuals act in order to satisfy an external demand or for an externally imposed reward condition. The locus of control or causation is viewed as entirely external. The second type of extrinsic motivation is introjected regulation, in which people act to avoid guilt or anxiety or to attain ego- or pride-centered reward or recognition. Extrinsic motivation through identification is a more-autonomous form of extrinsic motivation, in which an individual identifies with the personal importance or value of a particular action, perhaps as it relates to a personal goal. Integrated regulation represents the most autonomous form of extrinsic motivation, in which an individual brings external regulations, or the perceived instrumental value of a particular action, into alignment with his or her values or needs. They still perceive the outcome of a particular task as separate from engaging in the task itself, but the task becomes more integrated with oneself. Intrinsic motivation represents the most autonomous, self-determined form of motivation. Fig. 1 displays Ryan and Deci's taxonomy of motivation, including the four types of extrinsic motivation.

Whether one is intrinsically or extrinsically motivated can have important implications for the quality of one's experience and performance. The authors contend that intrinsic motivation results in "high-quality learning and creativity" [14, p. 55], though the differing types of external motivation vary in their outcomes. Ryan and Connell [18] found that for different forms of extrinsic motiva-
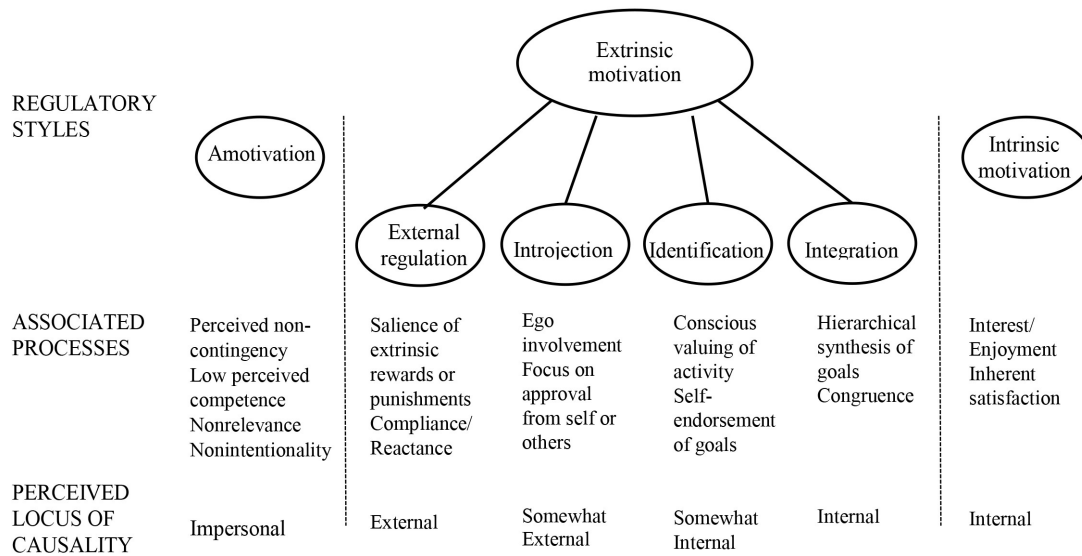
Fig. 1. Ryan and Deci's taxonomy of human motivation (adapted from Ryan & Deci, 2000).

tion, the more externally regulated a particular behavior was, the less likely students were to show interest, value, or effort in the task (though it is important to note that the population of study here was school-age children, not adult learners). In that same study, intrinsic motivation was associated with greater interest, enjoyment, perceived competence, and coping. Subsequent works leant support to Ryan and Connell's findings, suggesting that more internalized forms of motivation are associated with a variety of positive outcomes related to individuals' experience of and performance at a particular task [14].

Deci and Ryan argue that it is possible for an individual to initially engage in an activity due to some external consequence or reward but, if they do not perceive the external regulation to be too coercive or controlling, may, over time, recognize intrinsically interesting or enjoyable qualities of the task itself. This would result in a shift from a more extrinsic to intrinsic motivation for engaging in a particular task. This might be particularly relevant since, by Deci and Ryan's definition, one might characterize all dissertation-related research as at least somewhat extrinsically motivated, as the end goal, presumably, for nearly all PhD students is to complete a research project that will satisfy the requirements for earning a PhD. However, in this paper we aim for a more nuanced understanding of students' motivations for selecting a particular research, recognizing that students may choose a particular topic for multiple, overlapping reasons. We consider students' motivation not for opting to engage in research that will satisfy the requirements of a dissertation, but rather their motivation for selecting a particular topic of research.

4. Methods

In this paper, we draw on data from one phase of a multi-phase mixed-methods research study. The broad focus of the larger study was on experiences of engineering returners (defined here as those students with a 5 or more year gap out of school between their undergraduate and doctoral study) and direct-pathway students (defined as those who begin a PhD shortly after completing their undergraduate study) [19–21]. The study involved three phases: a national survey of returning and direct-pathway students meant to understand their PhD experiences and motivations, a qualitative phase that involves interviews with 53 engineering doctoral students about their research process and experiences and finally, interviews with stakeholders in academia, industry, and government about their experiences as they relate to returning students. This paper draws on data from interviews with returning and direct-pathway students and focuses on students' decision making about their research topic. Given the diversity of perspectives in students' background and prior experience, this sample is particularly helpful in understanding a wide range of engineering graduate student motivations for pursuing a particular subject for research.

4.1 Interview protocol development

Consistent with the goals of our larger study, our interview protocol focused on understanding students' decisions to pursue a PhD, selection of a research focus, their pre-PhD experiences, and the ways these past experiences may have shaped students' PhD work and experience in the program. Our interview development process was guided by

literature on best practices for interview design and administration [22–24]. Interview questions were grounded in the literature on graduate education and findings from our team's earlier work [8, 25].

We piloted our initial interview protocol with several participants who had either recently completed or were in the process of completing an engineering PhD. Both returning and direct-pathway students were included in this interview pilot. Participants' responses and feedback during the pilot phase helped us to refine our protocol and gauge the length of time it would require to complete each interview.

4.2 Interview content

Our final interview protocol covered several broad areas: (1) an introduction to the interview and basic background information about a participant's current position in their PhD program, (2) a characterization of their pre-PhD work and research experiences, (3) their process in deciding to pursue a PhD, (4) characterization of academic experiences and the their doctoral research, including the progression of their research agenda, (5) students' plans upon completing their PhD, (6) a hypothetical research scenario aimed at capturing various elements of their research process and related past experiences, and (7) how students believe their past experiences shaped their doctoral work. Within section 4 of the protocol, one subset of questions focused on students' process of selecting a research topic:

- Can you describe how your PhD research project has taken shape?
  - How did you choose your research project?
  - To what extent were you able to choose your project topic?
  - What factors influenced the choice of topic?

Follow-up questions asked for clarity and elaboration on participants' responses. While data for this paper drew primarily on the interview subsection relating to students' research work and their process of selecting a topic, we analyzed data from across all seven broad areas of the interviews.

4.3 Participants

We interviewed 53 total students, 27 returning and 26 direct-pathway students, about their paths through and experiences in PhD programs, motivations for pursuing an engineering PhD, and how their past experiences informed their PhD work. While our participant selection was guided by a balance in returning and direct-pathway students, we also sought to capture variation in participants' racial/ethnic background, gender, institution, and academic field. Approximately 15 percent (n=8) of our interview participants were underrepresented minorities and 40 percent (n=21) were female. Participants came from 19 different universities that differed in institutional type and geographic location. Students' engineering degree fields including mechanical, electrical, civil, bioengineering, aerospace, industrial, materials, computer science, and systems engineering as well as engineering education and several combined or multidisciplinary programs. Students varied in the number of years they had been in their doctoral programs, but, given our emphasis on students' selection of their research topics, we primarily opted to interview students who were at least in their second year of doctoral study.

4.4 Data collection

Participants were selected based on their responses indicating their willingness to be interviewed on a national survey distributed in the first phase of our larger study. We selected several interview sites to travel to in person based on the number of participants at each institution willing to be interviewed. We emailed all survey participants who indicated their interest in an interview at each site, informing them the days and times a member of our team would be on their campus conducting interviews. The majority of our interviews (n = 39) were conducted in-person at 9 different institutions. To ensure representation from a variety of institutions, we interviewed an additional 14 participants via Skype.

One researcher conducted all of the interviews over a 6-month period. The interviews ranged from approximately 35 minutes to 2 hours, with most interviews lasting between 45 minutes and an hour and a half. All participants were compensated $20 for their time. The interview protocols for returning and direct-pathway students were nearly identical, with only minor wording tweaks to account for the likely nature of their past work experiences.

4.5 Data analysis

Audio recordings of interviews were transcribed and checked for accuracy and all names and identifying information were removed. In our initial round of data analysis, one team member utilized an inductive analysis approach [26], identifying emergent themes. The team member carefully read, and re-read 10 full transcripts, paying particular attention to passages that illustrated participants' varied decision processes to pursue a PhD, choice of research topics, approaches to directing their research work, and their perceptions about the value of their research work. From this, we developed a codebook that included code names, definitions, and sample responses. Two undergraduate

Table 1. Summary of Students' Motivations for Choosing Their Research Topics

Motivation Type	Total Count	Returner Count	Direct-pathway Count
Intrinsic	18	13	5
Extrinsic	32	14	18
Advisor-assigned	10	4	6
External constraints, aligned with interests	12	4	8
Extrinsic, autonomous	10	6	4
Early Work: Advisor-assigned, Later Work: Intrinsic	3	0	3
Total	53	27	26

student coders utilized this codebook to identify and categorize all instances of where students spoke of their process of selecting a research topic, meeting weekly with each other and a graduate student member of the research team to discuss and resolve any differences in their coding. Codes were revised and clarified throughout this process to best reflect the data. For this paper, we focus exclusively on codes and data related to students' selection of their research topics.

Upon completion of an inductive coding approach for our data, we found Deci and Ryan's conceptualization of intrinsic and extrinsic motivation aligned well with our generated codes relating to research topic selection, particularly given the authors' emphasis on autonomy and internalization in characterizing different forms of extrinsic motivation. While the analyses presented in this work reflect our inductively-generated categories of research topic selection, Ryan and Deci's motivation framework informed our grouping of our findings by intrinsic and extrinsic motivation as well as our consideration of the role of students' autonomy and internalized values in our explanation of students' motivation for selecting their research topics. However, while Ryan and Deci's [14] taxonomy of human motivation informs our discussion about themes that characterize students' intrinsic and extrinsic motivations for selecting a research topic, we do attempt to map emergent themes from our data onto their taxonomy.

5. Findings

Students varied greatly in their motivation for pursuing a particular area of research. While all students presumably considered the need to select a research area that would allow them to satisfy PhD requirements, students' rationale for selecting a particular topic ranged from almost strictly intrinsic, motivated by an interest in pursuing a particular question or area of interest, to nearly strictly extrinsic, with little autonomy or over their topic selection process or little internalized interest in the topic. While some students (less than one-third of all students interviewed) described their project selection process as primarily driven by their intrinsic interest in or curiosity about a particular subject area or question, the majority of students interviewed described some external constraint or extrinsic motivation that shaped their experiences. Students differed widely in the degree of autonomy they had to select their own projects. Table 1 summarizes the types of motivations represented by students in each category. We discuss each of these with examples in the following subsections.

5.1 Intrinsic motivation

Students who were intrinsically motivated to pursue a particular research topic did so out of a personally-held interest in the subject. Consistent with Ryan and Deci's [14] later conceptions of motivation, students who were intrinsically motivated also had the autonomy to select their own topic and were not compelled or constrained by external constraint (outside of the need to conduct research in order to complete the requirements of the doctoral program). Approximately one-third of students interviewed described intrinsic motivation for selecting their research area.

Marcia's experiences illustrate intrinsic motivation for selecting a topic. She, of course, had to satisfy her advisor's requirements to successfully complete her research, but was driven by her personal interest in the area to select the topic she studied:

> I'd almost complete freedom. I've mostly been motivated by just what I think is interesting and what papers I've written. It's fairly almost completely up to me how I want to define it. [. . .] I got feedback on which things I should focus on [. . .] But it's pretty much fair game. I can do, I think, define it however I want. And then, the last part is, just convincing my advisor that that's enough, and that completes the PhD.

Marcia described her work as driven by her interest in the topic and her interaction with her advisor is to

persuade him/her to agree to her ideas rather than looking to him/her to direct her choice in topic.

Several other students with more intrinsically-motivated, self-determined research topics selected projects based on an interest in a topic that arose in their past experiences. Many of these students had prior work experience and sought to use their PhD to answer a question or address a problem related to their earlier work. Students often expressed a long-standing interest in pursuing this area of research. Georgia, an engineering education doctoral student who taught abroad before pursuing a PhD, described how her experiences led to her interest in her research area:

> Choosing engineering education, after being in [country], learning about learning, and how engineers stop engineering once they hit the classroom, and being such an advocate for integrating the curriculum, and seeing how so many courses, and so many colleges don't do that. That's really a passion of mine, and something that I know an engineering education degree will help me get.

Michelle, a PhD student with 12 years of experience as a practitioner before returning to graduate school, was similarly driven by an interest from her past work. She had previously worked in a position that instilled an interest in addressing a particular environmental issue. She decided that she hoped to pursue a PhD to address this issue and, when enrolling in a program, informed her program of her interest and intention to conduct research in a particular area. The program assigned an advisor with related research interests that enabled her to pursue her intended research project:

> I came in telling them what program I wanted to be a part of and what I wanted to do. It just happened that they selected my adviser for me. . . Now, I knew her, [advisor] is one of the ones that was doing the research that I thought was really interesting. [. . .] That ended up how I got there.

Claire explained she selected a research problem based on an issue she saw arising both in her current work with aspiring engineers during the course of her PhD program and her own experiences previously. She identified with this problem, considered it important, and decided to pursue it as a research topic. Like Michelle, having the autonomy to be able to pursue her interest was key in an intrinsically-motivated research agenda. Claire explained regarding her topic:

> ". . . it's wide open, wide, wide open. My advisor seems to have taken on one or two older [graduate students who] have more initiative, less coaching."

The practice of Claire's advisor in selecting students who able to select their own topic and her encouragement of them to do so is an example of how external factors may support intrinsic motivation. While in some cases external factors constrain individuals' decision making, our research also demonstrated instances in which these external conditions facilitated students' freedom to pursue intrinsically-rewarding work.

Many other students who had the autonomy to select their own topic were able to do so due to a financial opportunity that granted them significant flexibility. Paul, for example, attributed his ability to select his own topic to an abundance of funding available to the senior faculty members he worked with:

> I'm lucky. It's almost completely autonomous. Both groups are flushed with cash and if you're with a new professor who needs to get those papers out, who doesn't have the money he needs to direct that research, you won't have that opportunity, but when you have well-established tenured professors, they can take a little more risk for that reward.

Ursula selected a program that would allow her to pursue research on her topic of interest. She attributed her autonomy in selecting and directing her research focus to funding that was not attached to a particular project topic and her advisor's hands-off style:

> I think part of that is actually the NSF fellowship and the fact that because I'm not on a paid grant of my advisor there hasn't been a lot of pressuring. As he puts it, he's really given me next to no direction on it. He says it will make me a better researcher, and ultimately I suppose he might be right.

Like many other students hoping to pursue an intrinsically-motivated area of research, securing funding was critical for Brandon. Brandon was a returning student who had previously completed some coursework and was working full time at a university. For his job, he sought out a project that built on a piece of an earlier project that interested him. In addition to his intrinsic motivation to pursue this research project, he also recognized that it could fulfill the requirements to complete a PhD, and negotiated with the funding agency to allow him to use the project for that purpose as well. For him too, securing funding in advance was key in being able to pursue a project he identified as interesting.

> I knew that this was a project that would yield a PhD. When I was talking to the people about getting the funding, I told them very bluntly I'm going to structure this so I can get a PhD out of it. There will be some work I do that is not how you're used to watching me approach things that will yield a dissertation. I hope that you'll put up with that and if not let me know. Let's just not do the project.

Brandon, like other students who were intrinsically

motivated, reported nearly complete autonomy to select a research subject.

Intrinsically motivated students were able to select a topic based primarily on their interest in a topic. For some intrinsically motivated students, this interest came from a past professional or academic experience. While both returning and direct-pathway students may have had significant experiences prior to their graduate study that could have sparked an interest in a particular research topic, the majority (72%) of students who reported intrinsic research topic motivation were returners. In some cases, an external condition, like a supportive advisor or a fellowship, facilitated students' pursuit of intrinsically motivated research by providing them with the freedom to choose.

5.2 Extrinsic motivation

Students' whose research topics were extrinsically motivated varied in the extent to which their topic was personally held and the level of autonomy students had to select a topic. Students who were extrinsically motivated either lacked the opportunity to fully determine their own topic, were compelled or constrained by circumstances external to themselves, or were driven to pursue a particular line of research for reasons beyond a personal interest in the particular topic. Our findings pointed to several broad categories of extrinsic motivation in students' research topic selection. Some students were assigned a topic by their advisor with very little say in the matter, others found their choice in topic was constrained by external factors (such as funding) but still believed their topic choice was influenced by or related to their interests. Other students had the autonomy to select their own research topic but were still motivated by extrinsic factors beyond the research topic itself. Though we classified students based on their primary form of motivation for the purposes of summarizing trends in the data, it was possible in some instances that students expressed elements of more than one form of extrinsic motivation. For example, a student's choice of topic may have been constrained by external factors but still related to their academic interests as well as a desire to select a topic that allowed them to complete their degree quickly or publish in top journals.

5.2.1 Topic determined by advisor

Perhaps the most extreme cases of extrinsically motivated research topic selection were those in which the student had very little say in the particular topic. In most of these cases, students described their topics as dictated by funding or assigned by their advisor, with little to no input of their own. One student with such an experience was Adam,

who described his topic selection process as: "It was chosen for me [. . .] [My advisor] said 'Do this.'"

Another student, Steven, described his research topic selection as a series of "almost random" events: he did not have a strong sense of what he wanted to do during his PhD and applied to multiple programs. He was accepted into one department at a particular university and as a result, elected to pursue his PhD in that field. Once admitted, he was assigned an advisor with a lab, and assigned a funded project within that lab by his advisor. Of his choice of a research topic, Steven explained, "I have a task specifically outlined in that contract but it's all of like five sentences so it's kind of vague and so my primary focus is sort of solving certain problems outlined in that contract".

Other students also described having their primary research focus assigned by their advisor. Ike explained that given his advisor's position in the field and his own novice status, his advisor directed him to pursue a research topic on several occasions. While Ike was not able to self-select his own research topic, his description of the process suggested an acceptance of the process and happiness with his assigned topic:

> [My advisor is] tenured, he's been here a long time and he's very good in his field and I'm an incoming PhD student. Maybe that influenced my decision more than anything. What he says goes. In my mind he doesn't give off that vibe but yeah . . . I worked on that for the first 3 months which isn't related to my current research and then once it came through there was kind of an understanding, a mutual understanding. I'm not exactly sure how it happened. He has a very good way of reading people. Maybe my body language said I'm willing to work on this project and I would really like it but I do. There was no argument.

In some instances, students intentionally turned to their advisors for assistance selecting a research focus. Olga originally opted to join a research project conceptualized by her advisor and another graduate student but later, given difficulties with that project and personal stressors external to her research, asked her advisor to suggest another project. Though she asked to be assigned another topic, Olga expressed some frustration about not feeling a sense of ownership over her research topic as a result:

> My advisor was like, "Okay, well let's see, if you can't work on this other project, which is fine, here are some other ideas of what you could work on. I have been thinking about this project, what do feel about joining in on it?" It has definitely not felt as much of this is what I want to do, but I have really embraced it. He did say there are these different options here, but I've really been enjoying the idea of it. It is frustrating that it doesn't feel quite mine yet, 100% mine, but again that's just adjusting to life right now. There's been a lot of things going on.

Rich, another student who elected to have his advisor assign a research topic, had a funding package that allowed him to have complete autonomy in selecting a research area. However, he did not feel confident in his own ability to select a research focus as a relative novice in the field:

> I'm on a fellowship, so I'm not dependent on a research assistantship or a particular grant for funding. In theory, I get to research anything I want to. What that really means is, I don't know how to pick a research project. I'm new at this. So, I ask my advisor what he thinks. If he thinks it looks like something worth pursuing, then I'll pursue it if it sounds good to me. From a rules standpoint, I could whatever I want. From a practical standpoint, I'm working on something that he was interested in. That's fine with me, because it's an interesting project.

5.2.2 Externally constrained but aligned with interests

Funding was closely tied to advisors' research priorities and similarly served to direct and constrain many students' selection of research areas. Several students explained that funding availability was the primary driver of their research topic selection. Harriet, for example, described selecting a project with ample funding through NSF as "probably the biggest thing" driving her decision to pursue a given research area. However, many of these students sought to work within funding constraints to pursue their research using an approach that interested them while still meeting grant requirements.

Faye explained that she had some flexibility within the terms of her advisor's grant.

> He gives us a lot of freedom to do that, but we are constrained by, you know, the grant . . . how the grant was written, and what he wants to do with the grant. I mean, I'm paid by a certain grant from the NIH, and the part that I'm working on is supposed to be [*redacted*]. So, the way I'm doing it is up to me.

Similarly, Simon explained "As long as we are meeting the goals of the grant project, we can also do our own side analyses."

In addition to funding, work requirements also served as an external constraint on some students' choice of a research topic. For example, Brett, a returning student who maintained his position at the company he had been at for years, chose a project that aligned with his work needs. However, the project he chose also aligned well with his interests, and he describes the decision as a "kill two birds with one stone" solution. He explained:

> Part of that was dictated by the needs of work. [. . .] What they were really interested in was someone with a specialty in controls. That worked well for me and I chose that not only because of that reason but because

what I had been really interested in from the time I was a teenager until currently still [. . .] is robotics.

In some cases, students' choices were limited to several options. Harriet explained that her advisor suggested several projects in light of available funding. She explained her rationale for selecting between those projects:

> Obviously . . . well, obvious to me, if there's something that's going to be more hands-on, which I know a lot of engineering students say, of course I was going to jump on that. I think it just. . . that's just the reason. It sounded more interesting.

Harriet's motivation to pursue a particular line of research was similar to many other students' in this category: their options for research topics were limited due to external factors, but chose amongst those options based on the project that was most closely aligned with their intrinsic interests.

One student, Travis, whose choices were constrained by available funding, chose between two project options not based on his personal interest in the topic, but rather based on which option would be easier and more straightforward:

> I was given two choices. Why I chose it was because I was well-defined. There was another project that was there that was much more nebulous and it could have been funded to a bunch of experimental, but it wasn't somewhat structured where you know what the dissertation chapters would sort of look like going in. The advice that I was given by a friend that got a PhD would say, "Choose the well-defined project. You do not want the nebulous one. Go with that one. You'll be much better off." (Travis).

Travis' motivation represents a relative lack of autonomy in his decision; his choices were limited, as well as another type of extrinsic motivation in choosing between the two options.

Consistent with Deci and Ryan's theory of motivation, in several instances students described selecting a particular research area due to extrinsic motivation, only to, over time, become more personally invested in the project for its own sake, their motivation orientation shifting from extrinsic to intrinsic. Victor, for example, originally selected his project based on funding availability and his advisor's belief in the project's merit. However, after several days working on the project, Victor explained he became very enthusiastic about his research work and would be excited to do work in the area for multiple years:

> Choice of topic, the funding was huge, it was probably number 1. And then 2, my advisor, he thought it had legs and that mattered a lot to me, he advised a lot of people so if he's like this is a good topic, then I trust that a lot. And just like that in like about a day or two into it, I was really into it, I had a lot of ideas and I could see it going a long way. I felt like I could do it for 3 years, so that was huge.

Kristen was originally introduced to her project topic by her advisor 15 years prior to her PhD as an undergraduate student. She became passionate about that topic and worked in the field for many years before returning for a PhD to pursue the same topic further with her original advisor who first introduced her to the area.

> Well, my advisor is the one who got me into [my research area], 15 years ago, and I wanted to continue in the field so it was just pretty natural about what my interest of moving forward in [that field] would be as well as what his interests and expertise as a mechanical engineer would be so it's been just a really nice way to form a trajectory of what we're both interested.

> It was a very natural progression. When I was a senior undergrad I was taking his class and had enjoyed his teaching and asked him if he had any design projects for my senior design and he said, "Yeah, let's look at [this topic]." It just all fell into place from there.

Passionate about the research area, Kristen developed questions and agendas of her own within that research domain which she chose to pursue as part of her PhD research work.

5.2.3 Autonomous but extrinsically motivated

Not all forms of extrinsic motivation for selecting a research topic were external to the student or determined by an advisor or funding constraints. Some students had autonomy in their decision making and selected a research topic that would allow them to accomplish a personal goal. For some students, like Quincy this meant selecting a topic that would enable them to complete their degree in the most efficient way possible. Midway through his degree, Quincy had to change advisors and with his new advisor had the autonomy to select a research area of interest. However, while Quincy wanted a project that interested him, his primary motivation was to select a topic that enabled him to most quickly achieve his goal of completing his PhD:

> Well, with the new advisor, he was actually pretty open to almost anything, but he obviously pointed out where he was going to be able to help me most, both from an intellectual side and from a grant money side. I felt like I had a fair amount of leeway, but my goal then, just like when I had first started grad school was, find something that I can do right away and make progress right away.

Another student, Steven, explained that while his primary project was assigned by his advisor, he personally elected to pursue other interesting projects he believed would merit publications. In some ways, Steven's motivation for selecting these projects seems somewhat intrinsic, as he emphasizes his interest in the projects. However, his orientation toward publication in selecting research projects was driven by his goal to quickly complete the requirements of his PhD and be well-prepared for the job market, which ultimately reflects motivation extrinsic to the task itself:

> …Our boss has a much more hands off sort of advising style and so if there's other interesting problems that are pursued then I'll go after those as well, just sort of trying to get publications so I can get out of here.

Other students who had the autonomy to select a research topic of their own chose a topic for reasons that were still extrinsic, but more personally-held or internalized. John selected a topic that was closely aligned with his experience and skill where he felt he could contribute and, in part, as a response to a challenge from a colleague who did not believe he could solve the problem he proposed:

> In particular, a professor from [University], he said, "I don't think you can solve this problem [. . .] I took that as a challenge and came up with a method.

In conjunction with his desire to meet the challenge posed by his colleague, John also explained the other practical elements he considered before deciding to pursue his intended area of study:

> The key thing I had to decide was is this novel? Has anyone done this before? Is it feasible? Can it be done? Is the method better than existing methods? The answer to all those is, yes, and that's what the journal article shows.

Several students emphasized the importance of researching in a new or novel area that had not been well-tread by others. Alice expressed an interest in doing research in an area that was not only interesting to her, but also novel, that would allow her to build a reputation in her field.

> It was new and innovative; it wasn't kind of retreading something else that had been done. It was an interesting algorithm that I really wanted to learn more about. It's kind of a new field in general, not that it's been around only for a few years but it's still kind of being heavily investigated both in the computer science realm and also just starting to be introduced into a sort of engineering application. I like the fact that it really hadn't been explored thoroughly, because I didn't like the idea of . . . I never liked the idea of competing with dozens of other people who are already experts in a field. I always liked the idea of getting into something new and making a name for something that hasn't been done before.

5.3 Early work: advisor-assigned, later work: intrinsic

In several cases, students described shifting forms of motivation over their graduate career. In these instances, students were assigned an initial project by their advisor. However, they reported that for a later project, as they advanced in their graduate study, they had the autonomy to select their own topic and were driven by their intrinsic interest in a particular subject matter. Allen explained that even

though he was essentially required to work on a project initially, the funding situation changed and he was able to select his own projects:

> In the beginning, I had very little freedom to do that because we were in sort of a funding desert at the time, a lot of things kind of ran out at the same time which is unfortunate but once I started my PhD, I had considerable flexibility to choose where I wanted to go. The funding situation completely changed, I've paid my dues into the lab by spending time on this other project that I didn't necessarily want to be on.

Yvette described a similar situation in which she was given her initial project by her advisor but, in time, had a better sense of her own interests and has had the autonomy to select new topics based on interest.

> I had contacted him the summer before I started because I kind of wanted to get a head start. He had a number of things that he said he thought would be a good fit for me. I just selected the one that appealed to me the most. I worked with him on that. Since then it's been kind of a combination. It's typical of my field to have a number of projects going at the same time. Some of them I've just kind of identified a problem I think is worth investigating. Then I'll either talk to my advisor or someone else in my department who I think works on similar questions.

Though there were only several students who described multiple projects for which they had different motivations for pursuing, all of these participants were direct-pathway students. Their cases suggest that even though they did not enter with the flexibility or experience that enabled them to pursue intrinsically-motivated projects, over the course of their graduate degrees, they were able to conduct research that they felt compelled to pursue out of interest in or curiosity about the topic.

6. Discussion

Our findings provide some insights into the various influences on engineering PhD students' selection of their research topics. We drew on Deci and Ryan's self-determination theory and their characterization of intrinsic and extrinsic motivation, using principles of their work to inform our understanding of emergent categories of students' research motivation. While much of the advice for students on how to select a topic emphasizes passion and personal interest, our interviews with 53 returning and direct-pathway doctoral students suggested a more complicated picture of the factors that influence students' decisions. While approximately a third of engineering doctoral students interviewed mentioned strictly autonomous, intrinsic motivation for selecting their research agenda, the majority of students' decisions were influenced by some extrinsic factor. Extrinsically-motivated students often described their topic choices being con-

strained by funding, faculty goals, or work requirements but many also reported trying to work within these constraints to pursue a topic of interest.

Many of the students in our study who cited intrinsic motivation for selecting a particular research topic had both the financial autonomy necessary to pursue a topic of their choice and some sort of meaningful past experience that sparked their initial interest in the topic. Intrinsically-motivated students often drew on prior work experience in informing their work. The majority (72%) of students who reported intrinsic motivations in their selection of their research focus were returning students. Returning students may have the perspectives and experience that are helpful in understanding important problems and identifying gaps in the knowledge of field and developing research questions and interests of their own. This finding is in line with our prior work which suggests some returners were compelled to pursue a PhD to study an issue evident in their past work experiences [8].

Consistent with Deci and Ryan's framework, forms of extrinsic motivation varied widely. Our emergent categories of research motivation do not precisely mirror Deci & Ryan's types of extrinsic motivation, but consider the locus of control and how personally-held one's motivation is (two elements critical to their classification of forms of extrinsic motivation) in our classification and understanding of the forms of research motivation identified in our study. For some students, extrinsic motivation for pursuing a research area reflected an almost entirely "top down" assignment of a particular research project of their advisor's choosing. Several students had the opportunity to select their own topic, yet intentionally opted to draw on their faculty members' expertise for assistance in selecting a topic, not yet confident of their own ability to select a fruitful project. Other students tried to select one of several options offered to them by their advisors that aligned as closely as possible with their interests. In some instances, students had more autonomy to select a topic but were motivated to select a topic most closely aligned with their personal goals or identity. While such motivation differs significantly from having a topic assigned by an advisor, it still reflects motivation beyond selecting a topic for its own sake, or a personally held interest in the work itself.

In several cases, students were originally extrinsically compelled to select a particular topic yet, over time, they began to see intrinsic value in the work and their research became increasingly integrated with their personally-held interests. Other students' topics were initially externally determined but reported autonomy and intrinsic motivation for

their selection of subsequent research topics after time and experience in their graduate programs. In many cases, extrinsic motivation and intrinsic interest in a research area are intertwined and, at times, complementary. A student may be externally compelled to pursue a line of research, but still find that research interesting and rewarding in its own right.

For many students, funding played a critical role in determining the degree of autonomy they had in selecting a research topic. Some students were funded through an external fellowship that gave them the flexibility of a topic of their interest. Other students, however, selected their research topics based on funding, being assigned to a particular funded project by their faculty member or working within the requirements of a particular grant. While some students were able pursue their own interests within the requirements of a funded project, many students are not conducting research work in which they are intrinsically interested.

6.1 Educational implications

Many students who pursued intrinsically-motivated research topics received a fellowship, like the NSF Graduate Research Fellowship that enabled them to pursue research of their choosing. Fellowship applications ask students to describe their research interests and propose a study of interest. However, many students do not enter academia with the background knowledge and skills necessary to define their research interests or agenda. While returning students may have the perspective and experiences that are helpful in defining research questions, many students recently out of undergraduate degree programs may not have similar experiences that can inform their research. The changes to the NSF fellowship program, effective in 2017, that dictate students may only apply for the fellowship once, in their first or second year of graduate study, may further complicate this issue. Students may apply before they have had ample opportunity to understand the needs of the field and their own personal research interests. Thus, an implication is to consider the limitations that are set on when students can apply for funding to support their individually-initiated research agendas.

Many students are unlikely to begin their PhD with a clearly-defined personal research agenda and our study suggested that many students are also not getting the opportunity to select their own research topics once in the PhD program. Not all engineering PhD students plan to pursue academic careers, but many do. For many advanced engineering professionals in academia, and some of those in other positions as well, identifying a research agenda is a key skill. It is important to consider the implications

if students do not have any experience in directing their own research work prior to beginning these careers. Deci and Ryan's work suggests that intrinsically motivated achievement choices are associated with greater persistence at and satisfaction with the task. Students with rich past experiences may enter their PhD programs with the experience and support necessary to successfully explore a research topic of interest. However, these students are in the minority and universities should consider how to provide more students with the opportunity to develop their own research interests prior to or within the course of their PhD program. Undergraduate research presents one opportunity for students to gain exposure to different areas of and approaches to engineering research and begin to refine their own interests. Other opportunities within graduate school may also help facilitate students' participation in research that aligns with their own intrinsic interests. Given the size and expense of many engineering research projects, independently conceptualizing and running a project of their own design may not be possible for all engineering students. However, providing incoming doctoral students with fellowships to "shop around" by engaging in smaller-scale research projects with a variety of teams may allow students to find a research project more aligned with their individual interests or recognize opportunities within those teams to pursue their own research questions with existing tools or data. Survey courses on research methods and design may also be a promising opportunity for students to reflect on their own interests and formulate research questions. Such opportunities may be beneficial to support students' research work and training as advanced engineering professionals.

7. Conclusion

Though motivation type has important implications for one's experience of and performance at a particular task, there is little literature that addresses PhD students' motivation for selecting research topics. Our study drew on a diverse sample of returning and direct-pathway students to understand the range of motivations that guided engineering doctoral students' research subject decisions. The majority of students interviewed reported some form of extrinsic motivation guiding their work, a finding that is consistent with the complexity, scale, and cost of many engineering research projects. However, even for those students who were externally compelled to select a particular topic, many reported an alignment with their interests, a development of intrinsic interest in their work, and increasing potential for engaging in

intrinsically-motivated research with more time in the program. We found more returners in our study reported primarily intrinsic motivation for their topic selection, suggesting that experiences engaging in engineering work at a deep level may help inform, motivate, and prepare students to direct their own work. Collectively, our findings speak to the need and potential for a variety of ways for students to gain experiences that allow them to identify important engineering problems in which they feel personally invested. While returners may identify research areas of interest in their engineering jobs prior to their PhD, direct-pathway students may be able to explore different research interests through undergraduate or Master's-level research, or by engaging short-term in a number of research teams or projects at the beginning of their doctoral programs. Providing all doctoral students with opportunities to discover and engage with research areas that they are intrinsically motivated to pursue may contribute positively to students' dedication to their research, the quality of their work, and their persistence in engineering.

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