Non-Academic Career Pathways for Engineering Doctoral Students: An Evaluation of an NSF Research Traineeship Program

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Our evidence-based practice paper examines non-academic pathways, which are becoming increasingly common for graduate degree recipients, particularly those in STEM fields. However, career preparation by academic institutions, faculty, and advisors tends to overwhelmingly focus on academic career pathways. One program that seeks to prepare doctoral students for a wider range of career options is Data-Enabled Discovery and Design of Energy Materials (D3EM) at Texas A&M University, which began in 2016 and focuses on the interdisciplinary training of scientists and engineers for many potential future careers. Students in D3EM take part in a cross-disciplinary curriculum of 15 credit hours, in addition to many additional supports, such as mentoring "coffee chats" and writing groups. We are investigating the following evaluation question, in the context of this program:

What experiences and program components may help engineering doctoral students increase their interest and preparation for a career in industry or government, and why are they effective?

We conducted interviews with 12 participants from the 2017 and 2018 cohorts of the D3EM program. Other evaluation data provides context for these interviews. Following content analysis of the interview data, several themes emerged. In general, students reported a lack of stigma in D3EM around pursuing nonacademic careers. Internships and capstone design projects completed for government lab clients in particular increased students' interest in nonacademic career paths, and helped them develop contacts and experiences within government labs to better understand and prepare for full-time work as a government researcher. Informal mentoring opportunities, such as mentoring coffee chats, allowed students to ask questions related to careers by interacting with program faculty. Finally, students created portfolios and individual development plans which would be expected to support their career development, but students reported that these requirements were more onerous than helpful. The D3EM program serves as an example of how impactful programs can be designed to encourage students to explore a variety of potential future career pathways, particularly beyond tenure-track faculty positions. Implications from the findings include the continued implementation of such programs and sustained efforts to change the conversation about PhD careers that reflect the job market and graduate student interests.

Introduction

In the past decade, graduate engineering education has emerged as a research focus within the engineering education community. Prior research has centered around graduate student engineering identity (Choe & Borrego, 2019; Miller, Tsugawa-Nieves, Chestnut, Cass, & Kirn, 2017; Perkins et al., 2020; Satterfield et al., 2019), writing concepts and processes of engineering graduate students (Berdanier & Zerbe, 2018a, 2018b), and engineering graduate student attrition (Berdanier, Whitehair, Kirn, & Satterfield, 2020; Whitehair & Berdanier, 2018). Berdanier et al. (2020) created a model for graduate student attrition, called the GrAD model, based on Reddit posts of engineering doctoral students who were considering or had left their graduate programs. Additional research examines the experiences of engineering graduate students in research groups (Burt, 2019; Crede & Borrego, 2012), the roles of engineering graduate students as mentors in research contexts (Ahn & Cox, 2016), engineering doctoral student motivations (London et al., 2014), and socialization experiences (Mena, Diefes-Dux, & Capobianco, 2013; Szelényi, 2013). A recently published book investigated the experiences of engineering doctoral graduates post-graduation in roles in industry and academy (Cox, 2020).

However, institutions of higher education, including both administration and faculty, remain focused on academic pathways as the future careers of doctoral students (Austin et al., 2009; Roach & Sauermann, 2010), despite the large percentage of students who will work in different sectors directly following their graduation. Much of the research listed in the above paragraph takes place in academic contexts or focuses on preparing graduate students for future academic work. In addition to the academic sector, engineering doctorates are predominately employed in industry or government. In 2013, the career sector breakdown for engineering doctoral recipients 10-14 years after receiving their degree was 67% in Industry, 26% in Education, and 9% in Government. Similarly, for physical sciences at the same time period, 51% were in Industry, 39% in Education, and 10% in Government (National Science Board, 2020). While less common, they may also be self-employed or working at a non-profit. In 2010, 3.6% of all employed engineers with doctorates were self-employed (Milesi, Selfa, & Milan, 2014). Similarly, in 2013, 3% of engineering doctoral recipients were working in non-profit positions 10-14 years after receiving their degree (National Science Board, 2020). Furthermore, many graduates who take academic post-doctoral positions upon matriculation will end up working in industry or government positions later on in their careers (Yang & Webber, 2015).

While research skills developed at the doctoral level are useful for all three major career sectors (industry, government, and academia), it becomes disadvantageous for doctoral students if they are only socialized for one of those pathways or actively discouraged from pursuing different areas and exploring interests (Thiry, Laursen, & Liston, 2007). For example, if engineering doctoral students are not permitted to have internships in a government lab or industrial setting during the summer, they may miss out an experience that could inform whether to pursue a career in those sectors post-graduation. A few studies have considered the workforce experiences of engineering doctoral graduates in both industry and academia (Ahn, Cox, London, & Zhu, 2013; Cox, 2020) and how doctoral engineering programs should adjust curriculum and requirements for industry workforce preparation (Watson & Lyons, 2011).

Despite the prevailing academic focus, some universities have started to incorporate more career preparation for alternate pathways for doctoral students, modeled after national resources such as Science Careers (American Association for the Advancement of Science, 2019) and imaginePhD (Graduate Career Consortium, 2020). These resources help students reflect on how their specific research training develops transferable competencies, which competencies may be useful in different employment sectors, and which combinations fit an individual's strengths and interests. Publications describing and evaluating these types of programs are just beginning to emerge. What is missing from the research literature are analyses of whether and how specific programs and their components prepare PhD students for nonacademic career paths. To address this gap in the literature, our evidence-based practice paper examines the following evaluation question:

What experiences and program components may help engineering doctoral students increase their interest and preparation for a career in industry or government, and why are they effective?

We are presenting an example of how one program addresses non-academic career pathways for engineering and science doctoral students. Specific information about program design and components are included in the following section.

Methods

Methodology

We are approaching this work as a program evaluation, which informs our perspective during analysis and writing. The paper authors include external program evaluators, a graduate assistant supporting the educational mission of the program, and the program director. The role of programs in supporting non-academic doctoral career pathways is a relatively new area of research, which we believe needs to be studied to adequately support engineering doctoral students' interests and future career pathways. Due to the novelty of this work, it is not clear which theoretical frameworks should be used to interpret the data. Therefore, we conducted our analysis inductively to maximize themes and perspectives, rather than adhere to a specific framework which could potentially limit our interpretations. Since the program's underlying theoretical framework (Boix Mansilla & Duraisingh, 2007) was focused on interdisciplinary learning and unrelated to career preparation, we are gearing our focus away from theories or frameworks to identify what program components are successful before delving into theoretical perspectives which might explain their success.

Research Setting

Texas A&M University is a large public research (R1) institution located in the southwestern United States, in a suburban area. In 2019, almost 70,000 undergraduate, graduate, and professional students were enrolled at their main campus in College Station, TX. This location serves as their flagship campus for the university system, with ten additional campuses located throughout the state. The institution is consistently nationally recognized for their graduate and undergraduate engineering programs, currently ranked in the top 15 engineering graduate programs (US News & World Report, 2020). In 2018, over 1500 full-time doctoral students were enrolled in the institution's engineering departments. Seventeen different engineering disciplines are options for doctoral study (ASEE, 2020).

Program Description

As part of the effort of the Materials Genome Initiative (MGI), Data-Enabled Discovery and Design of Energy Materials (D3EM), an interdisciplinary graduate program funded by an NSF Research Traineeship grant, aims to train the next generation scientists and engineers and speed up the process of materials discovery and development (Chang, Semma, Fowler, & Arroyave, 2017; Lavadia, Chang, & Fowler, 2018). To create an innovative training model, D3EM recruited experts from materials science, informatics, engineering design, and STEM graduate education to develop and run the program. D3EM also collaborates with potential employers in industry, national labs, and academia to seek advice in preparing the graduate trainees for a wide range of career options. The program was funded in 2015 and began in 2016. Since 2016, this two-year training program has trained 44 doctoral students and 3 master's students from materials science & engineering, chemical engineering, mechanical engineering, electrical & computer engineering, industrial and systems engineering, aerospace engineering, chemistry, and physics.

Overall, the program aims to equip students with advanced skills in materials discovery and broaden students' career paths in several ways. In the first-year training, students were grounded in their home disciplines. In the second-year training, students took multidisciplinary courses (i.e., materials science, informatics, and engineering design), and then engaged in an interdisciplinary capstone course (materials design studio). This sequencing is designed to provide students with well-grounded experience that would integrate the materials science, engineering design, and informatics into their interdisciplinary capstone design projects and internships. Students were encouraged to complete summer internships during the two years of training. Additional program components, such as mentoring resources and tools for career development, were offered during the academic year for all students in the program. These program components included ePortfolios, Individual Development Plans (IDPs), a writing community, and coffee chats (Chang, Patterson, Harmon, Fowler, & Arroyave, 2020). Further details for all program components are included below in Table 1.

Table 1: Program Components of D3EM

Program Component	**Duration**	**Details**
Internships at U.S. National Labs	Summer	• Not required for all since international students ineligible • Specific national lab partners include NASA, AFRL, & Southwest Research Lab
Mentoring "coffee chats"	Bi-weekly during fall & spring semester	• Coordinated by faculty members, occasionally featuring guests • Topics related to career preparation and planning, including job searching; interview skills; and how to locate a position in industry, faculty, or postdoc • Student-chosen topics
ePortfolios	First two years	• Employer-focused • Designed to showcase skills developed in program
Individual development plan (IDP) and discussion with mentor/advisor	Updated annually	• Completed with advisors and mentors • Action plans for career goals, involves goal-setting and personal evaluation
Multidisciplinary courses	First two years	• Courses in materials science, informatics, and engineering design
Capstone course (i.e., materials design studio)	Second year	• Interdisciplinary, project-based course involving external clients and teams • Focused on materials informatics, often involving large datasets
Writing Community	First year	• Receive writing feedback from peers and consultants • Develop writing skills

Participants

We conducted interviews with participants who were in the 2017 or 2018 cohorts during summer 2019, i.e., participants who recently completed two-year D3EM program training requirements. All students in the 2017 and 2018 cohorts were invited to participate in an interview. Three cohorts of students have completed at least one year in the program. Students may still participate in D3EM activities after the two-year training. All participants were currently in their 3^{rd} or 4^{th} year in the program. Twelve members from the two cohorts participated in an interview, which reached theoretical saturation for our initial assessment purposes. All participants had completed at least two years of doctoral study at the time of the interview, with nine participants in their 3^{rd} year, one in their 4^{th} year, and two in their 5^{th} year. Two female students and ten male students participated in the interviews. For this reason, we use gender-neutral pronouns in our presentation of most findings. Disciplines of the participants were materials science & engineering (8 participants), mechanical engineering (1 participant), electrical & computer engineering (1 participant), industrial and systems engineering (1 participant), and chemistry (1 participant). All participants were pursuing doctoral degrees. Two international students participated in the interviews. The interview did not ask participants for race/ethnicity information, and this data was unavailable from program records. We refer to participants as Participant #XX (i.e., Participant #2) in the Findings section, rather than using pseudonyms. Since this is such a small program, we did not want to include a table listing individually identifying details for each pseudonym, which is a common practice when pseudonyms are used.

Data Collection

Twelve interviews were conducted via Zoom teleconference by an external evaluator to the program, who is an author on this paper, during a two-week period in summer 2019. Only the interviewer and a single program participant were present on the call during each interview. Interviews took place in a secure location, where participants could express their viewpoints freely without risk of being overheard by faculty or program staff. We used a semi-structured interview protocol, designed with questions to elicit meaningful responses from participants, while allowing the flexibility for follow-up questions based participant responses. Interview protocol questions focused on feedback about the D3EM program, participant career plans, their internship experiences, career training provided by the program, and general thoughts on career preparation. The interviewer took detailed notes on each interview. Interviews were not recorded due to the potentially sensitive nature of the interview subject, as most participants were still actively involved with the D3EM program. This ensured participants' privacy, while allowing them to freely express their viewpoints. The interviews lasted between 10 to 40 minutes in length. A similar protocol has been repeated annually since 2017; focused questions about career preparation were added in 2019. Interview protocol questions are listed below.

1. Currently, what are your career plans for after completing your PhD?
2. How do you think your D3EM training is preparing you for that career path?
3. When you were not on D3EM funding, were you completing a research assistantship or other funding? Did that experience(s) provide additional skills? Which skills?
4. What do you think is missing from your preparation to get a job and be successful in [industry/government/academia]?
5. How and where have you been getting useful information on different possible career paths?
    a. Have you discussed these career plans with your advisor, other faculty, or people who work in industry or government?
    b. Has your Individual Development Plan (IDP) helped you articulate your goals to others and identify what you need to get there? If so, in what ways?
6. Did you complete an internship? If so, how has that increased your understanding of skills needed to gain full-time employment there or at a similar organization?

7. Do you think the learning environment in D3EM will make yourself more competitive in the job market than your non-D3EM peers in your department? Why?

Data Analysis

The first two authors reviewed and discussed the written interview notes to determine initial themes emerging from the data, conferring with the interviewer (also an author) to fill in additional information about participant interviews. The first author completed further content analysis of the interview notes (Krippendorff, 2019), reviewing each participant's response individually and examining the responses by question for each of the seven questions in the interview protocol. Initial codes were created based on specific program components mentioned by the participants, using inductive coding methods (Miles, Huberman, & Saldana, 2014). While a few protocol questions addressed specific program components (i.e., internships and IDPs), different aspects of program components were discussed throughout most interviews. Additional codes were created to capture recurring ideas that spanned program components. Upon this analysis, codes were consolidated into related ideas, and four aspects of the program emerged as recurring themes throughout participant responses, particularly non-academic career options, internships and capstone design projects, informal mentoring opportunities, and individual development plans. While we started coding by program components, our analysis centered on creating themes around why certain program components worked for non-academic career preparation. Themes were reviewed and finalized by the first two paper authors, based on the interview notes, our experience conducting interviews with this program, and other personal experience with the program and program participants. For the past four years, we have interacted with the program as evaluators, which involves visiting in person for advisory board meetings and conducting annual student and periodic faculty interviews. Triangulation occurred when personal experiences with the program, such as past student interviews and other evaluation aspects, were used to confirm validity of the findings (Creswell & Miller, 2000). With the exception of the program director who is an author, all other authors are affiliated with the program in evaluator-type roles.

Findings

Lack of Stigma Associated with Non-academic Career Options

In general, students reported a lack of stigma in D3EM around pursuing nonacademic careers. The majority of participants were interested in pursuing non-academic career options, with two expressing a desire to continue down entrepreneurial pathways. For example, Participant #1 shared their plans for a data science company that helps other companies with their data analytics and had already discussed their intentions with professors to receive feedback and gauge their interest. Another participant, Participant #6, had previously joined a friend's start-up during their undergraduate study and wanted to continue in the start-up world following their doctoral degree completion, citing earning potential and desire to impact others' lives as appealing aspects of entrepreneurship. Future employment in industry or national lab settings were the top career options for half (6) of the participants. While some participants were largely ambivalent between these two options, others showed a clear preference for one over the other.

Two participants who had previous internships in the Air Force Research Lab stated they could see themselves continuing in that role or in industry. For example, Participant #12 preferred industry over national labs due to the shorter project timelines, ability to work with a more diverse group (particularly with non-engineers), and seeing the direct application of the research. However, Participant #8 felt that working in a national lab was more impactful than industry, viewing their contributions as helping with “advances in science” rather than “just helping a corporation make money”.

Only four of the 12 participants were seriously considering academia as a future option, with one also considering industry options. Both female participants were interested in academia and stated that developing relationships with students and the aspect of mentorship drew them to the academic sector. An additional participant (P#12) mentioned they could see themselves teaching as a professor long-term, after receiving experience in industry, similar to their undergraduate student experience at a smaller teaching-focused institution. Several participants actively expressed a disinterest in academic options. Reasons for this disinterest included desire to focus on research full-time without additional responsibilities, feeling unprepared for the teaching aspect of faculty positions, the stress of gaining and maintaining sources of funding, and perceived lack of work-life balance in academia.

Interactions with Government Labs through Internships and Capstone Design Projects

Internships and capstone design projects completed for government lab clients increased students' interest in nonacademic career paths and helped them develop contacts and experiences within government labs to better understand and prepare for full-time work in that sector. For example, Participant #4 expressed interest in working full-time in the Air Force Research Lab (AFRL) after completing an internship with them, citing the familiarity with the project, teams at the lab, and experience gained as contributing factors. Participant #8 commented on the quality of mentorship they received at the AFRL, which they viewed as existing in their internship and lacking in other aspects of the D3EM program. Similarly, Participant #9 stressed the connections made with others as a positive aspect of their internship, particularly the scientists and contractors working in the lab. Some internships provided participants with general skills on how to function as full-time employees in a professional workplace. Participant #6 shared that they learned how to present and communicate information, such as project results, in a useful format for others, particularly for their supervisor. Another participant, Participant #1, came up with an entrepreneurial idea for a start-up company due to their experience working at NASA, seeing a need based on their internship work.

A few participants specifically mentioned the capstone projects, which were part of the design studio course, as a beneficial part of the D3EM program. For example, Participant #6 stressed the skills they gained during the assigned research project on materials applications of data science. They noted the importance of learning how to effectively gather information through different sources and synthesize it into a cohesive paper. Time management was another skill learned through completing the project. Participant #11 noted that the coding present in the design studio course helped them become more well-rounded, as “almost nobody in their department has experience coding". They were able to take the skills developed in the design studio course and incorporate them into their research lab work.

However, a number of international students are affiliated with the D3EM program and are not eligible to work at US government facilities. For example, one participant mentioned that they were unable to complete an internship while in the D3EM program, indicating they wished there was a way "to reduce these barriers to have at least one" internship. Similarly, while another participant had two internships at the same company in South America, they were unable to complete an internship in the D3EM program due to their status as an international student.

Informal Mentoring Opportunities and Connection to Faculty and Peers

Informal mentoring opportunities, in particular mentoring coffee chats, allowed students to ask questions related to careers by interacting informally with program faculty. Six participants mentioned the coffee chats as a beneficial part of participating in the D3EM program. Participant #11 appreciated the casual nature of the interactions with faculty during coffee chats and information gained from those interactions, stating, "These should be a part of anybody's PhD program." Another participant, Participant #5, added "it helps to have discussions on the topics", emphasizing the helpfulness of having coffee chats in addition to scheduled seminars. Learning about the writing process and how to write effectively were mentioned as especially important topics covered during the coffee chats. In general, participants also thought having writing seminars and sessions were positive aspects of the program. A technical writing project assignment for the design studio course was another beneficial experience for participants in further developing their writing skills.

Although faculty affiliated with the D3EM program did not have experience working in industry themselves, they developed knowledge through research collaboration with government research labs and private companies. Participants recognized how faculty associated with the program worked to structure the program for the benefit of participating students. When asked about the perceived level of support in D3EM, Participant #4 stressed that "network advisors in D3EM have students' best interest in mind", providing the example of being "encouraged to present at conferences" and develop professional skills. Three participants mentioned the D3EM program PI as being particularly helpful, with one participant referring to their dissertation advisor and the PI as a "dynamic duo". While most participants felt comfortable having open conversations with advisors, particularly related to careers, one participant remarked that hadn't yet "built that kind of relationship" and it "feels uncomfortable right now". Participants also mentioned peers met through the program serving as both resources and as friends.

Creation of Portfolios and Individual Development Plans

Finally, students created portfolios and individual development plans (IDPs) which would be expected to support their career development, but students reported that these requirements were more onerous than helpful. Participant #2 went as far to comment that the IDP "frankly feels like paperwork for no reason" and that the portfolio was of limited use, since employers are more likely to refer to applicant resumes or LinkedIn profiles, saying it "feels like a waste of time". Participant #12 reflected similar concerns about the portfolios and IDPs, also stressing that LinkedIn already provides the same type of information for potential employers. Several participants had more ambivalent feelings about these deliverables. For instance, Participant #1 expressed that they felt the "IDP is OK, it's a great place to start, but feels general". Another participant (P#4) stressed the difficulties of filling out a development plan during their first year in the program and believed that it would be most helpful for traditional-aged students continuing from undergraduate programs with no industry experience. However, Participant #11 felt differently, remarking that the IDP was more helpful in the first year than later years, particularly for students with hands-off faculty advisors. While this student saw some value in completing an IDP, they also believed that other components of D3EM discussed earlier in this paper had greater importance.

In contrast, a few participants spoke very positively about creating their portfolio and IDP. Participant #5 shared that working through the IDP was "a decidedly challenging process", particularly the process of setting attainable goals that will help them progress. Participant #6 agreed that the goal-setting portion was useful, since it pushed them to think long-term, but viewed the portions reflecting on writing as unnecessary and difficult to complete on one's own. The act of thinking about and setting goals through the IDP was viewed as valuable for Participant #9, regardless of whether they ended up meeting their goals. Participant #10 appreciated the opportunity to receive feedback from their advisor outside of formal presentations, such as a dissertation defense, noting that typical conversations focus on data and results, rather than their development as a student and researcher.

Less Useful Program Components

Other program components, including multidisciplinary courses leading up to the capstone design studio and the writing community, were not linked by participants to career development or decision making. This is not to say that they were not useful for students in their academic success; students simply did not emphasize in these interviews that these components directly prepared them for careers. For example, several students described how the writing community helped them develop their first conference papers, and students commented on how the multidisciplinary courses are useful preparation for the capstone studio design course.

Discussion

The D3EM program serves as an example of how impactful programs can be designed to encourage students to explore all potential future career pathways, particularly beyond tenure-track faculty positions. Several components of the program stood out as positive aspects during participant interviews, including capstone team projects and internships, informal mentoring through coffee chats and other relationships developed with faculty, and writing groups. Other aspects, such as the portfolios and individual development plans (IDPs) were less positively received by participants than intended by the program developers.

Capstone team projects (i.e., design studio course), especially those for nonacademic clients, were particularly influential for some students. Participants mentioned gaining research proficiency, expanding their technical knowledge, such as coding, and learning general project and time management skills. Team projects are a popular component of many NSF traineeship programs (Borrego & Cutler, 2010). The client aspect and real-world applications of the projects appears to be the important characteristics in this case. Several potential explanations may contribute to the value students found in these projects. Students may respond differently to project deliverables originating from an external source rather than their advisor. Additionally, finishing a completed product for a client differs from typical graduate research assistant responsibilities, which might culminate in a journal article or recommendations to industry partners. The requirement to have a tangible product by the end of the semester could contribute to the project and time management skills learned by the students. For example, solving problems and meeting deadlines were identified as the most important skills for future job performance by engineering doctoral students interested in industry careers (Berdanier, Branch, London, Ahn, & Cox, 2014). Academic research, other than conference papers and presentations, often does not have set deadlines, which can cause graduate students to struggle to set realistic goals and complete work assignments. The capstone team projects might also involve a higher variety of different skills for their completion, rather than the narrow focus often associated with dissertation work.

Group mentoring coffee chats were an important time for students to interact less formally with program faculty around a specific topic. In a study where 63% participants were in STEM fields, mentoring has previously predicted increased self-efficacy related to doctoral student careers, with specific types of mentoring as particularly important for URM students and women (Curtin, Malley, & Stewart, 2016). Students reported the usefulness of topics and casual interactions with faculty as especially helpful. Examples of topics discussed include job searching, interview skills, and positions in specific career sectors. Participants may have found coffee chats beneficial for several reasons. First, interacting with faculty in a group setting may lessen any apprehension or awkwardness about scheduling a one-on-one mentoring meeting with a faculty member. The presence of other graduate students at coffee chats may reinforce that other students have similar questions and concerns about graduate school and future careers, resulting in increased confidence to ask faculty questions and reduce feelings of isolation commonly experienced by graduate students. Second, the informal nature of coffee chats, where students can drop by and talk in a more relaxed setting (as opposed to faculty offices), may influence student attendance and the types of questions that students feel comfortable asking. Third, coffee chats give students access to interactions with faculty besides their advisor, increasing their pool of potential mentors and ability to learn from a variety of different experiences. Additionally, students may feel more comfortable asking personal questions to faculty members other than their advisor. Fourth, since the coffee chats are provided by the program and faculty volunteers, students might worry less about wasting the time of any faculty or guest speakers. In general, coffee chats may provide a setting where students can see faculty as human, rather than on an academic pedestal, which could lead to a more open dialogue.

This paper gives more detail about how summer internships can work for doctoral students. Prior research highlights the importance of internships for career preparation in industry, as perceived by engineering doctoral students, who believe internships are a necessary component for industry careers (Borrego, Choe, Nguyen, & Knight, 2019). For life science graduate students, participating in internships led to increased confidence in career-decision making (Schnoes et al., 2018). In engineering in particular, the value of internships is clear to many faculty members. The reason more doctoral students do not complete internships may have more to do with lack of faculty support for time away from dissertation research, a climate that discourages students from openly declaring an interest in nonacademic careers, or lack of student knowledge about how to secure an internship. Although career services offices typically provide services to graduate students, much of their outreach on campus may be directed to undergraduates. Since doctoral research is so specific, the professional network of the advisor and other faculty in the discipline may be particularly important for securing a mutually beneficial internship placement.

Participants reported mixed reactions around the individual development plans (IDPs). While having goals has been found to increase perceptions of task usefulness for engineering graduate students (Tsugawa-Nieves et al., 2017), the act of setting goals was particularly helpful for several students. However, the aspects of the IDPs related to evaluating their own strengths and weaknesses were perceived by students as far less useful. Depending on their year of doctoral study, it may be fairly difficult for students to accurately self-assess areas where they need to improve and those where they are excelling. As students are learning norms in highly technical fields of study, it may be more beneficial for them to receive feedback from experts, such as their faculty advisors, rather than rely on self-assessment. IDPs were designed to be extensive and facilitate reflection for students with advisors who were not skilled (or had no interest in) mentoring students in this manner. However, our results suggest that faculty advisors used the IDP very differently depending on their personalities and management style, which influenced student perceptions of its usefulness. This variation suggests additional training on giving feedback and discussing long-term goals may be useful for faculty advisors.

Overall, participants spoke very highly of the program faculty and their interactions with students in the program. The program leader (project PI) was mentioned by multiple students as being particularly helpful and an influential part of their experience. While this reaction is partially due to the PI being a dynamic leader who takes time to get to know all students in D3EM, several other program faculty members also took responsibility for success of D3EM and the students involved. This finding emphasizes the importance of having a good leader to set the tone for a program, while stressing the importance of buy-in from all participating faculty. For example, this buy-in is reflected in faculty actions, from their support of different program components, which is needed to run a sustainable program, to how they talk and interact with students in the program. In this program, the PI taught the capstone design course, while other program faculty ran mentoring coffee chats and taught other courses. This recommendation does not mean that all faculty need to support each one of the program's aspects, but that there is a critical mass of faculty supporting the collective goals of D3EM. It is important for advisors to support student participation in program events, particularly when the students are funded by the program. To facilitate successful program implementation, there must be enough people invested in the success of the program. Programs that exist based on the vision of one person with limited additional input or buy-in are less likely to be sustained. Collaboration between faculty in the program is important for program success (Borrego et al., 2013).

Interview participants indicated an interest in non-academic career pathways, specifically government and industry. A few participants still prioritized academic careers over other options. Additionally, academic career-oriented participants tended to emphasize the reasons why academia was their desired career, rather than expressing any distaste for alternate career paths. Within D3EM, there was a lack of stigma associated with pursuing careers in industry, government, and academia. Most participants were considering multiple career options, seeing value in multiple career paths and weighing the pros and cons of jobs in different sectors. Not all non-academic options are similar; several differences exist between jobs in government and industry, and in some ways government research careers are more similar to academic careers (Choe & Borrego, 2020). Participants often compared government and industry as options, showing personal preference based on desired pace of research and amount of interactions with others. One participant discussed the desire to pursue multiple options, stating "I'll be a professor later". This example highlights the importance of discussing sequential career options with doctoral students, which occurs fairly often in careers of engineering professionals (Cox, 2020). For example, some engineering departments prioritize industry experience when hiring lecturers. Students may be unaware of this option as a potential career pathway, or if they are, how to pursue it. Future research should find ways to consider sequential career plans, rather than simply asking students about one alternative over another for their entire career (Choe & Borrego, 2020).

Future Work

Future research should further investigate how STEM graduate students are thinking about careers and how exemplary programs support those students. While our study fills a gap in identifying both more and less helpful aspects of the program, future work can ground successful program components within existing learning theories or theoretical frameworks. For example, socialization has been studied in relation to assistantships, such as teaching assistantships (Mena et al., 2013), and we need to further understand the role different programs play with graduate student socialization. Further, we should consider how existing theories of socialization for STEM doctoral students (Austin et al., 2009), which are predominantly geared towards academic socialization, could be adapted or changed to support socialization for careers in industry or government labs. The role of programs should also be examined in the context of engineering identity (Choe & Borrego, 2019; Perkins et al., 2020) and how programs currently support professional identity development or existing identity related to different career paths.

Conclusion

Implications from the findings include the continued implementation of such programs and sustained efforts to change the conversation about PhD careers that reflect the job market and graduate student interests. The D3EM program serves as an example of how engineering doctoral students can successfully be supported in pursuing non-academic career options. Specific program components that positively contributed to supporting students' future career interests were identified and included mentoring coffee chats and other informal networking opportunities, internships in government labs, capstone design projects, and the support of faculty within the program. The incorporation of these elements within similar programs has potential to further support graduate student career interests. We do not intend to imply that other programs or engineering departments are not currently supporting students in these avenues; however, there is very little literature on how to effectively provide this support. This paper acts as one example of an interdisciplinary program that encourages many future career options for doctoral students, providing additional detail on program structure and various components that contribute to its success.

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