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Engineering Graduate Education in the United States

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1 Introduction

Within engineering education research, graduate education within the US context is unique in a number of ways. There is less research on graduate education than most other education levels. We believe this is because graduate student experiences are highly influenced by their local context, including the graduate program and adviser/supervisor. Further, and perhaps because of the importance of local context, there is no culture of benchmarking data or transparency in completion rates and time to degree. Other aspects, such as how students are classified as master's versus doctoral students when their ultimate goal is a PhD, further complicate the graduate education data landscape.

Compared with other disciplines, engineering graduate education is also unique. Engineering tends to have a larger proportion of international students, lab and group-based collaborative research, and more collaborative relationships between students and adviser (i.e., more co-authorship). Thus, graduate education research from beyond engineering varies in its relevance to engineering. Since there is a lot of ground to cover, we scope this chapter to focus on studies of engineering graduate students (or including engineering in their coverage of STEM) in the United States conducted by those identifying as engineering education researchers.

Internationally, some of the biggest contextual graduate education differences are in student funding and required coursework (e.g., Australia and the United States (Deters et al., 2021)). For example, it is much more common in the United States for master's and doctoral students to complete approximately two years of coursework before focusing on research (if a thesis or dissertation is part of their program requirements); in many other countries, graduate education is focused almost exclusively on conducting research and is much more individually directed. These differences and varying needs in the global labor market lead to engineering PhD earners working in different sectors of the labor force in different countries (Mason et al., 2022). The graduate funding situation and dynamics in the United States are also quite complex, since students may be funded through a combination of mechanisms controlled by different stakeholders, and interactions with different types of stakeholders can lead to very different student experiences. For example, the federally funded National Science Foundation (NSF) fellowship allows students to have flexibility in their projects and allows them to publish their results, whereas Department of Defense or industry-funded projects can have higher expectations for deliverables, less freedom in what topics the student researches, and some restrictions on publishing due to intellectual property concerns. In other parts of the world, it

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is more common for engineering graduate students to be fully funded once admitted to a graduate program. Given these important contextual differences, we made the choice to scope this chapter to review the literature on engineering graduate education within US contexts. We encourage readers to look to our colleagues' work from around the globe for a broader view of this topic for features and considerations that do not necessarily translate across national contexts.

We have conducted a narrative review, which allows us to identify what has been previously published but can be limited by our experiences and perspectives as researchers in this area (Grant & Booth, 2009). We draw primarily from peer-reviewed journal articles and books in engineering education, as these tend to have more in-depth investigation into issues on graduate education. However, we do cite several conference papers, which are more commonly used for evaluation of specific programs for graduate students. The chapter is laid out in the following sections: "Why Engineering Students Pursue Graduate Education," "Recruitment of Graduate Students," "Engineering Students' Skills Development During Graduate Education," "Engineering Students' Identity Development During Graduate Education," "Supporting Engineering Graduate Students' Skill and Identity Development," "Why Engineering Students Leave Graduate Education," "Career Trajectories of Engineering Graduate Students," "Challenges of Reforming Graduate Education in Engineering," and "Opportunities for Future Research in Graduate Education in Engineering."

2 Why Engineering Students Pursue Graduate Education

We begin with what motivates engineering students to undertake graduate education. The most widely known preparation is undergraduate research (Dukhan & Jenkins, 2007), but it is difficult to understand whether the experience simply increases interest of students who have already self-selected into research. In a longitudinal study that controlled for self-selection bias, Eagan et al. (2013) found that STEM students who participated in undergraduate research experiences were significantly more likely to be interested in pursuing a STEM graduate degree. In addition to learning hands-on lab, writing, and presentation skills, students in formalized programs also learn about the *process* of doing research. For example, Issen et al. (2007) reported that students found it rewarding to overcome research obstacles and said the experience was pivotal in their decisions to attend graduate school. Additionally, the social community during and after the program, in which students made long-lasting friendships, was just as important as the research community during the short summer experience (Issen et al., 2007). In a summer research program specifically for minoritized students, May (1997) found that 89% of participants attended or planned to attend graduate school, a statistically significant finding compared to students who did not participate. Additionally, 60% of student researchers said that program participation helped them find funding for graduate school, a key concern for prospective students.

Undergraduate research experiences can affect students' interest in graduate school without them realizing it. Zydney et al. (2002) surveyed alumni of the University of Delaware, asking them about their experiences as undergraduates without disclosing that the purpose of the survey was to assess long-term effects of undergraduate research experiences. Over half of those surveyed who did research said it was "very" or "extremely" important (4 or 5 out of a 5-point Likert scale), with scores increasing according to the number of semesters of undergraduate research completed. Around 87% of alumni who went on to earn PhDs participated in undergraduate research, compared to only 8% of students who did not complete any research (Zydney et al., 2002).

However, not all students who participate in research decide to attend graduate school. Willis et al. (2013) found that some mechanical engineering students were less likely to be interested in graduate school at the end of their research experience than they were at the beginning, as they found research "tedious" and "slow," favoring working in industry where they could see more immediately applied results from their work (Willis et al., 2013). Though some may find it discouraging that students decide not to further pursue research, this decision-making is a natural part of students' discovery process. As discussed in Section 6, "Why Engineering Students Leave Graduate Education," many advisers hope that students can figure out early if graduate school is right for them, and having an undergraduate research experience is one mechanism for helping students make that decision.

There are also several non-research factors that contribute to students' decisions to go to graduate school. In a study of engineers 5 to 25 years after earning their PhDs, London et al. (2014) found that motivations to attend graduate school included passion for research or a particular technical area, the opportunity to pursue an academic career, or influence from a mentor. McGee et al. found that Black engineering PhD students were motivated to pursue advanced degrees due to passion for their fields, desires to be role models for other Black students interested in STEM, and aspirations to benefit society (McGee et al., 2016). Another important consideration is cost. As Kennedy et al. (2016) found in a study on students' knowledge of financial resources to attend graduate school, the second-most commonly cited factor when deciding between graduate school offers was financial incentives (personal fit within the institution was the most important factor). They also found that a lack of knowledge about financial resources was a deterrent for students considering graduate school, as many undergraduate students did not know about funding mechanisms, such as assistantships, and perceived that there are not as many scholarships available for graduate school as there are for an undergraduate degree. Students who did receive funding, however, found this to be an incentive to attend graduate school, though it seemed limited to PhD students and not available to master's students (Kennedy et al., 2016).

Engineering students' skills and personal factors also contribute to their decision to pursue graduate education. Ro et al. (2017) identified three factors: mathematics proficiency, self-assessment of teamwork and leadership skills, and co-curricular experiences. Students with higher math proficiency and self-assessed leadership skills were more likely to attend graduate school, whereas students with higher self-assessed teamwork skills were less likely to attend graduate school. Additionally, students who spent more time on non-engineering community volunteer work were more likely to attend a non-engineering graduate program (Ro et al., 2017). Two-thirds of study participants in non-engineering master's programs were in business or management, possibly as preparation for careers in engineering management. Borrego et al. (2018) identified personal factors that influenced students' intentions to go to graduate school. The most influential positive factor they identified was self-efficacy, which includes students' belief in their abilities to learn new skills, conduct independent research, and complete their graduate degrees. Other positively correlated factors were outcome expectations (e.g., perceived time to degree completion, impact of having a graduate degree on future job opportunities) and support (e.g., positive interactions with graduate students as an undergraduate, faculty adviser encouragement to attend graduate school, positive mentoring experiences). The more barriers a student encountered (e.g., lack of information about graduate school, perceived inability to pay for graduate school, worries about the competitiveness of application, anticipated low level of future support), the less likely they were to attend graduate school (Borrego et al., 2021).

While many engineering graduate students matriculate directly after earning their undergraduate degrees ("direct-pathway students"), a small percentage begin graduate school after several years in the workforce. These "returners" are an understudied student population, and their work experience gives them unique perspectives and preparation for graduate school. In a quantitative study on returners, Mosyjowski et al. (2017) found that prior to graduate school enrollment, returners reported less confidence in their ability to complete their degree than direct-pathway students, though confidence levels in the two groups were similar after beginning their degrees. Additionally, returners reported higher costs related to finances, work–life balance, and navigating a new environment (Mosyjowski et al., 2017).

3 Recruitment of Graduate Students

Engineering graduate students, especially at the doctoral level, tend to be well-funded. For example, nearly three-quarters of engineering doctoral students in the United States were funded via research assistantships or other grants and fellowships, and less than 10% funded their programs via personal means (Nettles et al., 2006). There is a complex ecosystem of potential funding sources for students, and so many are funded through research grants, making the US graduate recruiting environment fiercely competitive. This competitive arena is particularly present within highly ranked institutions, where a program's prestige is tied to their consistent ability to attract talented graduate students (Evans, 1993; Posselt, 2014; Rutter et al., 2016; Wall Bortz et al., 2020). There are several driving forces, largely stemming from the fact that there have been enormous financial investments to support university-based research engines, and graduate education and the research enterprise are strongly coupled (National Research Council, 1995, 2014). For example, the *US News and World Report*'s rankings of the best engineering schools operationalizes graduate student enrollments within the "faculty resources" category (25% of the ranking score), which considers more doctoral degrees awarded and higher graduate student-to-adviser ratios to be characteristics of higher-ranked institutions. Graduate student selectivity (10% of the ranking score) is operationalized by programs' acceptance rates and entering graduate students' average quantitative GRE (standardized exam for graduate school admissions) score (Morse et al., 2021).

Despite the highly competitive nature of graduate recruitment processes within engineering and their enormous financial implications, there has been surprisingly little systems-level research from the perspective of institutions, with single-institution studies being the predominant research design. One exception is a study (Wall Bortz et al., 2020) of STEM graduate recruitment across institutions which found that programs adopt the same kinds of strategies, even when those strategies do not align with program leaders' stated values or graduate students' priorities. Financial resources comprise the main mechanism used by programs to recruit graduate students and include fellowship offers, multi-year funding packages, research assistantship guarantees, or "top-off" stipends that can act as signing bonuses. However, as the prior section in this chapter highlighted, other factors, such as academic considerations, research interests, adviser fit, location, and program supports, may be even more important for students' decision processes (Le & Tam, 2008). As such, there is an opportunity to enhance and demonstrate such considerations throughout recruitment. Adviser involvement is critical for the graduate recruitment process within STEM fields, a factor of which many faculty members may not be aware (Baron, 1987; Bersola et al., 2014; Evans, 1993).

Exploring graduate recruitment processes is particularly important for a field that has been relatively stagnant with respect to diversifying the student body. The engineering graduate student population is even less diverse than the engineering undergraduate population, which has downstream implications for efforts to broaden participation in engineering. Main et al. (2020) demonstrated correlations between the number of women of color faculty members in a program and the number of women of color who complete bachelor's degrees in engineering. Ong et al. (2011) showed that mentors play an important role in women of color STEM students' decisions to attend graduate school. Mondisa (2018) found that same-race mentors bring some unique relationship- and identity-building approaches to mentoring of African American STEM undergraduates which support their educational and career persistence. Thus, there are multiple positive-feedback loops between diversifying graduate education in engineering so that more faculty members and other mentors can support the next generation and diversify the engineering field more broadly. In a systems-level approach, Fleming et al. (2023) illustrated the institutional pathways (and therefore limited institutional mobility) from bachelor's degrees at highly ranked, not highly ranked, non-US, and minority-serving institutions to PhDs at these same types of institutions for Black/African American and Hispanic/Latino PhD earners.

Despite these many reasons to diversify graduate education in engineering, programs have struggled to meet this goal. Engineering graduate recruiting is competitive, and doubly so for recruiting racially minoritized and women students within engineering. Posselt (2014) asserted that "attracting academically accomplished students from underrepresented backgrounds has become a way that programs evaluate themselves against one another, such that diversity itself is associated with prestige" (p. 501). To understand this more specific competitive arena, Wall Bortz et al. (2021) compared programs' recruitment and yield strategies with decision-making factors of minoritized students. Offering "diversity" fellowships was the most commonly mentioned strategy for attracting racially minoritized students and women in some engineering contexts, yet program leaders also cited a small pool of minoritized graduate students as the limiting factor (as opposed to a lack of available financial resources). Recent national-scale research focused on educational pathways of Black and Hispanic engineering doctoral recipients problematizes this "lack of supply" perception and instead argues that programs can broaden their recruitment efforts by considering bachelor's degree recipients from a range of institutional types and rankings (Fleming et al., 2023; Wall Bortz et al., 2021). Coupled with this idea, many researchers have shown that relying on GRE scores and grade point averages as admissions criteria systematically excludes racially minoritized and women students rather than considering their diverse experiences as valuable assets. Thus, broadening participation in graduate education within engineering requires changes to the "gatekeeping" system that currently characterizes admissions processes.

Wall Bortz et al. (2021) also noted a variety of other non-monetary recruitment strategies that aligned with minoritized students' priorities as well as with prior literature. Such strategies include personal contact with faculty and program personnel (Sowell et al., 2015), leveraging professional faculty networks, including those at historically Black colleges and universities (HBCUs) and other minority-serving institutions (MSIs) (Sowell et al., 2015), and conveying a positive and supportive campus culture, including connecting with faculty and peers (Griffin & Muñiz, 2011). Relative to White and Asian students, Bersola et al. (2014) found that racially minoritized admitted students place more importance on factors such as the diversity of faculty, students, and the community; quality of the campus infrastructure; urbanicity; and life considerations, such as childcare and housing. Student-facing strategies, such as hosting open house events, recruiting in intentional locations, forming and supporting cohorts of minoritized students, and offering a range of professional development activities, were all raised by minoritized students in the Wall Bortz et al. (2020) study. The literature has shown that cohort-based strategies are particularly important for recruiting and supporting minoritized students (Bostwick & Weinberg, 2018), which is a core feature of bridge programs that have been extremely successful in supporting the enrollment of minoritized students into STEM graduate programs (Gámez et al., 2021). Given all these different considerations, unless the overall financial package differs significantly between institutions, money is not likely to sway a minoritized student from an initial preference (Bersola et al., 2014; Freeman, 1984; Jackson & Chapman, 1984; Wall Bortz et al., 2021). Many of these student-facing strategies would also support graduate student retention, which is another pressing issue (Nicole & DeBoer, 2020; Sowell et al., 2015). Therefore, investing time and resources to support recruitment and yield likely will have multiplicative effects on a graduate program's culture of support of racially minoritized and women students.

4 Engineering Students' Skills Development During Graduate Education

We turn now to what and how students learn once they matriculate into an engineering graduate program. Although graduate students in some programs learn from coursework, most of the engineering education research on learning during graduate study focuses on the research group/

laboratory environment. A research group comprises students conducting research under the supervision of one or more advisers, often sharing equipment and methods. These groups can vary significantly in size, membership (i.e., undergraduate researchers, postdocs, and technicians), and climate (Crede & Borrego, 2012). Through their interaction with research group members, graduate students learn important skills, such as presenting research, receiving and responding to feedback, and solving and troubleshooting problems (Burt, 2017).

A small body of research within engineering education has focused on specific skills that develop during engineering graduate students' programs. In a study of engineering PhD earners working in academia and industry, London et al. (2014) found that having a PhD provided additional knowledge, skills, and attributes, including the ability to conduct scientific work and a deeper understanding of fundamental concepts. Science and engineering graduate students and postdocs who mentor undergraduate researchers develop specific skills related to mentoring, including understanding students' needs, building positive working relationships with mentees, developing interpersonal skills, and specific character traits such as patience, flexibility, and humility (Ahn & Cox, 2016). Using a survey-based approach to understand students' perceptions of different kinds of skill development, Grote et al. (2021) focused on four different sets of skills: (1) research skills, (2) communication skills, (3) peer training and mentoring skills, and (4) teamwork and project management skills. Each of these different skill sets could position a student for a variety of different kinds of careers, but the results found a correlation between students' predominant graduate study funding mechanisms and their perceptions that they had opportunities to develop certain skill sets (Grote et al., 2021). Receiving a fellowship is often viewed as prestigious because of the autonomy and, sometimes, pay rate associated with such awards, but these results suggest that receiving a fellowship could come at the cost of having fewer opportunities to develop a range of career-relevant skills. This finding is similar to research by Kinoshita et al. (2020), which used national-scale data to show that women and racially minoritized students funded via fellowships were more likely than other students to report no job offers when they completed the Survey of Earned Doctorates.

Also within the engineering education literature, writing as a skill has been highlighted as essential for graduate students' academic and career success, even though many engineering graduate students select the field because it may seemingly emphasize other kinds of skills, such as math or statistics skills. Research conducted by Berdanier (2019) highlighted distinct rhetorical moves within engineering graduate students' National Science Foundation Graduate Research Fellowship Program proposal materials to help students visualize different argumentation patterns that can be applied within their writing (Berdanier, 2019). Her subsequent research demonstrated linkages between prospective and current engineering graduate students' attitudes about writing and the actual rhetorical patterns that appeared in their writing (Berdanier, 2021). Writing skills are crucial for PhD students, as they need to write dissertations in order to obtain their degrees. A dissertation writing workshop for racially minoritized PhD students enabled them to understand the utility of their dissertations in relation to their career paths, adjust their perceptions (particularly around perfectionism) about writing their dissertations, and improve how to plan writing (Miller et al., 2020).

There is also research into what STEM graduate students learn from interdisciplinary training programs. This analysis used a curriculum design framework to understand the intended outcomes, evidence, and learning experiences. Among interdisciplinary graduate traineeship programs, including at least one engineering discipline, 73% listed various technical skills and knowledge, including grounding in multiple disciplines, 54% sought to cultivate in students a broad perspective of their interdisciplinary domain and ability to integrate multiple disciplines, 49% had the goal of creating an interdisciplinary environment for students, 42% focused on teamwork skills needed to collaborate across disciplines, and 24% addressed interdisciplinary written and oral communication skills. Specialized coursework and team-based research were the most common approaches for cultivating these skills (Borrego & Cutler, 2010; Borrego & Newswander, 2010).

There is also a recent and increasing focus on professional development for graduate students. In the United States, instructors generally do not receive such training, and students who are interested in an academic career find that the professional development available to them as a graduate student is insufficient to prepare them for the teaching aspects of those positions. Coso Strong and Sekayi (2018) found that many advisers and departments are not supportive of teaching or other non-research activities; students needed to actively seek out professional development on how to teach, such as through teaching certificate programs. Focused on developing the professoriate, preparing future faculty (PFF) initiatives are sponsored by institutions for their own and/or external students and by professional societies. Funding has been available for institutions to host PFF programs, particularly aimed at increasing faculty gender and racial/ethnic diversity. These initiatives fall under a wide variety of formats, including workshops (Tormey et al., 2020), formal mentoring programs, formal courses (in which students earn credit), short courses and seminars, structured teaching practicum, reading and writing assignments, formal networking experiences, and research mentoring practicum. Though formal PFF programs were established in 1993, there are few, if any, reported studies on the efficacy of these programs in developing engineering faculty members; rather, reports on PFF programs have focused on best practices and program content (Diggs et al., 2017). Some PFF programs are targeted specifically for students from minoritized populations (Diggs & Mondisa, 2022).

5 Engineering Students' Identity Development During Graduate Education

Identity has emerged as a lens for studying graduate student retention and interest in various roles within and beyond graduate study, two areas that we focus on specifically in subsequent sections. To avoid overlap with the identity chapter in this volume, we focus on studies of graduate students' teacher, researcher, engineer, and scholar identities. This role identity approach can be heavily influenced by the roles undertaken by faculty members and, therefore, is often tied to future faculty programs and research questions.

Svyantek et al. (2015) examined the influence of electronic portfolios in graduate student role identity development, finding a mismatch in teacher identity between where students were at the time of the study and where they would like to be in the future. Participating students were much more confident in the trajectory of their researcher identities. One of the co-authors, Kajfez and colleagues (2016), extended this work to study teacher identity and motivation in graduate teaching assistants. Their longitudinal model of motivation and identity includes future faculty identity and recommends that graduate teaching assistants interact with faculty members who may serve as role models.

Kirn, Perkins, and collaborators (Bahnson et al., 2021) culminated their many qualitative and quantitative studies of graduate student identity with a survey instrument measuring engineer, researcher, and scientist identities, each with their own recognition, interest, and performance/competence subscales. For a national US sample, they reported significant differences by engineering discipline, gender, and race/ethnicity within engineer identity, but not for researcher or scientist identities. Following a similar approach of adapting performance/competence, interest, and recognition identity constructs to the graduate level, Choe and Borrego (2020) related engineer and researcher identities to interest in academic, industry, and government careers among doctoral and thesis master's students. Their results suggest a positive relationship between engineer identity and industry career interest and a correspondingly negative relationship of engineer identity with academic and government career interest. Gelles and Villanueva (2020) found that engineering doctoral identity evolves during graduate school, and engineering PhD students think of people who are earning (fellow students) or have earned (faculty) PhDs as "insiders," and non-PhD earners as "outsiders," with defending their dissertations being a rite of passage to prove themselves to other "insiders." The study's participants described only engineering PhDs as innovative and creative problem-solvers, devaluing the skills and abilities of non-PhD engineers.

In general, there are many more quantitative studies of where graduate students actually end up in the workforce than there are qualitative studies exploring their decision processes. One notable exception is Burt's (2019) work, which integrates many aspects of peer networks, adviser relationships, and social identities into his theoretical model of engineering professorial intentions, which seeks to explain why doctoral students decide whether to pursue academic careers.

International students play important roles within the engineering graduate education ecosystem in many countries. For example, South Africa's doctoral programs had an enrollment of 40% international students in 2016 (Herman & Meki Kombe, 2019). In Canada, 28% of graduate students are international (Universities Canada, 2014). Further, over the past decade, graduate schools in several nations have increased their number of international students. For instance, the number of international graduate students in South Korea doubled from 2009 to 2017 (Ministry of Education of the Republic of Korea, 2018). In addition, the Institute of International Education (2016) reported an influx of international graduate students to US graduate programs over the past two decades, with over half of science and engineering PhDs earned by temporary visa holders (National Science Foundation, 2017). These students face many difficulties related to acculturation (the process of adapting to the new societal norms and behaviors of a host culture) upon arriving in their graduate programs, including facing acculturation stress, gaining cultural competency, and mastering another language (Burdett & Crossman, 2012; Newberry et al., 2011; Wang, 2008; Watkins & Green, 2003). Women international students face additional stressors in US graduate programs, such as feeling excluded in their classes and research groups, needing to work harder to overcome stereotypes, and experiencing tokenization. They work to overcome these barriers by speaking up in study groups and creating social networks where they can provide and receive support from others with similar experiences (Dutta, 2015). In addition to societal integration, international engineering graduate students also go through a process of integration into a new profession, which has its own culture. While they may have been engineers (by education or employment) in their home country, the professional norms of being in the United States can be very different (Newberry et al., 2011). For example, in Japan, engineering identity is strongly linked to one's employer, whereas in France it is tied to where one earned their degree. German engineering identity is tied to a collective social responsibility, which developed as a reaction to technology's role during World War II (Newberry et al., 2011). These international engineering PhD earners go on to contribute to the US engineering workforce, with almost 70% of temporary visa holders planning to stay in the United States after graduation (Sanderson et al., 2000). Models of idea generation show the potential impact that these graduates have: for each 10% increase in international students, there is a resulting 5% increase in the number of patent applications, 7% university patent grants, and 5% non-university grants (Chellaraj et al., 2008).

6 Supporting Engineering Graduate Students' Skill and Identity Development

Unlike in undergraduate education, in which students can have many people providing support, engineering graduate students' primary support comes from their academic program and their research adviser. There are different processes for student–adviser matching, which can sometimes depend on disciplinary norms (Artiles et al., 2023). In many engineering disciplines, students begin their graduate studies without an adviser, and the student–adviser matching process takes place without assistance from the graduate program. In other disciplines (e.g., civil engineering), a program may assign a temporary adviser, and students and advisers find matches without the assistance of the program. Finally, some graduate programs have a formal matching process (most commonly in chemical engineering), in which the graduate program facilitates creating student–adviser pairs (Artiles & Matusovich, 2022a, 2022b; Artiles et al., 2023). During the matching process, students consider future career prospects as well as a potential adviser's funding, research area, personality, and average graduation time; advisers consider students' academic credentials and perceptions of students' research abilities (Joy et al., 2015). New graduate students learn about prospective advisers through information systems in the forms of research seminars, one-on-one interviews, rotation programs (particularly in biomedical engineering), undergraduate research experiences, and independent study courses (Artiles et al., 2023). However, simply accessing these information systems does not equally provide students with the same benefits in navigating the adviser selection process, as students with prior research experience better understand how to use this information to develop criteria for choosing an adviser (Artiles & Matusovich, 2022a).

Advisers often serve to enculturate their advisees to the norms of academia (Boyle & Boice, 1998) and socialize them to the professoriate by demonstrating the different duties a faculty position entails, such as supervising students, managing a research lab, serving on committees, and obtaining external funding (Saddler & Creamer, 2009). Students also learn about many aspects of conducting research from their advisers, including uncertainty, time commitment, publishing, and competition (Saddler, 2009). Advisers are students' primary example for developing a faculty prototype, or their idea of what it means to be a professor, which can influence their interests in academic careers (Burt, 2019) and how they themselves are as advisers, if and when they become faculty (Lee, 2008). There are different approaches to advising, which are not mutually exclusive: functional (acting as a project manager), enculturation (encouraging students to join their discipline's community), critical thinking (encouraging the student to "question and analyze their work"), emancipation (encouraging the student to "question and develop themselves"), and developing a quality relationship (inspiring and caring for the student) (Lee, 2008, p. 267). Students feel supported by advisers who are approachable, foster good working relationships, and frequently communicate with them (De Welde & Laursen, 2008). However, as De Welde and Laursen (2008) found, not all students consider their advisers "mentors": only half of participants in their study on STEM PhD students said they viewed their adviser as a mentor, although an additional 21% said they still viewed their non-mentor adviser as a good adviser. Moreover, they found that advisers do not always provide their students with career advice, with 36% of participants reporting they received no career advice and 20% receiving some advice but less than they would have liked.

In the United States, women and racially minoritized graduate students can have very different experiences than their peers from majority groups (e.g., White and Asian men) (McGee, 2021a). Advising can be a racialized experience: in a study of Black men engineering PhD students, Burt et al. (2016) found that microaggressions from advisers caused the students to question their ability to engage in and feel less comfortable in engineering. In a study of Black engineering and computing PhD students, racialized experiences caused significant stress and strain, leading to academic performance anxiety, impostor syndrome, and poor physical and mental health (McGee, Griffith, et al., 2019). Identity as a scientist, engineer, or researcher is impacted by a student's relationships with their peers and advisers, and these impacts vary for engineering PhD students from different gender and racial/ethnic groups (Perkins et al., 2020). Asian women's poor relationships with their advisers partially cause low science interest, and women of color report stronger benefits from positive relationships with their advisers than their peers (Perkins et al., 2020). Women and racially minoritized graduate students face discrimination, often in the forms of racism or sexism, from peers, advisers, and other faculty (Corneille et al., 2019; De Welde & Laursen, 2011; Fabert et al., 2011; McGee, Griffith, et al., 2019), which reinforces their self-perceptions as insiders or outsiders in their programs (Bahnson, Satterfield, et al., 2022). While such discrimination is rooted in a larger historical and societal context, students are often not aware of the systemic nature of these exclusionary practices (Bahnson, Satterfield, et al., 2022). Engineering education researchers interested in conducting research on race- or sex-based discrimination should be aware of the Discrimination in Engineering Graduate Education (DEGrE) scale, a validated survey including sections on interactions with a student's adviser and other faculty, sexism, and lab culture (Bahnson, Hope, et al., 2022).

7 Why Engineering Students Leave Graduate Education

When talking about engineering graduate education, in addition to discussing the reasons that students pursue a graduate degree and their experiences during degree completion, it is also important to recognize that not all students who begin a degree complete one. There are several reasons that doctoral students decide to leave prior to completing their PhD. It is difficult to quantify retention rates, as some students begin with the intention of completing a PhD but leave after completing a master's degree (colloquially, "mastering out") and are therefore counted together with terminal master's students. There are not many studies of attrition in engineering graduate students. In a study that included graduate students from engineering and other fields, Gardner (2009) found that common reasons students provide for departing prior to PhD completion are personal problems (family and physical/mental health issues), departmental issues (poor advising, lack of financial support, department policies and politics), and graduate school being a poor fit for them personally. "Poor fit" also encompasses students who began their PhDs with a specific goal, but that goal changed over time and the students no longer needed a PhD for their new career goals. Students do not necessarily feel that the time spent figuring out what they wanted is a waste of time but rather a natural part of the maturation process (Gardner, 2009; Zerbe & Berdanier, 2019). Advisers, on the other hand, do not always view such changes of mind so positively and perceive students changing their minds after beginning a PhD as a waste of adviser time and resources. Advisers also cite very different reasons for student departure, including students lacking ability, drive, or motivation; students who should not have begun graduate school in the first place (i.e., the students should have figured out prior to starting their PhDs that it was not right for them); and personal problems. It is notable that there is only a small overlap (i.e., personal issues) between the reasons provided by faculty compared to reasons provided by students to explain departures.

These themes are not stand-alone reasons for attrition but are rather interconnected. Berdanier et al. (2020) conducted a study which used the social media website Reddit to gather reasons for engineering PhD student attrition, and six interconnected themes emerged: adviser role and relationship, student support network, quality of life and work, cost (both time and money), perception by others should they depart, and lacking or changing goals (Berdanier et al., 2020). Though the primary sources of students' issues were problems with their advisers, students were more likely to depart if they were experiencing more than one of these themes. Additionally, a good relationship with one's adviser when experiencing other detrimental factors can complicate a student's decision to depart without a PhD, as students feel guilty about letting their adviser down. While it might seem that students' reasons for early degree departures are the accumulation of events, a single critical event, such as an incident with an adviser, change in funding, or medical event, can also precipitate such decisions (Zerbe et al., 2022). These critical events can take place inside or outside the university setting and appear in either a routine or unexpected context.

Attrition rates between students from different demographic groups are far from equal. US women engineering PhD students have an estimated attrition rate of 35%, compared with just 24% for men (Council of Graduate Schools, 2008). Two studies sponsored by the Council of Graduate Schools (CGS) investigated this further. Sowell et al. found that attrition rates are even higher for racially minoritized students, with 36% of racially minoritized STEM PhD students withdrawing from their programs prior to completion. Black/African American students had a lower completion rate than Hispanic/Latino students (Sowell et al., 2015). The other CGS study found that White

STEM PhD students had a ten-year PhD completion rate of 55%, while Black/African American and Hispanic/Latino students had ten-year completion rates of 47% and 51%, respectively (Sowell et al., 2008). The rates of students considering early degree departures are even higher. Bahnson and Berdanier (2022) surveyed engineering PhD students and research-based master's students and found that 70% had considered leaving their programs in the previous month alone, with women considering leaving at higher rates than men, and US PhD students considering leaving at higher rates than international PhD students. As previously discussed, student–adviser relationships play an important role in students' decisions to complete their PhD. Interviews with advisers and racially minoritized graduate students revealed that students placed higher value on engaging in tasks associated with a personal sense of identity, while advisers placed higher value on tasks that provided mastery and utility, such as preparing presentations and writing grants (Artiles & Matusovich, 2020). Artiles and Matusovich posit that this mismatch between what advisers and racially minoritized students value could possibly lead to a communication discrepancy and contribute to higher attrition rates for racially minoritized students. Similarly, Gardner found that women and students of color also have higher rates of attrition because of being less integrated with their peers and program faculty (Gardner, 2009).

The other side of the attrition coin is student retention. Crede and Borrego (2014) conducted a survey of engineering graduate students across multiple institutions across the United States to determine the student demographic differences in relation to completing their PhD. Factors that were related to student intentions to complete their degree included their perception of their adviser valuing their work, project ownership, and climate. They uncovered differences between students from different regions in the world; notably, students from the Middle East and India reported the highest rates of feeling their work is valued by their adviser and ownership of their projects. Students from the United States had the most positive view of their group climate, while students from East Asia had the lowest climate scores. Additionally, students in more competitive groups (for example, with competition for resources, such as adviser time, funding, or equipment) were less likely to complete their degree (Borrego et al., 2018).

8 Career Trajectories of Engineering Graduate Students

Many of the professional development resources for graduate students have focused on preparation for academic careers. Yet master's- and doctoral-level engineering graduates end up in a variety of employment sectors, including industry, entrepreneurial/start-ups, government, academia, nonprofit, and postdoctoral positions across all those sectors (Fiegener, 2010; NSF & NCSES, 2017; Turk-Bicakci et al., 2014). A survey of engineering master's and doctoral students found that most students simultaneously consider multiple careers within and outside of academia (Choe & Borrego, 2020). US engineering doctoral recipients enter industry positions at rates (38%) nearly as high as academia (45%, including faculty and postdoctoral research positions) (Fiegener, 2010), with a majority (59%) of new US engineering doctorates beginning employment in private, for-profit industry (NSF & NCSES, 2017), and an additional 8% entering into government roles. There is much less career trajectory data for master's students, even though there are over four times as many engineering master's recipients as doctoral recipients (NSF & NCSES, 2015). One survey study from Wendler et al. (2012) found that nearly 25% of 1,500 engineering master's graduates entered into government careers. Considering all of STEM, 81% of master's recipients will enter industry or government jobs (NSF & NCSES, 2017).

There are also noteworthy differences by race and gender as well as expected salaries across sectors. In a study of US engineers in 2010, more than half of male engineering doctorate holders worked in the for-profit industry sector (Turk-Bicakci et al., 2014). Black, Hispanic, and White women were more likely to work in government than other demographic groups, and there are more Black women PhDs in government than any other career sector (Turk-Bicakci et al., 2014). The gender wage gap for graduate-level engineers working in government is less than in industry (Buffington et al., 2016), and government and industry careers have been linked with higher salaries as compared with academic careers (Yang & Webber, 2015). There is also evidence of differences by gender and race in attaining a job offer at the time a PhD student completes their program. Kinoshita et al. (2020) showed that women engineering doctorate holders, particularly those who were married, and racially minoritized engineering doctorate holders were more likely than their peers to have no job offers upon completing NSF's Survey of Earned Doctorates at the end of their programs. Thus, despite claims that there are "supply" or "pipeline" challenges for diversifying engineering, there is still evidence of systematic differences in job offers by gender and race, even among individuals in the United States with the highest levels of education.

The *Graduate STEM Education for the 21st Century* report by the US National Academies of Sciences, Engineering, and Medicine (2018) lamented that many academic institutions do not have a student-centered STEM graduate education system with respect to helping students prepare for a variety of career pathways. According to the report, in an ideal STEM graduate education system:

- Students would be encouraged and given time & resources to explore diverse career options, perhaps through courses, seminars, internships, and other kinds of real-life experiences. . . .
- Graduate programs would develop course offerings and other tools to enable student career exploration and to expose students to career options. . . .
- Institutions would help students identify advisors and mentors who can best support their academic and career development. Faculty advisors would not stigmatize those who favor nonacademic careers.

(National Academies of Sciences, Engineering, and Medicine, 2018, pp. 3–4)

Despite evidence that decreasing percentages of graduates seek entry into academic careers (Fiegener, 2010; NSF & NCSES, 2015), and those who do face increased competition for a limited number of tenure track positions (Larson et al., 2014), the majority of research and resources focus on academic career paths (Main & Wang, 2019), reinforcing a culture that privileges academic positions over nonacademic career pathways (St. Clair et al., 2017; Thiry et al., 2007). Many engineering PhD students begin their graduate studies interested in academic careers (Choe & Borrego, 2020) but lose interest as time goes on because of perceived norms and pressures of working in academia, including stressful environment, pressure to find funding, and work–life balance (McGee, Naphan-Kingery, et al., 2019). As Burt's (2020) article describing the journey of one graduate student's developing interests in the professoriate argues, however, much more research is needed to understand how and why graduate students from marginalized backgrounds choose to pursue a career in academia. Overall, the messages graduate students receive about suitable PhD employment and their understanding of their own preparation leaves much room for improvement. Borrego et al. (2021) conducted interviews with STEM graduate students and highlighted a power differential between advisers and students that makes it difficult for students to express interest in nonacademic career plans. These interviews also described how students find it challenging to articulate the skills and preparation needed to work in industry, even when it was their intended career. Engineering graduates also make career choices based on nonacademic lived experiences. In studies on STEM PhD students of color, McGee and collaborators found that students' career paths were influenced by President Donald Trump's anti-science policies and the COVID-19 pandemic, with some students expressing interest in work on social and racial justice (McGee, 2021b; McGee et al., 2021). For students who are interested in tenure-track faculty careers, the prestige of their PhD institution plays a significant role in where they end up: only roughly 15% of engineering faculty work at a more prestigious institution than where they earned their PhDs (Wapman et al., 2022), and a non-reportable, small number of Black/African American or Hispanic/Latino faculty who earned their PhD outside the US News and World Report's top 25 engineering PhD programs works at a top 25 program (Fleming et al., 2023).

A few prior studies address skills and preparation for PhD engineers in the nonacademic workforce. Cox (2019) asked 40 engineering PhDs in the United States who had entered the workforce across an array of sectors to reflect on the most important skills necessary for career success. They identified communication as most important, followed by teamwork, problem-solving, and deep technical knowledge. Engineering PhDs in industry pointed "particularly to the ability to transition within and across roles in an organization and moving between technical and non-technical roles" (p. 31) as well as confidence-building, scientific/research skills, expertise, and flexibility to design their careers as advantages unique to PhD holders working in industry. Participants from this study recommended students be exposed to interdisciplinary and collaborative research experiences, have ample opportunities to practice communication and presentation skills, and also be exposed to industry PhDs to ask them about life in industry careers (Cox, 2019). In a similar study surveying 100 engineering PhDs working in industry, Watson and Lyons (2011) found that the most important skills needed by entry-level PhD engineers at the respondents' organizations were learning and working independently, working in teams, written and oral communication, and solving problems, while the least important skills were marketing products/processes, managing others, identifying customer needs, and writing peer-reviewed papers. Even though writing specifically peer-reviewed papers was not ranked as highly needed, analysis of job postings showed that written communications skills were highly sought after by companies (Watson & Lyons, 2011). Related studies have also pointed to the benefits of added exposure to teaching, research, professional skills, and industry expectations as part of the doctoral process in STEM (Cox et al., 2011; London et al., 2014). In a national-scale quantitative study, Main et al. (2021b) explored the role of post-PhD early career management training on individuals' subsequent career paths as leaders in industry. Findings specific to women PhD holders in STEM showed that expanding such professional development opportunities for women can result in boosting opportunities for women to hold leadership roles. Amelink and Artiles (2021) surveyed US racially minoritized engineering PhD students and found that internships and related interactions helped students figure out their career goals and understand available nonacademic career options by learning new ways to utilize their skill sets.

In sum, prior literature has shown that most graduate-level engineers spend at least some of their careers outside of academia, yet we know very little about how to prepare them for these careers. Cox's (2019) landmark study identifies important skills needed in industry and makes suggestions for interventions. There are pockets of experiences that have been shown to support preparation for a variety of career paths. For example, Borrego et al. (2021) and Denton et al. (2020) showed that internship experiences can be promising for industry and government career preparation. Informal mentoring interactions around career decisions also can make it easier for students to express and discuss nonacademic career aspirations with program faculty (Denton et al., 2020). The rest of the details supporting nonacademic career paths remain to be filled in by future research, particularly on ways that engineering graduate programs can strategically support and position both master's and PhD students for nonacademic career pathways.

Despite the growth in nonacademic pathways for engineering PhDs, a considerable proportion of new PhDs begins in postdoctoral positions. There are many reasons that PhD earners choose to accept a postdoctoral position, including that other jobs were not available, postdoc training is expected for one's field, and desiring additional training in the same or a different field (Main et al., 2021a; Stephan & Ma, 2005). Postdoctoral work is a common and beneficial preparation for a tenure-track academic position. Wang and Main (2021) found that STEM PhD earners who completed a postdoc were 13% more likely to obtain a tenure-track position than those who did not.

They also found that early career average salaries are similar for people who have and have not completed a postdoc (Main et al., 2021a). Denton et al. (2022) explored engineering and physical sciences postdocs in academic, industry, and government sectors, finding that for US PhDs eligible for government postdoctoral positions, the likelihood of attaining a tenure-track position was comparable to that of academic postdocs, but the potential long-term salary was higher, particularly if they ended up in industry or government permanent positions. When hiring a postdoc, advisers expect postdocs to know about the scientific process, have certain levels of mastery in field-specific methodologies and techniques, and be strong written and oral communicators (Bahnson, Berdanier, et al., 2022). During their appointment, advisers expect postdocs to master new technical skills, contribute to publications and grant proposals, and learn how to navigate the academic ecosystem in preparation for achieving a faculty position and, eventually, tenure (Bahnson, Berdanier, et al., 2022).

People from certain demographic groups are more likely to complete a postdoc. In an analysis of 19 years of PhD earners in science and engineering using the Survey of Earned Doctorates, Stephan and Ma (2005) found that women in engineering were more likely to engage in a postdoc than men, though the reason is unclear. Additionally, they found that people with a temporary visa were more likely to engage in a postdoc than US citizens and permanent residents. This finding is not surprising, given that many jobs in engineering industry and at national laboratories are restricted to US citizens and permanent residents and a postdoc is an option for people to obtain a visa to continue working in the United States. In another study, Main et al. (2021a) found that PhD earners from higher-ranked universities and from programs with higher percentages of graduates who go on to postdoctoral employment are more likely to become a postdoc.

9 Challenges of Reforming Graduate Education in Engineering

Given all that we know from prior research about how to improve graduate education, why is it so difficult to change? Institutions with large graduate engineering enrollments have been around for many years, which makes it extremely challenging to make changes. Particularly in institutional contexts that have strong shared governance between administrators and faculty members, organizations are intentionally designed to withstand sudden changes and shifts caused by external pressures. As the US National Academies (2018) wondered in their report *Graduate STEM Education for the 21st Century*

> dramatic innovations in research technologies, changes in the nature of work, shifts in demographics, and growth in occupations needing STEM expertise all raise questions about how well the current STEM graduate education system can adapt to these changes to continue meeting the nation's needs.
>
> *(p. 1)*

What we do not know, as a National Academies Working Group (2017) articulated in its analysis on graduate student mentoring, is how to effectively change graduate education to develop integrated networks across organizational layers – institutions, departments, programs, and individual advisers. Graduate education is complicated to change because there is a need to understand how to change the entire system.

Graduate education tends to be controlled at the individual discipline or department level as opposed to at higher levels of the organization, such as the college or university (De Valero, 2001). As has been shown by many researchers, graduate student socialization tends to happen at this discipline or departmental level (Gardner, 2007; Golde, 1998) as all processes tied to students' time in programs tend to occur here, including admissions, funding, and degree requirements, all of which are influenced by disciplinary norms and practices (Golde, 2005). Because disciplines drive faculty members' behaviors and attitudes much more than institutions (Bowen & Schuster, 1986), it is quite difficult for any one university to challenge the norms of a particular discipline (Abbott, 2001). The net result is that the same discipline at two different institutions tends to be more similar in their processes than two different disciplines at the same institution. This decentralization is even more pronounced for engineering, as a large proportion of students are funded via research assistantships, which tend to be managed and controlled at the individual adviser level. Relative to life and physical sciences, engineering graduate education is less coupled to the undergraduate education enterprise from a funding perspective (i.e., in the form of teaching assistantships) (Knight et al., 2018), so colleges of engineering have even fewer internal resource mechanisms to incentivize or demand changes in graduate education. Thus, US graduate education in engineering is a highly decentralized process, which makes integrated reform strategies extremely challenging.

There are also challenges to collecting, sharing, and monitoring data about graduate education. The graduate education community does not have the same culture of data reporting and benchmarking as seen at the undergraduate level. Characteristics of enrolled students and graduate degree recipients are reasonably straightforward to obtain, since many of the same databases report on all degree levels. Examples in the United States include Integrated Postsecondary Education Data System (National Center for Education Statistics), American Society for Engineering Education (ASEE), and National Center for Science and Engineering Statistics (National Science Foundation). Publicly reported completion rates, however, are notoriously difficult to find. This may be in part because completion rates are so low. The Council of Graduate Schools (2012) estimates that master's completion rates are less than 70%, and the National Academies reports completion rates of only 60% for doctoral degrees (Ostriker et al., 2015) – both values are over a decade old despite calls for more recent data and concerted efforts for more transparent data reporting (National Academies of Sciences, Engineering, and Medicine, 2018). Further, retention rates across graduate programs can be difficult to calculate, given the variation in how students without master's degrees who are admitted to PhD programs are classified in information systems, particularly when they "master out" by completing a master's degree but are not retained in their PhD program. Greater transparency in graduate program retention rates would likely lead to better-informed decisions by prospective students, deeper discussions in the field of who leaves a graduate program and why, and redoubled efforts to improve student retention at the graduate level.

10 Opportunities for Future Research in Graduate Education in Engineering

Each of the areas we reviewed in the prior sections has enormous potential for additional research. The engineering education research community focused on US graduate education within the engineering disciplines is growing but is still quite small relative to the entire community. Particularly because of the enormous investment in graduate education and its importance for the overall research enterprise, the body of literature focused on graduate education in engineering is surprisingly small. As expectations for employment will continue emphasizing higher levels of education, understanding graduate education in engineering will become even more important in the future.

We want to explicitly point to a few topics that received little or no attention in prior work; these areas represent gaps in the literature base and are opportunities for future research in this area. Much of the prior work on engineering graduate students has focused on doctoral-level processes, experiences, and pathways. However, enrollments in master's programs are far higher than enrollments in PhD programs, yet we know very little about this stage of education. Understanding recruitment processes and why students may choose to engage in an engineering master's degree program, for example, represent areas of research that have not been undertaken. As colleges and universities build out professionally oriented master's degree programs to better serve industry needs, engineering education researchers can learn a lot about these programs that bring together a unique mixture of students with a wide range of backgrounds and goals (Stewart & Chen, 2009). While in this chapter we have relied extensively on engineering education research conducted by individuals who identify as engineering education researchers, there is also important work being done by researchers in their role as practitioners of graduate education. In these cases, the emphasis is on delivering high-quality programs rather than publishing about them. Program details and evaluation evidence are more often published as conference papers, as in the case of dissertation institute, a week-long dissertation-writing workshop for racially minoritized students (Cruz et al., 2018; Cruz et al., 2019; Hasbún et al., 2016); the NSF Integrative Graduate Education and Research Traineeship (IGERT) program (Borrego & Cutler, 2010; Haapala et al., 2021; Wang et al., 2020); and the NSF Research Trainee (NRT) Program (Denton et al., 2020; Duval-Couetil & Yi, 2021). There is an opportunity for future research investigating the long-term effects of such programs and synthesis of multiple graduate education innovations through systematic review or similar means, which is of particular interest, given the substantial amount of funding that is allocated to such programs. Another area for future research is considering what methods are used to investigate issues in graduate education (particularly, how large-scale quantitative data is difficult to obtain). An example of this is early degree departures, since institutions report this differently: as Berdanier et al. (2020) point out, only some departures are captured because many are characterized as master's degree conferrals.

We also note that engineering graduate education is characterized by very high percentages of international students: non-US students comprise over half of the enrolled graduate student population (National Science Foundation, 2017). Much of US engineering education research has prioritized domestic students' experiences and trajectories, and so there is an enormous opportunity for research to understand processes, experiences, and trajectories of international students, which often comprise the majority of enrollments (Silva et al., 2016). Research that has taken a closer look at these students tends to aggregate international students into one group, which does not consider the different cultures and prior systems of education experienced by these students. Disaggregating research approaches that consider international students' home countries or regions more specifically can enhance understanding of graduate education. Moreover, in considering international differences, we see an opportunity for comparative graduate education research that explores differences across national and continental systems of graduate education (e.g., McQueen, 1994), which connects to a theme advanced in a different chapter. In Europe, for example, the Bologna Process created the European Higher Education Area (EHEA), which encourages the 49 member countries to offer (if not require) pedagogical training for instructors to cultivate an "inclusive and innovative approach to learning and teaching" (European Commission). Different education systems stand to benefit from learning from one another, and the engineering education research community can play a role in advancing such work.

As we note in a prior section, much of the prior research on graduate education within engineering has focused on academic career trajectories, which represents a misalignment with the predominant career paths of graduate degree holders in engineering. Although developing the professoriate, particularly for individuals with marginalized identities, has critically important feedback loops for the future of education and the field, we see a critical gap in the engineering education research literature on understanding nonacademic career paths of engineering graduate students. There are substantial opportunities for understanding how such individuals succeed once they enter a range of work sectors, how they uniquely contribute to the workforce, and how programs can best support such pathways. Disaggregating each of these ideas to consider a range of social identities represents important future work.

Finally, the engineering education research community can continue addressing important systemic issues within graduate education. As we explained in prior sections, it is challenging to disentangle different elements of the complex system of graduate education. When thinking about advising processes, for example, there needs to be a consideration of admissions and funding processes as well as considerations of both adviser autonomy and student agency. Systems-level research that interrogates this complexity across a wide range of engineering disciplinary and institutional contexts can help programs identify focused areas in need of reform as well as strategies for becoming more efficient with limited resources while also maintaining an eye on inclusivity. Finally, as is the case for nearly all aspects of engineering education research, US graduate education research within engineering must continue addressing systemic issues of diversity, equity, and inclusion. This lens must be applied to all aspects of the system, from recruitment processes to admissions, funding, and advising processes; to program-level experiences and supports processes; to preparation for a wide range of career trajectories; and to experiences of graduate degree holders within those subsequent career destinations. The engineering education research community can play an important role in building out new, sorely needed datasets and subsequent understanding around graduate education in engineering.

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