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Current Trends in Attrition Considerations of Graduate Engineering Students in the United States*

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Available attrition statistics for graduate engineering students do not adequately inform current attrition research because they focus on degree completion rather than attrition or early departure; aggregate science, technology, engineering, and mathematics (STEM) students; and reflect out-of-date data. While recently some work has begun to explore doctoral attrition qualitatively, the purpose of this study is to describe current trends in graduate engineering students' consideration of departure from their programs of study by capturing current numerical data specific to engineering about students' recent attrition considerations. This is important because, since the last studies were conducted, higher education systems have experienced a global pandemic, economic downturn, and sociopolitical turmoil in the United States. Graduate students (n = 2204) in the U.S. completed a survey. The sample includes master's (n = 535) and doctorate (n = 1646) degree-seeking students from 27 engineering disciplines and includes U.S. domestic and international populations. A majority of students considered leaving their degree program in the month before they took the survey: nearly 70% of Ph.D. and 39% of master's students, while 31% of Ph.D. and 16% of master's students seriously considered leaving their program without their degree. Descriptive statistics provide early departure considerations by engineering discipline, gender identity, race/ethnicity, nationality, and year in program by degree sought. Comparisons between groups are presented for gender, nationality, and career stage. It is essential to have an updated and discipline-specific benchmark of attrition considerations for continued engineering education research purposes, for mentorship, and for administrative purposes. Early departure from graduate school remains a threat to innovation and broadening participation in engineering and the professoriate.

Keywords: graduate student; attrition; PhD; Master's; demographics

1. Motivation and Literature Review

Stemming from concerns for national competitiveness and broadening participation in the professoriate [1], concerns about attrition from graduate engineering programs began decades ago, spurring degree completion and attrition reports from federal agencies or the Council of Graduate Schools (CGS). These reports show that graduate science, technology, engineering, and mathematics (STEM) degree completion rates remain lower than desired by national agencies [2], with some estimates yielding 10-year completion rates for engineering doctoral students of only 57–64% for women and men, respectively [3]. These national census level reports are frequently cited to motivate research conducted in engineering graduate education to investigate identity [4, 5], motivation (e.g., [6]; persistence of students with marginalized and intersectional identities (e.g., [7]), and attrition (e.g., [8, 9]).

The typical reports employed to motivate studies in engineering and STEM graduate attrition are from the Council of Graduate Schools, presenting data from their inaugural study [3, 10] and the follow-up study on minorities [11, 12], reporting on cohorts of students from the decade prior. Therefore, some of that data reflects individuals who were in graduate school over 20 years ago, who engaged in a past generation's research economy, career landscape, and sociological climate. While these data are useful to demonstrate trends over time, much of this data is aggregated with respect to gender and race or discipline, with engineering numbers often indiscernible from other science, technology, and math disciplines (for example, in the degree completion rates for racially marginalized populations). None of these studies presents degree completion data for international students.

The collection of standardized data has some limitations that erode the usefulness of these national data for engineering, given that engineering differs in demographics, student funding, average time-to-completion, and in attrition mechanisms than other disciplines [4, 8, 13]. First, the aggregation of STEM fields obscures the data that will continue to motivate research in engineering graduate education. Second, many reports [e.g., 10, 11] count the number of completed degrees

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rather than counting students that leave their programs without their intended degree, indicating either seven- or ten-year completion rates [10]. These cutoffs are problematic for engineering because the average duration for an engineering doctoral degree is estimated by different reports to be between 5 [11] and 6.7 years after starting graduate school [14], such that ten-year completion rates do not help researchers understand how and when engineering students leave their programs. Further, no reports capture the change of degree from Ph.D. to the master's as an "off-ramp" from the Ph.D., which we characterize as a prevalent mechanism of attrition in engineering [8], and with the exception of a few studies [e.g., 15], there are limited studies on international students in engineering. We argue that along with "endpoint" degree conferral numbers, there is also a great deal of value in understanding how many students are considering attrition as a precursor to the actual act of departure, aligning with the view of many current scholars that attrition is a process that ends with departure.

In the engineering education research community, more attention has been paid recently to understanding the competency development and experiences of graduate students, aligning with a larger national focus on graduate student mental health and well-being [16]. Researchers have investigated the role that writing plays in doctoral persistence and preparation [17–21]; and the development of career intentions, particularly toward the professoriate [22, 23]. Others have illustrated how structural elements of the doctoral process, such as the advisor-matching process, enable or inhibit success for graduate students [25]. Another branch of doctoral-level research has sought to qualitatively investigate adverse experiences contributing to attrition, especially relating to academic identity development [26–29], noting the persistence of toxic and hostile climates to minoritized populations [7, 11]. Qualitative research further explores the experiences of engineering graduate students and the impact on attrition considerations [22, 23, 30]. Rather than replicate existing work that illustrates why students consider attrition, this work seeks to demonstrate the frequency of attrition consideration at a national level.

Two significant issues further compound issues for today's generation of graduate students that have influenced engineering graduate student enrollment and degree completion since the most recent reports [2]. First, U.S. visa policy oscillated between 2016 and 2020, impacting international graduate students who required a U.S. visa and decimating numbers of international students [12]. Then, in parallel, the COVID-19 pandemic caused significant disruption in graduate education for many students, causing issues with milestone and degree completion, an influx of mental health and well-being concerns, and reduced enrollments [31]. For these reasons, in addition to the limitations of aggregated data and lack of information on international students, the engineering education research community needs an updated understanding of graduate attrition and attrition considerations to continue to motivate research in graduate-level engineering education research.

In this work, we present the results of a national cross-sectional survey to benchmark attrition considerations (a precursor for attrition) in current domestic and international master's and Ph.D. engineering students. This work is not intended to substitute federal reports on degree completion but is intended to offer a timely perspective on how current graduate students are thinking about their intentions to persist. While other studies have sought to understand attrition considerations, they are typically institution-specific [32, 33], and are not specific to engineering. The present study is the first to collect attrition consideration data from graduate engineering students across the United States, the first to quantitatively compare US domestic and international students' departure considerations in engineering, and the first to be conducted after the onset of the COVID-19 pandemic. This study will be invaluable in continuing to motivate research and policy attention on graduate engineering students for researchers, advisors, and administrative decision-makers.

As part of a larger project concerning graduate attrition decision-making processes, this research provides a benchmark assessment of current departure considerations in engineering graduate students in response to our research questions:

1. What are the current levels of departure considerations for engineering graduate students?
2. How do attrition considerations differ based upon intended degree, engineering discipline, gender, race/ethnicity, nationality, and years in the graduate program?

1.1 Epistemological Stance, Conceptual Framework, and Researcher Positionality

While a traditional theoretical framework does not appropriately inform this kind of benchmarking research, our conceptual framework and a statement of our epistemological position ground the study in existing attrition literature. Large-scale quantitative attrition research is motivated by positivist census-level data that demonstrates disparities in degree completion. Qualitative researchers then often employ these numbers as motivation for

constructivist qualitative research projects to investigate reasons for disparities in degree completion. In this work, we take a post-positivist stance that employs numerical representation of departure consideration while valuing the sociocultural context that influences and dominates departure considerations at the individual level. We fully appreciate that each participant has their own narrative and story, such that even as we seek to understand overarching patterns, we also acknowledge that the lived experiences of those that are not captured in the majority are just as legitimate as those having normative experiences. In reality, this present work does seek to provide voice to populations that may feel isolated or marginalized in academia by revealing exactly how common attrition considerations are, stigmatization of these conversations.

While much research frames all attrition or early departure as bad, we do not subscribe to that belief. Many reasons (e.g., employment, life events) may lead students to consider early departure or to actually leave their program. In fact, we would argue some departure consideration is appropriate – if students decide they no longer want or need a PhD, then attrition is appropriate. If a student departs to escape an abusive advisor relationship, we would also consider that a success on the part of the student, not a student's failure. In this work, we are focused not on the valence of the reasons for departure consideration, but the frequency of considerations and the implications for graduate programs. Good or bad, departure considerations should not be ignored by researchers or graduate programs rather, understanding the frequency in addition to the causes described in qualitative research provides necessary quantification for decision-makers.

We also consider the positions of the populations we hope to reach with these numbers. Given that most engineering faculty unknowingly seek a positivist numerical justification for how and why we should focus on various populations, we hope that our data can continue to motivate quantitative, qualitative, and mixed methods research focused on graduate engineering students.

We as authors approach departure considerations as a meaningful step in investigating the consistently high early departure trends in engineering graduate education. The first author is a psychologist completing a postdoc in engineering education with experience investigating the impacts of racism and sexism on persistence and identity in engineering graduate students. The principal investigator holds a faculty position in mechanical engineering and conducts engineering education research to investigate attrition. Together, we bring a diverse set of expectations, experiences, and perspectives to attrition investigation. This work seeks to generate knowledge to support students' and institutions' better understanding of departure decision-making.

2. Method

2.1 Recruitment and Data Collection

After IRB approval, we compiled a list of the top 50 engineering doctoral and the top 50 engineering master's degree-conferring universities in the United States per the ASEE 2020 By the Numbers report [34] at which to recruit participants. In October 2021, we emailed survey invitations to departmental graduate program directors or those with similar titles in all engineering programs at each of these universities to forward a survey to their current Master's and Ph.D. graduate students. This recruitment strategy was selected to represent engineering graduate students at the largest engineering degree-granting universities in the U.S: In 2020, the top 50 engineering Ph.D.-granting institutions conferred 64% of total engineering PhDs in the U.S. Graduate students volunteered to participate in the survey by clicking an embedded link. Participants completed the survey via a Qualtrics online survey and did not receive compensation for completing this survey.

2.2 Participants and Survey Instrument

After consent, participants indicated their intended degree by selecting Ph.D., Master of Science (M.S.) requiring research, Master of Engineering (M.Eng.) or coursework-based Master of Science NOT requiring research, online (or primarily online) M.S. or M.Eng. degree. Only participants pursuing engineering degrees in Ph.D. and Master of Science (requiring research) programs were invited to continue the survey. In data cleaning, we removed participants if they completed less than half of the survey. Students (n = 2204) completed the survey with representation from 27 graduate engineering disciplines. The analytical sample included 535 master's degree and 1646 doctoral degree-seeking students. Raw data are presented in Table 1, showing the sub-disciplinary gender and degree categories. The inclusion of race/ethnicity data into this table would have yielded much of our data identifiable.

Participants indicated gender identity by selecting Woman (n = 938), Man (n = 1202), non-binary or third gender (n = 35), another gender identity (n = 6), or prefer not to identify (n = 22). Participants indicated race or ethnicity identity by selecting one or more of the following: Hispanic/Latinx (n = 107), African American or Black (n = 53),

Table 1. Participants by Discipline, Gender, and Degree

	Gender									Total		
	Woman			Man			Non-binary/Third Gender; Another; Prefer Not to Say					
Discipline / Degree	Ph.D.	M.S.	Total	Ph.D.	M.S.	Total	Ph.D.	M.S.	Total	Ph.D.	M.S.	Total
Aerospace	23	10	33	53	24	77	2	1	3	78	35	113
Ag. & Bio.	11	6	17	4	0	4	1	0	1	16	6	22
Bioengineering	23	6	29	15	1	16	1	2	3	39	8	47
Biomedical	120	17	137	86	11	97	8	3	11	214	29	243
Chem. & Bio	24	4	28	28	0	28			0	53	4	57
Chem.	82	7	89	91	12	103	8	0	8	181	19	200
Civil & Env.	61	22	83	69	28	97	2	1	3	132	51	183
Comp. Eng.	2	7	9	15	5	20			0	17	12	29
Comp. Sci.	34	33	67	43	53	96	4	1	5	81	87	168
Comp. Sci & Eng.	13	2	15	17	1	18			0	30	3	33
Elec. & Comp. Sci.	61	22	83	100	46	146	4	1	5	165	69	234
Environ.	18	6	24	12	6	18	0	2	2	30	14	44
Eng. Sci. & Applied Math.	7	0	7	6	0	6			0	13	0	13
Eng. Physics	1	0	1	3	0	3			0	4	0	4
Industrial	14	6	20	18	15	33	2	0	2	34	21	55
Materials	58	8	66	62	12	74	2	1	3	122	21	143
Mechanical	108	33	141	187	70	257	5	2	7	302	105	407
Mech. & Aero.	12	0	12	14	3	17			0	26	3	29
Mining	1	3	4	5	2	7			0	6	5	11
Nuclear	9	0	9	13	2	15	0	1	1	22	3	25
Ocean	2	0	2	4	1	5			0	6	1	7
Other	13	3	16	17	6	23	4	0	4	35	9	44
Petroleum	1	1	2	3	0	3			0	4	1	5
Reliability	0	1	1	2	0	2			0	2	1	3
Robotics	3	6	9	7	6	13	0	2	2	10	14	24
Systems	10	9	19	7	3	10	2	0	2	19	12	31
Transport.	2	1	3	2	1	3			0	4	2	6
Total	713	213	926	883	308	1191	45	17	62	1645	535	2180

Note: Some participants did not provide discipline or gender.

Asian (n = 873), Native Hawaiian or Pacific Islander (n = 1), Native American or Alaskan Native (n = 2), white or Caucasian (n = 916), another identity (n = 45), or prefer not to identify (n = 41). Participants indicated nationality by selecting their citizenship status as U.S. Domestic (n = 1179), U.S. permanent resident (n = 80), international (n = 899), another citizenship status (n = 22), or do not wish to identify (n = 21). Participants also indicated their year in engineering graduate school by selecting first, second, etc., with "tenth or later" as the highest option. Participants provided their engineering discipline and university in text entry boxes.

After demographic questions, the survey included lines of questioning regarding attrition considerations that varied slightly between the Master's and Ph.D. students to best reflect the differences in the two populations. The attrition questions were designed to emphasize departure considerations in a very immediate current timeframe. Master's seeking students responded to an attrition consideration question: "Have you considered leaving graduate school within the last month?" Response options included: Yes, I have seriously considered leaving my M.S. program; I sometimes consider leaving my M.S. program, I rarely consider leaving my M.S. program, I have never considered leaving my M.S. program, or Another statement describes my experiences in considering leaving the M.S. with a text response option. Doctoral degree-seeking students responded to the same question with a different but similar set of response options: Yes, I have often seriously considered leaving my Ph.D. program with no degree, Yes, I have often seriously considered leaving my Ph.D. program by taking a master's degree, I sometimes consider leaving my Ph.D. program, either with or without a Master's degree, I rarely consider leaving my Ph.D. program, I have never considered leaving my Ph.D. program,

or Another statement describes my experiences in considering leaving the Ph.D. with a text response option. The full survey instrument is presented in Appendix 1.

2.3 Analyses

Using SPSS, we generated frequency statistics for each demographic category by the departure consideration responses. Raw numbers and percentages are presented where appropriate. Raw numbers in some categories risk reidentification, resulting in our decision to show only percentages. In other categories, the differences in raw numbers do not meaningfully convey the significance of departure considerations, and we present percentages for more meaningful interpretation.

Some categories call for comparison – for instance, the difference in considering departure by gender identity. However, comparison between groups with unequal representation would produce errant results. To compare groups, some aggregation is necessary for some categories. In other categories, the disparity in representation is too great to make meaningful comparisons. However, where possible, simple comparisons are made using Chi-Square tests.

Data for comparison were dummy-coded into binary groups. Past month attrition considerations were coded to 0 (never) and 1 (often, sometimes or rarely), with other options eliminated from comparison. Because the question asked if the participants considered leaving within the past month, even a note of "rarely" indicates recent attrition considerations. Gender identity was also reduced to binary for the ability to make comparisons, with women coded to 1 and men coded to 0, though we do have participants who identify as other genders. Nationality was coded for U.S. citizen or permanent resident (0) and another nationality (1). The number of years in a graduate program was expected to influence departure considerations. For incomplete yet straightforward comparison, an early year was compared to a later year in the program such that for master's students in their first (0) and second (1) years and doctoral students in their second (0) and fifth (1) years are compared. The reason for the difference in these comparisons for master's and PhD students occur because of the structure of the degree program and because of the timing of the survey in the academic year. For master's students, it makes sense to compare first– and second-year master's students was because most master's programs are approximately two years in length. However, for doctoral students, we compared second-year students with fifth-year students, understanding that first-year doctoral students would have only been in their doctoral programs for one or two months at the time of the survey, whereas second year students are still in their early stages of the PhD, but having completed the first year of their long-term program of study.

2.4 Limitations

As with all studies, there are limitations to this study stemming from population and methods. First, because this study is cross-sectional and not longitudinal, we cannot fully describe the change in an individual's attrition considerations over time. However, we compare early (second year) and later (fifth year for doctoral and second year for master's) students to check for cross-sectional differences based on the year in the engineering graduate program. The way our data was collected (e.g., categorical data) influences the types of analysis that can be utilized, and our population of respondents limit the extent to which we can meaningfully make comparisons. Specifically, racial and ethnic minorities represent the most marginalized groups in engineering, and comparison of departure considerations would benefit attrition research. However, the difference in representation in engineering and our sample make race and ethnicity comparisons inappropriate. The differences in representation of our participants across the years in program categories limit all categories' statistical comparison. Our sample does not represent perfect census-level graduate engineering students perfectly and is limited to traditional (in-person, research-based) degree-granting programs at the institutions that confer the most graduate degrees. While this study is the first to compare domestic and international students, we also understand that international students are not a monolithic group. The timing of this study also influences results: For first-year students, this survey was conducted only a few months into their inaugural year of graduate school. We also cannot distinguish between our sample and the students who did not complete the survey, such that response bias (e.g., students who consider attrition may be more interested in completing a study on graduate student experiences than those who do not) may be reflected in our participants. It is also important to note that the data we present reflects departure consideration, not actual departure: Trends provide an idea of students' intentions but do not directly predict future behavior. However, the attrition considerations provide valuable insight into student decision-making as a precursor to attrition.

3. Results

In this section, we present data in two main sections, separating doctoral students from master's

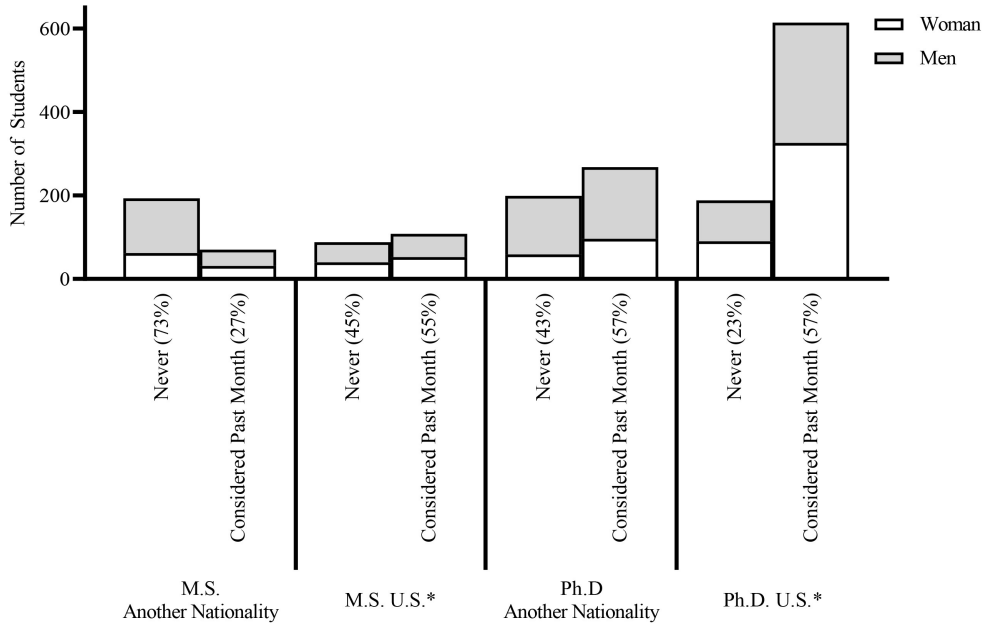

Fig. 1. Panel A. Past month early departure consideration percentage by nationality and gender. *U.S. includes U.S. citizens and perminant residents.

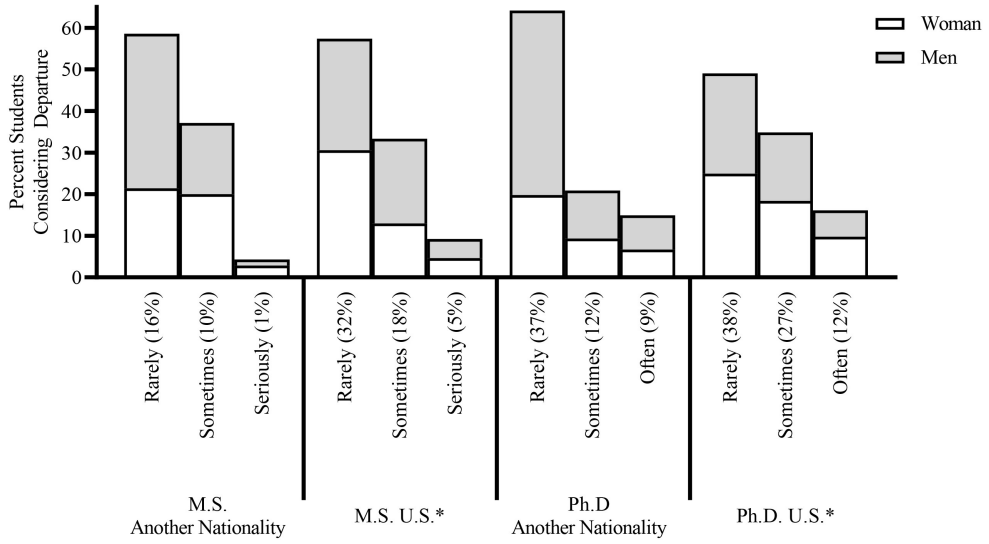

Fig. 1. Panel B. Frequency of past month early departure consideration percentage by nationality and gender. *U.S. includes U.S. citizens and perminant residents.

students. Within these populations, we discuss the trends in U.S. domestic and international students. Our presentation of the descriptive and comparative statistics will be slightly non-traditional: In each section, we present the meaningful statistical comparisons amidst the descriptive population-level data. We have explicitly chosen this arrangement to highlight important trends in attrition considerations. The presentation of results is kept succinct and direct to facilitate the use of this data as baseline readings of attrition consideration. Our intention is that the results serve as a timely highlight of the continued problem of attrition in engineering graduate education.

3.1 Doctoral Degree Seeking Students

The majority of doctoral students considered leaving their program without their doctoral degree in the month prior to completing the survey with responses: Rarely (n = 473, 37%), Sometimes (n = 270, 21%), or Often (n = 139, 11%). The category "rarely" is included as the lowest frequency of departure considerations which is still rather frequent given the short period of time with the item asking students to consider the past month. Less than a third of doctoral participants had not considered leaving in the month prior to completing the survey (n = 387, 30%). Doctoral participants' departure considerations differed based on their

nationality: 77% of U.S. domestic doctoral students considered departure in the last month compared with 57% of international doctoral students (Fig. 1). This difference is significant ($\chi^2(1,878) = 17.42$, $p < 0.001$). In our data set, a slightly larger proportion of women than men considered leaving their program without their intended degree ($\chi^2(1,892) = 5.63$, $p = 0.018$).

A majority of women and men in all race/ethnicity groups considered early departure from their Ph.D. program within the month prior to the survey (Fig. 2). In each race/ethnicity group, women and men considered early departure at approximatly the same rates. However, the *frequency* of departure considerations differed for women and men at the intersection of race/ethncity and gender identity.

In the month prior to completing the survey, more than half of Ph.D. students had considered early departure in nearly all race/ethnicity groups in each year of study (Fig. 3). The proportion of students who considered early departure in the month prior to completing the survey increased each year upto those participants who were in their sixth year. Participants in their first year of a Ph.D. program considered early departure less than students further along in their graduate degree. Most students in their sixth and seventh year or

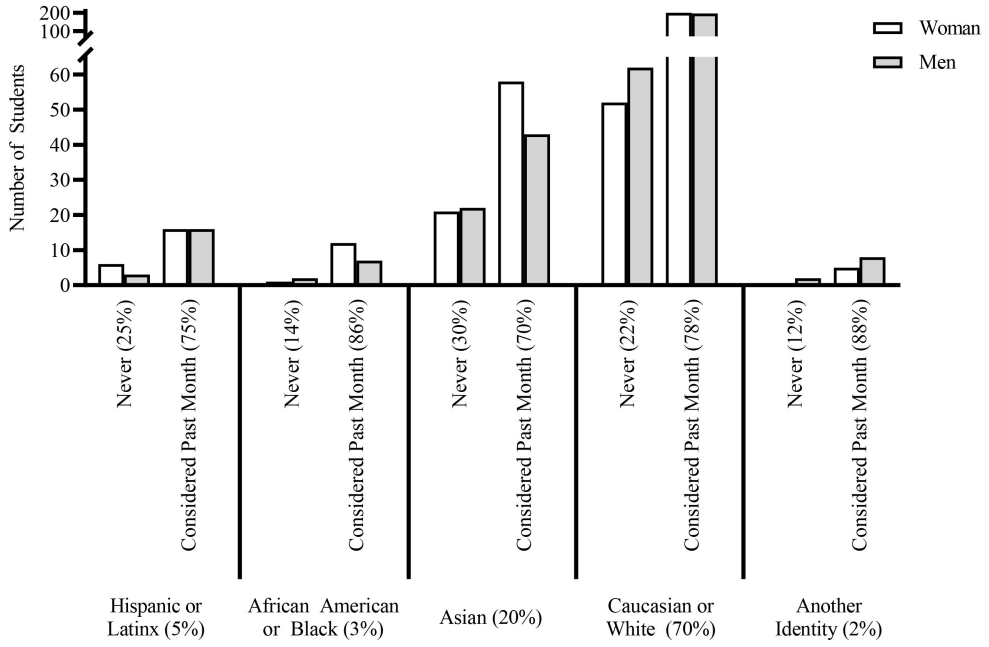

Fig. 2. Panel A. Past month consideration of early departure from a Ph.D. by race/ethnicity and gender.

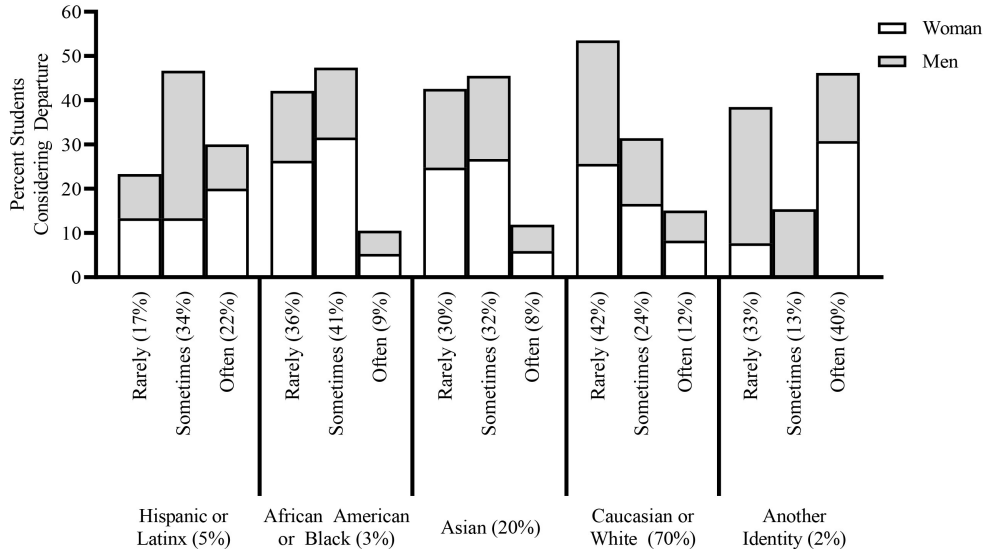

Fig. 2. Panel B. Frequency of past month consideration by race/ethnicity and gender.

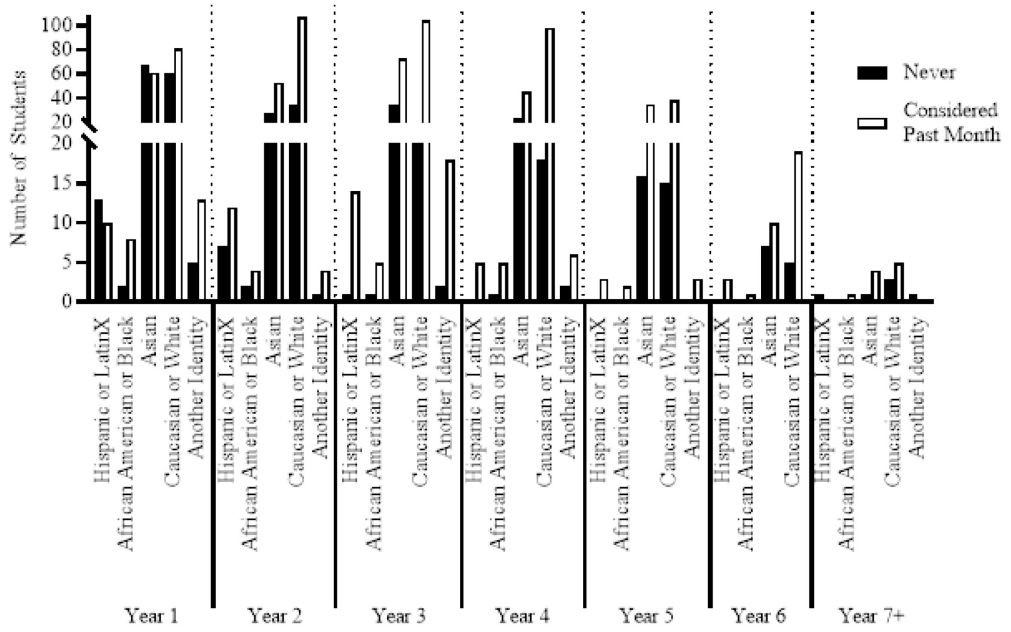

Fig. 3. Panel A. Past month early departure consideration by year in Ph.D. program and race/ethnicity.

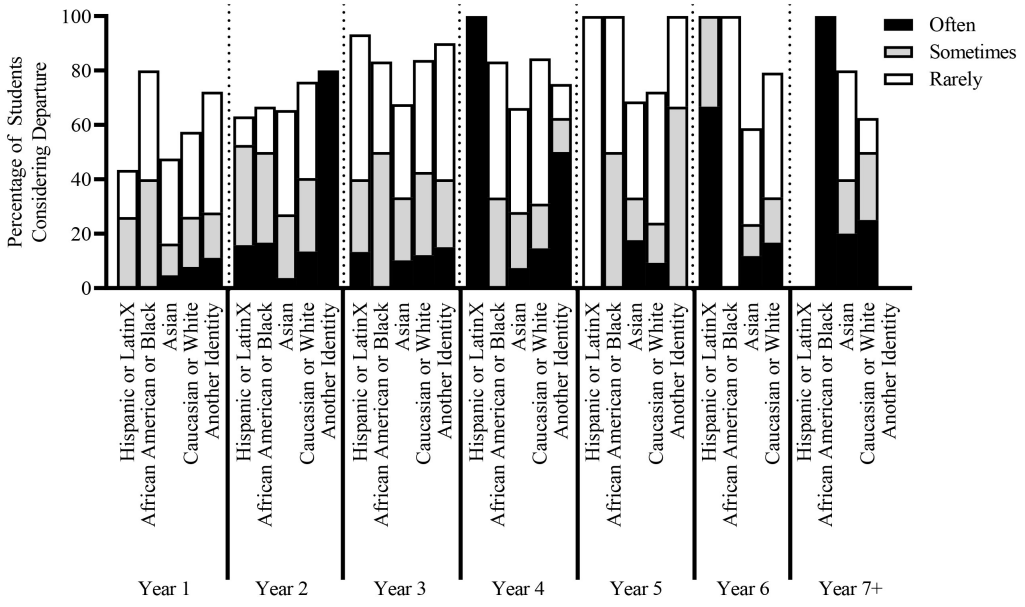

Fig. 3. Panel B. Frequency of past month considerations by year in Ph.D. program and race/ethnicity.

more in the Ph.D. program had considered early departure. In statistical comparison, the difference between second-year students' and fifth year students' attrition considerations were not significantly different for doctoral students ($\chi^2(1,601) = 1.99$, $p = 0.157$), though past qualitative literature may provide insight that these considerations may perhaps be for different reasons. However, particularly notable is the higher rate of departure consideration amoung African-American or Black and another race/ethnicity identity participants in the first year. Asian students considered departure at lower rates than other groups in every year.

3.2 Master's Degree Seeking Students

Overall, the majority of master's degree-seeking students did not consider leaving their program without their degree in the month prior to completing the survey (n = 281, 61%). With 39% of master's students rarely (n = 103, 22%), sometimes (n = 62, 14%) or often (n = 13, 3%) considering leaving without a degree in the month prior to completing the survey. The intersection of nationality and gender demonstrate a difference for master's students (Fig. 1). The proportion of women and men who considered leaving was not significantly different for domestic master's degree-seeking students

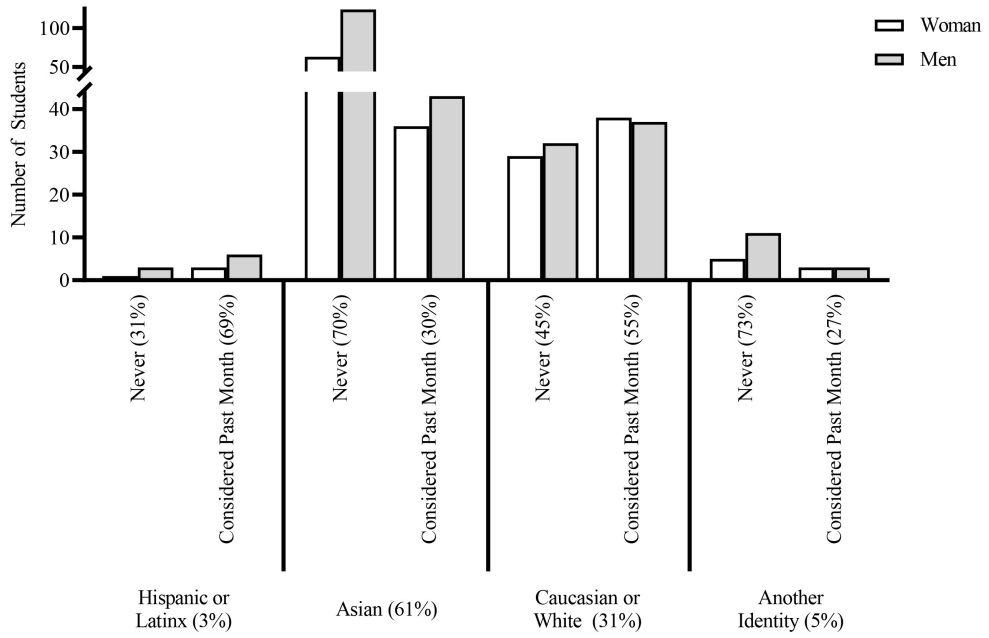

Fig. 4. Panel A. Past month consideration of early departure from a M.S. program by race/ethnicity and gender for domestic and international students.

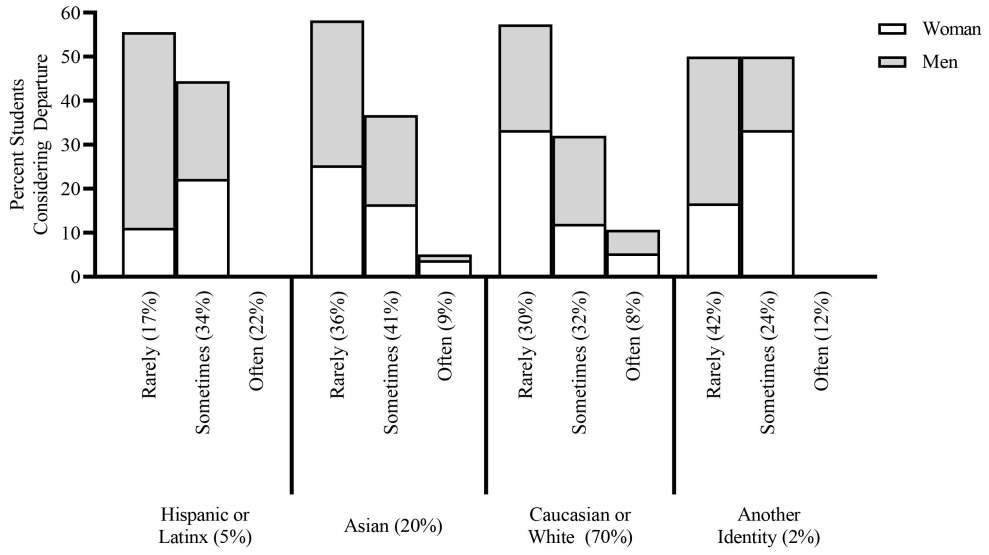

Fig. 4. Panel B. Frequency of past month consideration frequency by race/ethnicity and gender; Percentages are of race/ethnicity group.

($\chi^2(1,453) = 1.76$, $p = 0.185$). A larger proportion of U.S. domestic master's students considered leaving than students from other countries ($\chi^2(1,448) = 13.54$, $p < 0.001$). International women master's students considered early departure more frequently than international men master's students, however the difference was not significant.

Departure considerations differed by race/ethnicity and gender for international and domestic master's degree-seeking students (Fig. 4 Panel A). Most Asian students and those who identified another race/ethnicity identity did not consider early departure in the month prior to completing the survey. However, more than half of white and Hispanic or Latinx men and women considered early departure in the month prior to completing the survey. Of those that considered early departure in the month prior to completing the survey, most selected the *sometimes considered* option, followed by the *rarely considered* option (Fig. 4, Panel B).

A significantly larger proportion of second-year master's students considered leaving than first-year students ($\chi^2(1,439) = 7.92$, $p = 0.005$). Most first year master's students had not considered departure in the month prior to completing the survey regardless of race/ethnicity (Fig. 5). However, in the

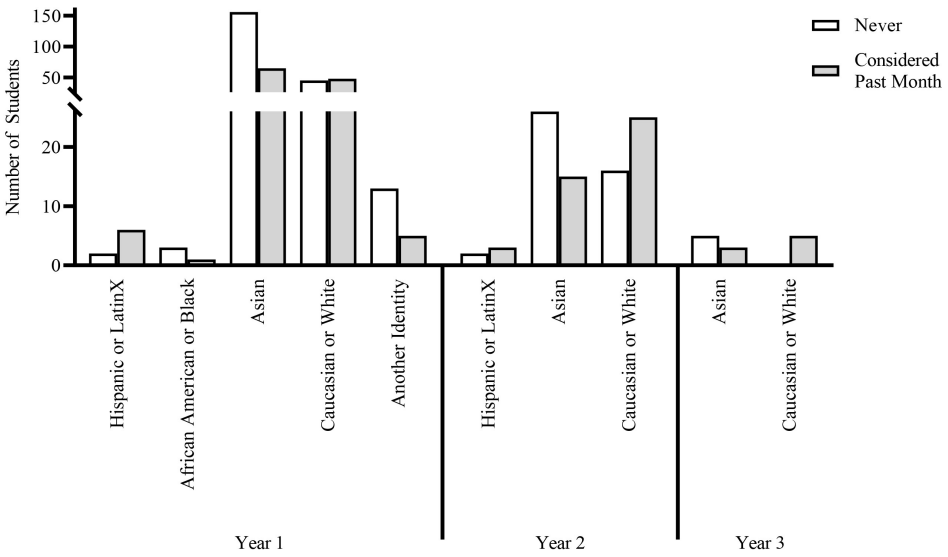

Fig. 5. Panel A. Past month early departure considerations by year in M.S. program and race/ethnicity.

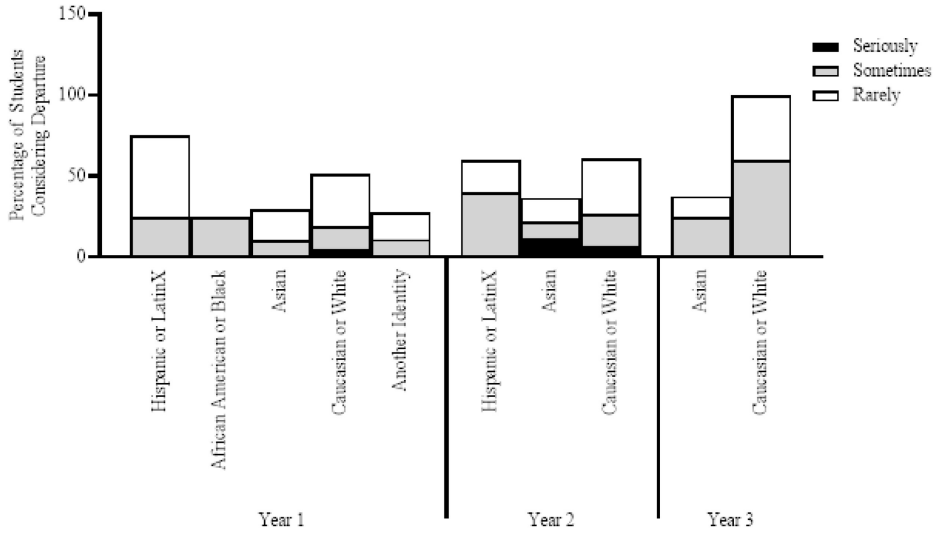

Fig. 5. Panel B. Frequency of past month early departure considerations by year in M.S. program and race/ethnicity.

second and third year more students considered early depature in all race/ethnicity groups. The lack of African-American or Black participants in the second or third year and beyond limits conclusions about early departure considerations, however the absence itself may indicate conserns about increased departure. Similarly, with no Hispanic or Latinx participants in the third year and beyond we cannot draw conclusions.

4. Discussion

Our findings show that attrition considerations are concerningly high in graduate engineering students. The data presented here substantiate previous reports that indicate women consider departure more than men and that U.S. domestic students consider departure more than international students [4, 9, 35]. However, women and men consider departure at relatively high rates, even with significant differences. Given women tend to leave engineering at higher rates, indicating a possible difference in the meaning of departure consideration. Recalling prior qualitative research on gender and "chilly climate" in graduate school [30, 32, 35], women's considerations may be more likely to lead to actual departure more often than men, though this study does not follow participants longitudinally to make such a determination.

Identity intersections demonstrate the nuance of departure considerations and the variation by gender, race/ethnicity, and nationality. For instance, the difference in doctoral departure considerations disaggregated by gender and nationality highlight the need to understand the departure considerations both international students and of

international women students, supporting existing qualitative reports [15, 36]. Similarly, gender and race/ethnicity intersections illustrate differences in departure consideration. For example, increases in doctoral degree completion for Hispanic/Latina women, but not Hispanic/Latino men [12] reflect the frequency of departure consideration is lower for Hispanic/Latina women (73% considered) compared to Hispanic/Latino men (84% considered (Fig. 2, Panel A). However, Hispanic/Latina women considered departure more often in the past month (Fig. 2, Panel B).

In master's seeking students, the years in program show the first-year students less likely to seriously consider departure, while second year students are more likely to consider early departure. This is logical, especially concerning the timing of the survey deployed in October 2021 asking about attrition considerations in September 2021: Incoming graduate students would only have been in their programs a short time, and it is likely that they would not have become discontented in that sort time than second-year students. Though we did not find statistically significant differences in the attrition considerations between second-year and fifth-year PhD students (representing early-career and late-career students, respectively), we propose based on the deep qualitative research presented in the literature review that the reasons for consideration in these two populations is likely qualitatively different: Early career students may still be working to understand their lab, department, and expectations [37], whereas late-career graduate students may be operating under the sunk-cost fallacy [24] considering the amount of time and energy they have already invested in their programs. Ultimately, this finding motivates future qualitative work to understand attrition mechanisms and experiences at different stages of the doctorate.

While some of the trends we show are confirmed by past work, this work presents updated data specific to engineering for today's graduate students given the multiple societal factors that have been tumultuous to graduate education. This new understanding of attrition consideration also shows exactly how prevalent attrition considerations are, despite attrition still being extremely stigmatized in engineering and academia. This work shows that engineering students at all stages of their degree program consider attrition, though most literature still treats attrition in engineering as something rare. Even if these attrition considerations do not result in departure from the degree, the consideration likely causes psychological distress [38–42] and "emotional exhaustion" [32]. Prior work also demonstrates that students considering leaving their programs often worried about what others will think of them [8]. These adverse effects of attrition may be especially harmful if students do not have trustworthy confidantes or strong social support networks (things that are especially difficult for brand new graduate students incoming to a new institution).

Students' responses were likely shaped by the impact COVID-19 had on them individually, their families, communities, and university responses to the pandemic. The impact of COVID-19 on students will be influential on graduate education for the next decade as students who experienced the pandemic move through the education system into graduate education. We must be prepared to understand the implications of the pandemic on attrition considerations – even when those students who experienced pandemic during graduate school leave their programs. The data provided here provides a baseline set of information as we move forward beyond immediate pandemic influences on attrition considerations.

4.1 Future Research and Implications for Faculty and Administrators

The high frequencies of past-month attrition considerations captured in this study indicate needed changes in engineering graduate education. Our findings support the necessity of additional qualitative and longitudinal research, mainly focused on the early departure decision-making process. Qualitative or mixed-methods approaches could bring depth and nuance to the frequency of departure considerations beyond the baseline data reported here. In this research, we asked participants about past month considerations. However, given the number and continuously changing nature of the psychosocial, emotional, and relationship conflicts driving departure consideration [8], we must acknowledge that students in our research may respond differently at another time point. Therefore, the snapshot of attrition considerations presented from this data motivates future studies employing longitudinal methods to track attrition considerations over time, especially considering the myriad factors (e.g., advisor relationship, funding climate, mastery experiences and milestones) that comprise student success. While our data provide an updated indication of the frequency of early departure considerations, more comprehensive data can only be achieved by continuously tracking students' trajectories, attrition considerations, and departure in engineering would provide a clearer idea of how concerning early departure consideration is for disciplines and institutions, but this research design would be resource intensive and very difficult to achieve. Further, early departure rates based on marginalized group identities remain necessary to identify attrition discrepancies by gender, race or

ethnicity, and nationality. Particularly, international research to compare attrition consideration and degree completion between leading engineering higher education countries could provide meaningful context to a potentially global problem.

Similarly, additional research should connect considering departure to realized departure decisions. While considerations naturally precede early departure, the exact relationship remains unknown. For instance, some considerations may be expected but may not lead to early departure. Further, we also want to engage with attrition as a not-necessarily-bad thing: Some students may realize they do not want or need a graduate degree and decide to leave, which is not necessarily a bad thing. Tracking attrition decision-making over time would provide much-needed answers to model and understand attrition decision-making to better answer these questions and could answer questions about attrition mechanisms that may differ by gender, race or ethnicity, and nationality, spurring more focused qualitative research avenues.

We hope that the data presented in this paper can justify and motivate practical changes for engineering faculty and administrators. While as faculty, it is easier to assume that our graduate students are happy and not considering attrition, these numbers show that our students do consider leaving at a high rate. While our research partly confirms anecdotal narratives that U.S. domestic students consider leaving at higher rates than international students, our international students still consider departure. Some faculty may be apprehensive about bringing up conversations about departure with their students in case it "plants an idea" – but this research dispels that myth. Our students are already thinking about it. We envision this paper as a jumping-off point, perhaps, for advisors to engage with their supervised graduate students about career trajectories, academic pathways, and yes, considerations of departure.

Administrators and decision-makers can also use this paper to better motivate the allocation of resources to graduate student populations, who often find themselves in a grey area between being treated as students and treated as employees. Armed with statistics and numbers from our nation-wide cross-sectional study, engineering deans, department heads, and graduate chairs can advocate for institutional resources for student support. While the degree conferral numbers do show that attrition in the humanities and social sciences is higher than in science or engineering fields, our work shows that our engineering students often considering leaving. However, lower attrition than other fields does not mean attrition is not a problem to be addressed. Lastly, decision-makers can interpret from this work that graduate students are not escaping unscathed from their doctoral programs: Even students that will complete, if they are considering attrition, have encountered difficulties that are substantial enough to make them consider changing their academic identity and professional trajectory. As such, our study can better inform and motivate administrators on the thought processes of today's engineering graduate students, across genders, races, and nationalities.

5. Conclusions

Given that national reports on doctoral completion rates are becoming outdated, often aggregate engineering with other science, technology, and math disciplines, and cannot capture attrition considerations, this work presents results from a nationwide cross-sectional survey of engineering doctoral and master's students from the top 50 Ph.D. – and top 50 Master's-degree conferring universities in the U.S. The results from our study show that a majority of Ph.D. students considered attrition from their programs in the month prior to completing the survey, and descriptive and comparative statistics show that these trends vary with nationality, gender, and race. From this study, we dispel potential myths that attrition is not a problem for engineering programs: Indeed, even if not all considerations of departure end in attrition, the process of considering attrition impacts quality of life and work. These current results – in the first national study that focuses on engineering graduate student attrition, especially in the recent times as graduate students are impacted by both the pandemic and national immigration and visa policies, are invaluable to the research and practice communities. We intend to use these results to motivate longitudinal studies on graduate engineering student attrition decision-making processes and encourage administrators and faculty to use these numbers to advocate for resources for graduate engineering students.

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Appendix 1. Survey Instrument

Q1. In what type of engineering program are you currently enrolled?

PhD (1),
Master's of Science (M.S.) requiring research (2),
Master's of Engineering (M.Eng) or coursework-based Master's of Science NOT requiring research (3),
ONLINE (or primarily online) M.S. or M.Eng degree (6),
I am not an engineering graduate student (4).

Skip To: Q4 If In what type of engineering program are you currently enrolled? = Master's of Engineering (M.Eng) or coursework-based Master's of Science NOT requiring research.

Skip To: Q4 If In what type of engineering program are you currently enrolled? = I am not an engineering graduate student.

Skip To: Q4 If In what type of engineering program are you currently enrolled? = ONLINE (or primarily online) M.S. or M.Eng degree.

Q21
We are collecting longitudinal data following trends in graduate engineering student experiences using text-message survey methods, following participants for at least a year. Would you be interested in participating in our study?

If you agree, and we select you for this study based on your screening criteria, you will receive very short surveys on Mondays, Wednesdays, and Fridays. Monday and Wednesday surveys will take approximately 30 seconds. Weekly, monthly, and semesterly surveys on Fridays will take 1 to 3 minutes. (We understand not every university is on the semester system, but these are the time points at which we will collect data.)

Consecutive participation will be rewarded with a **$10 Amazon.com gift card each month of participation** (missing fewer than 2 Monday/Wednesday surveys or 1 Friday survey each month). In addition, participants who complete each of the monthly surveys and semesterly surveys each term (Fall, Spring, Summer) will be entered in a drawing for one of three **$50 Amazon.com gift cards at the end of each term.**

Although you have the option to be removed from our study at any time, ideally participants would remain in the study for a year, at which point we will reach out to see if you would be interested in continuing your participation. Longitudinal data is extremely valuable to our research, so participants continuing in a second year will be entered into an additional drawing for another $50 Amazon.com gift card.

You can download the informed consent text here for more information about this study.
Yes, I would like to participate in this longitudinal text message-based study (1).
No, I am not interested in participating in this study (2).

Skip To: Q34 If We are collecting longitudinal data following trends in graduate engineering student experiences... = No, I am not interested in participating in this study.

Display This Question:
If In what type of engineering program are you currently enrolled? = PhD.
Or In what type of engineering program are you currently enrolled? = master's of Science (M.S.) requiring research.

Q12. In what engineering discipline/department/major are you enrolled for your graduate program? [Text Response].

Display This Question:
If In what type of engineering program are you currently enrolled? ! = I am not an engineering graduate student.

Q13. At what university are you enrolled for your graduate program? [Text Response].

Display This Question:
If In what type of engineering program are you currently enrolled? = PhD.
Or In what type of engineering program are you currently enrolled? = master's of Science (M.S.) requiring research.

Q16. How many years have you been in graduate school for engineering?
I am a first-year engineering graduate student (1).
I am a second-year engineering graduate student (2).
I am a third-year engineering graduate student (3).

I am a fourth-year engineering graduate student (4).
I am a fifth-year engineering graduate student (5).
I am a sixth-year engineering graduate student (6).
I am a seventh-year engineering graduate student (7).
I am a eighth-year engineering graduate student (8).
I am a ninth-year engineering graduate student (9).
I am in my tenth (or later) year of graduate program (10).

Display This Question:
If In what type of engineering program are you currently enrolled? = master's of Science (M.S.) requiring research.

Q9. Did you ever consider earning a PhD?
Yes (1) No (2).

Display This Question:
If Did you ever consider earning a PhD? = Yes.

Q10. What statement best describes your ideas on enrolling in an engineering PhD program?
Yes, I was once enrolled in a PhD program, but now am a Master's student (1).
I considered doing a PhD, but decided a Master's was better for me (2).
I will complete my M.S., and plan to continue into a PhD in my same program of study (3).
I will complete my M.S. and plan to continue to a PhD in my same program, but under a different advisor (5).
I will complete my M.S., and plan to pursue a PhD at a different university or in a different program of study (4).
I have not yet decided whether to pursue a PhD after my M.S. (6).

Display This Question:
If How many years have you been in graduate school for engineering? = I am a first-year engineering graduate student.

Q37. At this point, have you found a research advisor to oversee your graduate work?
No (1) Yes (2).
In progress. Elaborate on issues arising if applicable: (3) [Text Response].

Q38. At this point, do you have financial support within the university/department? (e.g., research assistant, teaching assistant, grants, scholarships, etc.)
No (1).
Yes, Research Assistantship with my research advisor (2).
Yes, Research Assistantship with someone who is not my research advisor (3).
Yes, Teaching Assistantship (4).
Yes, I am funded through a grant, fellowship, or scholarship opportunity (5).
Yes another, Please describe: (6) [Text Response].

Display This Question:
If At this point, do you have financial support within the university/department? (e.g., research as... ! = No)

Q39. How aligned is your funding with your professional goals?
Extremely well-aligned (1).
Well-aligned (2).
Somewhat aligned (3).
Poorly aligned (4).
Very poorly aligned (5).

Display This Question:
If In what type of engineering program are you currently enrolled? = master's of Science (M.S.) requiring research.

Q40. Have you considered leaving graduate school within the last month? (Select all that apply, and remember this information will not be shared)
Yes, I have seriously considered leaving my M.S. program (1).
I sometimes consider leaving my M.S. program (2).
I rarely consider leaving my M.S. program (3).
I have never considered leaving my M.S. program (4).
Another statement describes my experiences in considering leaving the M.S. (please fill in) (5) [Text Response].

Display This Question:
If In what type of engineering program are you currently enrolled? = PhD.

Q17. Have you considered leaving graduate school within the last month? (Select all that apply, and remember this information will not be shared).
Yes, I have often seriously considered leaving my PhD program with no degree (1).
Yes, I have often seriously considered leaving my PhD program by taking a Master's degree (2).
I sometimes consider leaving my PhD program, either with or without a Master's degree (3).

I rarely consider leaving my PhD program (4).
I have never considered leaving my PhD program (6).
Another statement describes my experiences in considering leaving the PhD (please fill in) (7) [Text Response].

Q28. With which gender do you identify?
Woman (1).
Man (2).
Non-binary / third gender (3).
Another gender (4) [Text Response].
Prefer not to say (5)

Q29. What citizenship status describes you? (Note: This information is not shared with anyone)
US Domestic (1).
US Permanent Resident (2).
International (3).
Another (4) [Text Response].
Do not wish to identify (5).

Display This Question:
If What citizenship status describes you? (Note: This information is not shared with anyone) = International.

Q30. What is your native country? [Text Response].

Q31. With which racial/ethnic groups do you identify? (Select all that apply).
African-American or Black (2).
Asian (3).
Hispanic or Latinx (1).
Native Hawaiian or Pacific Islander (4).
Native American or Alaskan Native (5).
White or Caucasian (6).
Another (7) [Text Response].
Prefer not to answer (8).

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