Engineering graduate students' perceptions of challenges and stressors: A comparison of master's vs. doctoral students and domestic vs. international students

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Abstract

The purpose of this study is to better understand engineering graduate students' perceived stressors and challenges while considering degree and citizenship status. In spite of the growing attention on the need to create inclusive learning environments by supporting equitable participation of students, academic and research cultures in engineering graduate education are still characterized as unwelcoming. The existence of the large master's (degree status) and international (citizenship status) student populations is also often overlooked. In this study, we identified perceived academic and psychological stressors for four different engineering graduate student groups with varied degree (e.g., master's and doctoral) and citizenship status (e.g., domestic and international) and compared similarities or differences in the student's identified stressors between the groups. We also explored the perceived challenges regarding the identified stressors for different student groups, focusing on unique challenges being associated with degree or citizenship. We did so by conducting an explanatory mixed-methods study using a dataset collected from 2019 to 2021 from students (n=376) enrolled in a mandatory graduate seminar course focused on promoting equity in STEM. The findings illuminate unique stressors for specific student groups and generate a nuanced understanding of why and how different groups of students feel pressure from the identified stressors, which are often related to individual or institutional attributes associated with degree or citizenship.

Introduction

In higher education, a growing body of research focused on diversity and equity has explored the educational benefits of an inclusive learning environment [1]. As it relates to graduate education in engineering, attention has similarly been paid to creating inclusive learning environments and supporting the full participation of students. In a report titled "Graduate STEM Education for the 21st Century", the National Academy of Sciences, Engineering, and Medicine (NASEM) mentioned that, in an ideal STEM (science, technology, engineering, and mathematics) graduate education system, "Students from all backgrounds would fully participate and achieve their greatest potential during their educational experience through transparent institutional action to enhance diversity and promote inclusive and equitable learning environments" [2, p.3]. Despite this growing attention and acknowledgment of the need to improve graduate education in engineering, cultures and practices in these spaces are seldom characterized as welcoming.

In response to the above calls, this study explores the engineering graduate student's experience, focusing on their perceived stressors or challenges, while considering the student's degree and citizenship status. This study is situated in a three-year effort to develop and implement a mandatory graduate seminar course focused on promoting equity in STEM at an R1, research-intensive university in the Mid-Atlantic U.S.

The following sections will discuss prior literature in this area (see *Background*) provide research methods (see *Methods*), including more information on the context of this study, and detailed findings and discussions (see *Findings and Discussion*), followed by their implications (see *Conclusion and Implications*). The insight from this study may help educators develop an

inclusive learning environment by better understanding varied stressors or challenges perceived by diverse student groups in the context of engineering graduate education.

Background

Research on graduate students' sense of belonging, which is known as an indicator of a student's perceived inclusiveness within an academic unit, provides empirical evidence of the unwelcoming culture of engineering graduate education. According to Gardner et al. [3], engineering graduate students reported a relatively lower sense of belonging within their academic department compared to students in other disciplines. O'Meara et al.'s [4] research on STEM students' sense of belonging echoed this claim, highlighting that there are fewer facilitators (e.g., a critical mass of women, micro affirmations) for creating an inclusive environment in STEM graduate programs compared to those in non-STEM disciplines. These authors collectively emphasized the need for investigating engineering graduate student experience and integration, including perceived challenges, barriers, or stressors, while considering the discipline-specific features in the engineering graduate education environment (e.g., unique demographic features, culture in engineering graduate education).

In many engineering graduate programs in the U.S., a defining feature is the large proportion of international students. The number of international students enrolled in full-time graduate engineering programs at U.S. universities has increased from 24% to 58% between 1980 and 2017 [5]. The percentage of international students varies by discipline, and in some disciplines, such as computer science engineering and electrical engineering, international students represent 88% and 93% of all students, respectively (National Foundation of American Policy [NFAP], 2017). Policymakers have begun to acknowledge this large international student population—for example, the aforementioned NASEM's report includes citizenship in diversity indices along with traditional measures, particularly in STEM graduate education [2]. Despite these inclusion efforts and acknowledgment at the government level, the current research on engineering graduate students' experiences lack sufficient consideration of international students [6].

In addition to international students, there is another group of students who has been overlooked both in engineering and higher education—master's students. Despite the long history of master's programs, which began early in the U.S. higher education history, there has been a lack of research or national dataset focusing on master's-level students separately from doctoral students, and little has been known about the master's student's experience [7]. Considering that master's programs might be of comparatively higher interest for non-traditional students, i.e., adults who are pursuing their higher degree part-time while working full-time, or others returning to school full-/part-time while remaining other obligations in their life (e.g., employment, family, etc.), the current lack of understanding of the master's student's experience may lead to a failure for engineering graduate schools in providing appropriate support to this population.

In addition to the characteristics of student demographics, it is suggested to consider the unique cultures in the engineering graduate education environments to investigate students' experiences and integration. For example, the advising relationship in engineering was characterized as a supervisor-supervisee relationship where the dominant interaction is focused on academic support [8]. Psychological and social supports, which play essential roles in building a positive and meaningful relationship between advisors and students, has a major impact on student integration and inclusion; such relationships are often lacking in engineering

graduate education [9]-[11]. Researchers also argue the need to emphasize the healthy development of belonging and a psychological sense of community considering prevalent ideologies or mindsets in engineering, such as individualism and meritocracy [3]-[4], [12].

Methods

In light of the insights from prior literature, this study seeks to: 1) understand similarities or differences in the student's identified stressors between engineering graduate student groups with different degrees (e.g., master's and doctoral) and citizenship statuses, (e.g., domestic and international); and 2) explore the perceived challenges regarding the identified stressors for different student groups, focusing on unique challenges being associated with degree or citizenship. To achieve this purpose, we used an explanatory sequential mixed-methods approach with two phases to analyze a dataset consisting of closed-/open-ended survey responses.

The first, quantitative phase involved a multivariate analysis of variance (MANOVA) and a series of one-way univariate analyses of variance (ANOVA) to examine whether there are differences in the identified academic and psychological stressors depending on the student's degree or citizenship status. This phase focused on analyzing closed-ended survey responses. The second, qualitative phase then analyzed the open-ended survey responses to help explain the quantitative findings with voices from individual students (See *Qualitative Data Analysis*). Details on each phase will be provided after introducing the context (See *Context*) and data collection procedure (See *Data Collection*) and participants' demographic information (See *Participants*).

Data Collection

Data were collected from 2019 to 2021 from students enrolled in a mandatory graduate seminar course focused on promoting equity in STEM at an R1, research-intensive university in the Mid-Atlantic U.S. This one-credit course was designed to help first-year doctoral and master's students: (1) integrate into the university environment, (2) navigate the interpersonal relationships associated with graduate school, (3) prepare for professional success as a student and scholar, (4) build awareness of diversity and inclusion values, and (5) understand their role in the research mentor/mentee partnership [13]. At the end of the 5-week course, students completed a survey that consisted of both closed- and open-ended questions on the students' perceived stressors and challenges in various aspects of their graduate education experiences (e.g., advising relationships, faculty/peer interactions, etc.), the usefulness of the course content, and a demographic survey. From the complete dataset, the data collected from 2020 to 2021 was utilized for this paper considering that a pilot data collection was conducted prior to 2020 with pilot survey questions.

This study focuses on the data that is relevant to students' perceptions or experiences of stressors and challenges. This includes responses to 21 closed-end questions on diverse stressors, one closed-end question on students' satisfaction, and two open-ended questions on the students' perceived challenges in graduate experiences. The closed-ended questions on stressors asked participants to reflect on their graduate education experience and indicate the extent to which each of the 21 stressors disrupted their ability to perform academically and/or professionally.

Another question asked participants to rate their experience as a graduate student at their institution. Response options for the 21 stressors and one satisfaction questions were arrayed on a five-point Likert scale from 0 (none) to 4 (severely), and a five-point Likert scale from 1 (Very unsatisfied) to 5 (Very satisfied), respectively. The two open-ended questions include, 1) What

are some of the most pressing challenges you've encountered when interacting with your advisor and other faculty? 2) What are some of the most pressing challenges you encounter when interacting with your peers?

Participants

As a reminder, we were interested in comparing similarities and differences in students' perceptions of stressors and challenges depending on their degree and citizenship status. Consequently, we grouped all participants (n=376) into four groups, by degree (e.g., master's and doctoral) and citizenship status (e.g., domestic and international). The resultant four groups include the following:

Group 1: Domestic master's students (n=152)
Group 2: Domestic doctoral students (n=72)
Group 3: International master's students (n=78)
Group 4: International doctoral students (n=74)

To contextualize the student population in each group, Table 1 provides student demographic information (e.g., race/ethnicity, gender, LGBTQ, first-semester status, and financial support) for each group. In terms of race and ethnicity, the majority of domestic participants (Groups 1 and 2) are predominantly White and European whereas most international participants are South Asian or East Asian. Except for domestic doctoral students (Group 2), more than half of each group's participants are male, and more domestic students, regardless of degree, reported that they belong to the LGBTQ community compared to international students. Varied sources of financial support were indicated, and most international doctoral students (Group 4) are shown to rely on research and/or teaching assistantships.

Table 1. Comparisons of demographics by the participants' groups

Demographics		**Group 1**	**Group 2**	**Group 3**	**Group 4**
Race/ Ethnicity	Black or African American	10	8	0	4
	[1]East Asian	18	4	10	22
	Hispanic or Latino	4	6	6	2
	Middle Eastern or North African	4	0	2	12
	[2]South Asian	10	4	58	23
	White or European	104	48	2	6
	I prefer not to answer	2	2	0	4
	Missing data	-	-	-	1
Gender	Male	90	40	60	55
	Female	56	28	18	23
	Non-binary	2	4	0	0
	A gender not listed	4	0	0	0
	I prefer not to answer	0	0	0	0
LGBTQ	Yes	12	16	2	0
	No	134	54	74	76
	I prefer not to answer	6	2	2	2

First semester	Yes	130	60	70	58
	No	22	12	8	20
Financial / Support	Research and/or Teaching assistantship	32	32	30	54
	[3]Fellowship/scholarship/grant	6	20	0	2
	[4]Self funded/[5]Student loans/[6]Others	28	0	38	4
	Employer reimbursement/assistance	6	2	0	2
	Assistantship(s) and [3]Fellowship	32	6	4	10
	Assistantship(s) and [456]Non-fellowship	46	12	6	2
	I prefer not to answer/Others	2	0	0	0

Note: [1]East Asian includes Chinese, Korean, Japanese, etc.; [2]South Asian includes Indian, Pakistani, Bangladeshi, Sri Lankan, etc.; [3]Fellowship/scholarship/grant indicates gifted monetary award that students do not need to repay; [4]Self funded indicates personal finances and/or savings; [5]Student loans indicate money borrowed from a financial institution that must be repaid; [6]Others include money borrowed from family/friend with an expectation to repay or from parents, and foreign (non-U.S.) support.

Data Analysis

The first goal of this study—*To understand similarities or differences in the student's identified stressors between engineering graduate student groups with different degrees (e.g., master's and doctoral), and citizenship statuses, (e.g., domestic and international)*—was addressed in the quantitative phase, using a combination of one-way multivariate analysis of variance (MANOVA) and one-way univariate analysis of variance (ANOVA) as necessary. A MANOVA was used to test whether or not there are mean differences in scores across the four groups for a total of 21 stressor variables, including seven academic stressor variables and 14 psychological stressor variables. All assumptions for MANOVA were met for the comparison between participants in the four groups. Based on the MANOVA results, one-way ANOVAs were followed for the stressor variables that showed statistically significant differences between the groups. The statistics reported for each of the analyses were the F-statistic, p-value, and eta-squared ($\eta 2$). Eta-squared is an effect size measure for the variance associated with each variable and the values can range from 0 to 1. The following cut points were used for interpretation: 0.01 (small), 0.06 (medium), and 0.14 (large) [14].

The second goal of this study—*To explore the perceived challenges regarding the identified stressors for different student groups, focusing on unique challenges being associated with degree or citizenship*—was achieved by the qualitative phase. We employed a multiple-cycle inductive deductive approach to qualitative coding [15] to gain a deeper and more nuanced understanding of the student comments. The responses from the survey were analyzed and coded in Excel. In an initial inductive coding phase, the responses were reviewed and coded based on their content and categorized into themes. Next, in a deductive coding phase, themes based on the inductive coding and the quantitative results were used as a guide to code the remaining data and identify quotes that were explanatory to the quantitative data.

Limitations

Before reviewing the results, the reader should consider the following limitations. First, the data used for this study was collected from a single institution. This can be regarded as the major limitation considering the different demographics of the engineering graduate student population at different institutions (e.g., percentage of part-/full-time students in master's programs, percentage of domestic and international graduate students, demographics of domestic

and international students, funding options for graduate students, etc.) and different institutional culture, which collectively influence the students' perception of stressors and challenges. In this study, the authors paid extra attention to being cautious about interpreting findings not to be overgeneralized by providing contextual information relevant to our explanation.

Second, another potential limitation of this study is the lack of explanatory qualitative data. The original purpose of data utilized for this study was to evaluate the seminar course. And thus, the closed- and open-ended questions were not systematically designed to explain one another. For example, the 21 closed-ended questions focus on the students' perceived stressors but the two open-ended questions are about students' perceived challenges in their interaction with peers and an advisor, which is a part of the quantitative data. Such misalignment may lack or limit the depth of explanation relevant to some quantitative findings, and it is recommended to conduct further qualitative studies focusing on the specific stressors not being fully answered by this study (e.g., *Discrimination* for domestic and international students).

Lastly, the data collection was conducted during the pandemic, which may have impacted how participants rated some variables closely related to educational (e.g., an abrupt transition to the online modality, etc.) or life (e.g., working from home, social distancing, etc.) events happened during that time. For example, some of the open-ended responses shared the added difficulties or challenges in maintaining communication or developing relationships with peers or the advisor, implying the potential impact of the pandemic on the collected data. Because the authors will continue collecting data from the same seminar course, it would be necessary to compare the current analysis results with that from future data to address this limitation.

Findings and Discussions

This section consists of four sub-sections. The first section provides an overview of the student perceived stressors across the groups and how they look similar or different between the groups using the (quantitative) descriptive and MANOVA results. While some of the commonly perceived stressors (e.g., *Academic/Coursework, Research responsibilities, Burnout, Anxiety,* and *Depression*) align well with the widely known themes identified in prior literature on graduate education, disaggregating the graduate student population shed light on unique or not yet identified stressors for certain groups that can possibly be explained by the varied degree and citizenship status. Consequently, each of the following subsections focuses on a specific student group (or groups) that unique stressors were determined compared to at least one other group according to the follow-up ANOVAs results. The (qualitative) open-ended thematic analysis results will help explain the quantitative results, focusing on why or how the differences were identified considering the contextual differences in student experiences from distinct degree and citizenship status.

Perceived Academic and Psychological Stressors

Table 2 compares descriptive statistics of students' perception of 21 stressor variables (e.g., seven academic and 14 psychological stressors) between the four groups of students (e.g., *Group 1: Domestic master's students, Group 2: Domestic doctoral students, Group 3: International master's students*, and *Group 4: International doctoral students*). MANOVA results were also included in this table (noted *) to indicate variables that showed significant differences between the groups.

Table 2. Descriptive comparisons of the participants' groups

Stressors		Mean (Standard deviation)				
		Group 1 (n=152)	**Group 2 (n=72)**	**Group 3 (n=78)**	**Group 4 (n=74)**	**Total (n=376)**
Aca-demic	Academic/Coursework	**1.70 (0.92)**	**1.86 (0.95)**	**1.77 (0.87)**	**1.89 (1.07)**	**1.78 (0.95)**
	Teaching*	0.71 (1.03)	0.47 (0.90)	0.87 (1.02)	**1.59 (1.23)**	0.87 (1.11)
	Research*	**1.25 (1.09)**	**1.42 (0.99)**	**1.36 (1.11)**	**1.81 (1.17)**	**1.41 (1.11)**
	Peer interactions*	0.36 (0.73)	0.28 (0.77)	0.62 (0.81)	0.81 (1.04)	0.48 (0.84)
	Advisor interactions*	0.34 (0.76)	0.31 (0.57)	0.59 (1.06)	0.78 (1.20)	0.47 (0.92)
	Faculty interactions*	0.22 (0.62)	0.39 (0.80)	0.33 (0.73)	0.54 (0.89)	0.34 (0.75)
	Staff interactions*	0.12 (0.40)	0.25 (0.77)	0.26 (0.63)	0.46 (0.86)	0.24 (0.65)
Psychol-ogical	Tech issues	0.67 (0.82)	0.86 (0.90)	0.74 (0.78)	0.89 (1.07)	0.77(0.88)
	Work-like balance	**1.46 (1.00)**	**1.42 (0.87)**	**1.54 (1.07)**	**1.30 (1.27)**	**1.44 (1.04)**
	Discrimination*	0.13 (0.34)	0.17 (0.38)	0.49 (0.79)	0.59 (1.03)	0.30 (0.67)
	Finances and debt*	0.43 (0.70)	0.56 (0.73)	**1.08 (1.03)**	**1.30 (1.3)**	0.76 (0.99)
	Reliable funding*	0.53 (0.91)	0.53 (0.93)	**1.15 (1.32)**	**1.59 (1.41)**	0.87 (1.20)
	Lack of social support*	0.79 (0.88)	0.64 (0.86)	**1.00 (0.97)**	**1.11 (1.21)**	0.87 (0.98)
	Burnout*	**1.79 (1.07)**	**1.44 (1.07)**	**1.64 (1.11)**	**1.05 (1.02)**	**1.55 (1.10)**
	Anxiety	**1.54 (1.12)**	**1.58 (0.9)**	**1.31 (1.02)**	**1.59 (1.13)**	**1.51 (1.07)**
	Depression	**0.99 (0.98)**	**1.11 (1.00)**	**0.95 (1.02)**	**1.11 (1.14)**	**1.03 (1.03)**
	Health issues*	0.72 (1.00)	0.53 (0.80)	0.9 (0.71)	**1.03 (1.33)**	0.78 (1.00)
	Family issues*	0.67 (0.94)	0.42 (0.69)	0.74 (1.04)	**1.03 (1.31)**	0.71 (1.02)
	Relationship issues	0.61 (1.03)	0.39 (0.78)	0.36 (0.81)	0.65 (1.10)	0.52 (0.97)
	Loss	0.37 (0.96)	0.39 (0.76)	0.18 (0.50)	0.43 (0.89)	0.35 (0.83)
	Traumatic event	0.32 (0.85)	0.42 (0.84)	0.18 (0.45)	0.35 (0.75)	0.31 (0.76)
Experience*		4.01 (0.84)	4.03 (0.65)	4.21 (0.83)	4.32 (0.70)	4.12 (0.79)

Note: * indicates that the stressor variable showed a statistically significant difference between at least one other group according to a MANOVA.

The mean scores for academic stressor variables ranged from 0.12±0.40 (*Staff interaction* for Group 1) to 1.89±1.07, (*Academic/Coursework* for Group 4) and from 0.13±0.34 (*Discrimination* for Group 1) to 1.79±1.07 (*Burnout* for Group 1) for psychological stressor variables, showing that most variables were perceived as stressors that have non (scale 0) to the minimum (scale 1) or moderate (scale 2) negative impacts on the participant's ability to perform academically or professionally. Most standard deviations were closer to or sometimes above their mean scores, which indicates high within-group variations in students' perceptions. Although variables with mean scores above one will be interpreted as identified stressors in the following subsections, the authors acknowledge the wide range of differences in students' experiences and perceptions even within the same group of students.

Perceived academic stressors

All four groups of students perceived *Academic/coursework* (1.70±0.92 to 1.89±1.07) and *Research responsibilities* (1.25±1.09 to 1.81±1.17) as stressors that have minimal or

moderate negative impacts on their ability to perform academically or professionally. For these stressors, the mean scores for doctoral students (Groups 2 and 4) regardless of their citizenships were higher than those for master's students, i.e., Groups 1 and 3 vs. Groups 2 and 4, but there were no statistically significant differences between the groups. *Teaching responsibilities* was identified as stressors only for international doctoral students (Group 4, 1.59±1.23), with a significant mean difference from their domestic counterparts (Group 2, 0.47±0.90). Interpersonal interactions with an advisor (0.31±0.57 to 0.78±1.20), peers (0.28±0.77 to 0.81±1.04), and other faculty (0.22±0.62 to 0.54±0.89) and staff (0.12±0.40 to 0.46±0.65) members were generally not regarded as stressors. But interestingly, there were statistically significant mean differences between international doctoral students (Group 4) and all other groups (Groups 1, 2, and 3) for *Peer interactions* and *Advisor interactions*, and between international doctoral students (Group 4) and domestic master's students (Group 1) for *Faculty* and *Staff interactions.*

Perceived psychological stressors

Among all four groups, *Work-life balance* (1.301.27 to 1.541.07), *Burnout* (1.051.02 to 1.791.07), *Anxiety* (1.31 to 1.59), and *Depression* (0.951.02 to 1.111.14) were perceived as stressors. MANOVA results showed a statistically significant mean difference only for *Burnout*, between domestic and international master's students, and international doctoral students (Groups 1, 3, and 4).

Similar to academic stressors, varied perceptions of psychological stressors were noticed between the groups. For example, some finance- and social support-related stressors, *Finances and debt, Reliable funding,* and, *Lack of social support*, were perceived as stressors only for international students (Groups 3 and 4) with significant mean differences with domestic student groups (Groups 1 and 2). Like *Teaching responsibilities*, there were variables considered as stressors only for international doctoral students (Group 4) with significant mean differences with their domestic counterparts (Group 2), *Health issue* and *Family issue*. Although the mean score for all groups was below one, *Discrimination* showed a significant mean difference between domestic (Groups 1 and 2) and international (Groups 3 and 4) student groups. Details on the unique stressors identified by international students, international doctoral students, and domestic master's students will be provided in the following subsections.

Unique psychological stressors for international students

International student groups (Groups 3 and 4) commonly identified three psychological stressors related to finance and social support (e.g., *Finances and debt, Reliable funding,* and *Lack of social support*) with mean scores significantly different from domestic student groups (Groups 1 and 2). Tables 3, 4, and 5, respectively, present the MANOVAs and ANOVAs results (e.g., the means, Tukey's HSD test, F- and *p*-values, and effect sizes η2) for the variables that showed significantly higher mean scores for international students, international doctoral students, and domestic master's students.

Table 3. Comparisons of the MANOVAs and ANOVAs results between the participants' groups

Stressors	Group 1 (n=152)	Group 2 (n=72)	Group 3 (n=78)	Group 4 (n=74)	F (3,372)	η^2
Finances and debt	0.43[1]	0.56[1]	**1.08[2]**	**1.30[2]**	18.96	0.13

Reliable funding	0.53^{1}	0.53^{1}	$\mathbf{1.15^{2}}$	$\mathbf{1.59^{2}}$	18.96	0.13
Lack of social support	0.79^{4}	0.64^{4}	$\mathbf{1.00^{5}}$	$\mathbf{1.11^{5}}$	3.67	0.03
Discrimination	0.13^{1}	0.17^{1}	0.49^{2}	0.59^{2}	7.33	0.09

Note: Post hoc: the results with superscripts 1, 2, and 3 are significantly different from the results with different numbers in the same row at $p < .001$ and the results with superscripts 4 and 5 are significantly different from the results with different numbers in the same row at $p < .05$. For example, the Finances and debt variable is significantly different for Group 1 and 2 because they have the same superscript, but is significantly different for Group 2 and 4 as they have different superscripts.

Finances and debt, and reliable funding

Table 3 presents the one-way ANOVAs results for the two finance-related stressors, i.e., *Finances and debt* ($F(3, 372) = 18.96$, $p < 0.001$, $\eta 2 = 0.13$) and *Reliable funding* $F(3, 372) = 18.96$, $p < 0.001$, $\eta 2 = 0.13$). Results from ANOVA and Tukey's HSD test for multiple comparisons for each of the stressors showed that there was a significant mean difference by students' citizenship statuses, i.e. Domestic (Groups 1 and 2) vs. International students (Groups 3 and 4).

The demographic survey results provide potential explanations for this quantitative finding. According to the participant's responses on financial support (*see* Table 1), there are several types of financial resources that most international doctoral (e.g., Graduate research or teaching assistantships) and master's (e.g., Money borrowed from a financial institution, family, or friends with an expectation to repay, or being funded by self, parents, or foreign (non-U.S.) support) students rely on. Compared to domestic students who are eligible for diverse fellowship or scholarship opportunities that can relieve the students' financial burden, international students are often ineligible for most of the national (vs. international) fellowship opportunities. Also, for international students with F-1 visas, their job cannot exceed 20 hours during the semester, which hinders them from having multiple or additional financial resources (e.g., off-campus jobs) if they commit the 20 hours to their assistantships. These restrictions caused by the international students' citizenship status might be able to help explain the extra financial burden represented in the quantitative data.

Lack of social support

It is not surprising, but the ANOVA and Tukey's HSD test results showed that international students both in their master's and doctoral programs (Groups 3 and 4) identified the lack of social support as a psychological stressor ($F(3, 372) = 3.67$, $p < 0.012$, $\eta 2 = 0.03$) (Table 3).

This is also supported by the qualitative data, where students commented on challenges building social support with peers and their advisors. One student describes not feeling like they are able to connect with their advisor in the way they would like to:

> *With my adviser, I often feel like I am not as 'liked' as the other graduate students who are exactly at the same level as I am. It could be me, but it does make me question myself and makes me feel very insecure at times. I know the goal shouldn't be to be liked by your adviser, but I am someone who needs that type of energy from someone I look up to/want to make proud. With other faculty, no major challenges. Mostly my own inability to network well.* (Group 3)

This student feels that they are not as supported or 'liked' as some of their peers by their advisor. They also mentioned their challenges with networking, which also may contribute to a lack of social support.

Students also mention differences in cultural and academic backgrounds as contributing to challenges when interacting with their peers: *"Since all are from different countries and different cultural and academic backgrounds, I am finding it a little difficult to communicate and mingle with them."* (Group 3)

Students also expressed concern related to developing a sense of belonging with a group of people that were so different from them: *"The feeling that I may not fit in with the group of people who are so different in their upbringing and culture"* (Group 3)

Other students also expressed that they expected to interact more with peers and build a larger network, but mention the additional effort required in doing so when it comes to learning new cultures:

> *I have experienced that chances of interactions are comparatively lesser than what I expected. I have not been able to form friendships as such. The friends that I already have are those that I have known since before. I imagined that I will be able to experience different cultures and be able to learn about them during my stay here but perhaps graduate student life is very hectic to be able to pursue a social life. Getting to know different cultures also requires efforts and I think even I am not able to put in those efforts.* (Group 3)

Building social support may be challenging for students when considering these additional barriers.

Discrimination

Although the mean scores across the groups did not indicate *Discrimination* as a stressor, it was another psychological stressor variable that showed a significant mean difference ($F(3, 372) = 2.33$, $p < 0.001$, $\eta 2 = 0.09$) between the domestic (Groups 1 and 2) and international (Groups 3 and 4) student groups (Table 3).

Unique academic and psychological stressors for international doctoral students

In addition to the identified stressors as international students, *Teaching responsibilities, Health issue,* and *Family issue* were perceived as stressors only for international 'doctoral' students (Group 4) with a significant mean difference from at least one other group. The international doctoral student population also showed significantly higher mean scores for all four variables on interpersonal interactions (e.g., *Advisor, Peer, Faculty,* and *Staff interactions*) compared to other groups although the mean scores were below one.

Table 4. Comparisons of the MANOVAs and ANOVAs results between the participants' groups

Stressors	Group 1 (n=152)	Group 2 (n=72)	Group 3 (n=78)	Group 4 (n=74)	F (3,372)	η^2
Research	**1.25**[4]	**1.42**	**1.36**	**1.81**[5]	4.47	0.04
Teaching	0.71[1]	0.47[1]	0.87[1]	**1.59**[2]	16.45	0.12
Health issues	0.72	0.53[4]	0.9	**1.03**[5]	3.61	0.03

Family issues	0.67	0.42^{1}	0.74	**1.03^{2}**	4.60	0.04
Peer interactions	0.36^{1}	0.28^{1}	0.62^{1}	0.81^{2}	7.33	0.06
Advisor interactions	0.34^{1}	0.31^{1}	0.59^{1}	0.78^{2}	5.29	0.04
Faculty interactions	0.22^{4}	0.39	0.33	0.54^{5}	3.18	0.03
Staff interactions	0.12^{4}	0.25	0.26	0.46^{5}	4.81	0.04
Experience*	4.01^{4}	4.03	4.21	4.32^{5}	3.31	0.03

Note: Post hoc: the results with superscripts 1, 2, and 3 are significantly different from the results with different numbers in the same row at $p < .001$ and the results with superscripts 4 and 5 are significantly different from the results with different numbers in the same row at $p < .05$.

Teaching responsibilities

Compared to *Research responsibilities*, which was considered as a stressor for all four groups, Teaching responsibilities was identified as a stressor only for international doctoral students (Group 4) (see Table 4). Table 4 shows the results from One-way ANOVA ($F(3, 372) = 16.45$, $p < 0.001$, $\eta 2 = 0.12$) and Tukey's HSD test for multiple comparisons, which collectively provide evidence of a significant mean difference between this group and the other three groups.

These findings are supported by the qualitative data, where international doctoral students talked about challenges relating to differences in teaching cultures, for example:

> *The teaching method of giving HWs to the student. I have seen this method only in [the] US. In other foreign universities, there are not HW, but just a big exam at the end. This allow[s] the students to manage better their time.* (Group 4).

This student describes that the use of homework as a requirement was not familiar to them. This also extended to differences in terminology or how concepts were taught:

> *The same concepts were taught a little differently back in my home country, using a little different terminology. So while discussing something, it takes a little more effort than usual to convey and decode conversations* (Group 3)

Additionally, students discuss the language barrier and how this can impact how they are understood: *"Language or accent when speaking English, the meaning of words spoken out may not be 100% understood*" (Group 4). For international doctoral students who may have completed more of their education in a different educational culture and in a different language, teaching responsibilities may be an increased stressor compared to the other groups. Interestingly, only international doctoral students (Group 4) viewed their teaching responsibilities as a stressor despite the impact that the language barrier may have on all the international student groups (Groups 3 and 4). A possible explanation of this finding can be provided by the demographic survey results that showed different trends regarding financial support. A relatively higher number of international doctoral students were funded through a teaching assistantship (Group 4 - Teaching assistantship only: 26; Teaching assistantship and other sources of support: 12) compared to international master's students (Group 3 - Teaching assistantship only: 12; Teaching assistantship and other sources of support: 12), which may have associated with the number of students who indicated teaching responsibilities as a stressor, and thus, resulting in the differences in the average scores.

Health and family issues

The international doctoral student population also identified *Health* and *Family issues* as stressors (Table 4). One-way ANOVA and Tukey's HSD test for multiple comparisons found that each of them showed a significant mean difference from their domestic counterparts, i.e., international doctoral students (Group 2); *Health issues* ($F(3, 372) = 3.61$, $p < 0.001$, $\eta 2 = 0.03$) and *Family issues* ($F(3, 372) = 4.60$, $p < 0.001$, $\eta 2 = 0.04$).

Interpersonal interactions with peers and an advisor

None of the variables on the interpersonal interactions with different groups of people in the student's academic unit were perceived as stressors across the groups. But the mean score for international doctoral students (Group 4) showed a significant difference from those for domestic student groups (Groups 1 and 2) for *Peer* ($F(3, 372) = 2.33$, $p < 0.001$, $\eta 2 = 0.06$) and *Advisor* ($F(3, 372) = 5.29$, $p = 0.001$, $\eta 2 = 0.04$) *interactions* (Table 4). Although not identified as stressors, the qualitative data provided rich information on what aspects of such interpersonal interactions were perceived as challenges and how they look different for domestic and international students. The emergent findings on how the engineering culture plays a role in those interactions will also be provided.

In the qualitative analysis results, students mentioned in their comments that they sometimes faced challenges in interacting and making connections with peers and advisors. Students specifically mention cultural differences and conflicts, for example: *"Cultural conflict. I feel like I have to explain myself all the time, and ask them to explain themselves all the time too."* (Group 4)

Another barrier related to peer and advisor interactions mentioned by international doctoral students was related to language barriers. For example, *"English as a second language for the professor, [with] English as [a] second language I don't understand some accents."* (Group 4). These students expressed that since English is both their second language and the second language of their professor, they have difficulty understanding them. Further, this challenge is also present in peer interactions. One nuance to consider is that one student's response also considered body language relating to a lack of confidence in making eye contact, *"Self-consciousness and lack of confidence in making eye contact"* (Group 4).

Graduate students expressed the desire for more structure and explicit expectations for their work, and also mentioned that they felt expectations were sometimes unrealistic with their workload. Students felt they were expected to be independent in their studies, and also often expressed difficulty finding time to meet with their advisor due to their advisor being too busy. In the qualitative comments, graduate students' also expressed competitiveness to engineering culture that resulted in challenges in interactions or building relationships with their peers. PhD students in both groups share similar sentiments related to interactions with peers:

> *I have noticed some of my peers are more self-serving and interact with lecturers with questions or statements to affirm themselves that they already know the material and not ask questions to benefit their learning. They can come as they are gloating or the material is simple for them while others may not be at that level yet.* (Group 2)

> *Selfishness- keeping resources and information to themselves.* (Group 4)

These elements of the culture in engineering do not foster relationship-building amongst peers. Some students mentioned specifically that these types of behaviors upset them. Graduate

students described feeling competitiveness in both the classroom related to grades and also in the lab.

Unique characteristics of domestic master's students

According to the previous sub-sections, there was a trend that international students, particularly those who are in their doctoral degree program, showed the highest mean scores across most of the identified stressors. For *Burnout*, however, a reverse trend was shown and domestic master's students expressed the highest level of disruption caused by the identified stressor.

Before presenting and discussing this finding, the authors note that this finding is closely related to the context of the institution where the data collection was conducted. According to the demographic survey responses, most domestic master's students in our dataset are self-funded, at least as a part of their financial resources, and less than 10 students were supported by their employers to pursue the degree. This demographic information might be able to provide a contextual understanding of the domestic master's student population in our dataset which potentially includes students with work obligations to pursue their degrees.

Table 5. Comparisons of the MANOVAs and ANOVAs results between the participants' groups

Stressors	Group 1 (n=152)	Group 2 (n=72)	Group 3 (n=78)	Group 4 (n=74)	F (3,372)	η^2
Burnout	**1.79**[1]	**1.44**	**1.64**[2]	**1.05**[3]	8.28	0.06

Note: Post hoc: the results with superscripts 1, 2, and 3 are significantly different from the results with different numbers in the same row at $p < .001$ and the results with superscripts 4 and 5 are significantly different from the results with different numbers in the same row at $p < .05$.

In Table 5, domestic master's students (Group 1) showed the lowest mean scores for most variables, except for *Burnout, Work-life balance, Lack of social support, Health* and *Family issues*, and *Peer* and *Advisor interactions*. *Burnout* and *Work-life balance* were identified as stressors among those variables, and *Burnout* particularly showed a significant mean difference from international doctoral students (Group 4). Table # presents the results from the one-way ANOVA ($F(3, 372) = [8.28]$, $p < 0.001$, $\eta 2 = 0.06$) and Tukey's HSD test results.

The qualitative data support these findings, as students sometimes referred to working during their masters resulting in additional challenges with scheduling. One student described their biggest challenge with their advisor is finding time to talk,

> *Finding time to talk. I don't have a lot of availability in my schedule since I work part-time while pursuing full-time school. Sometimes when we do talk, he's not fully present because he's busy with his own stuff.* (Group 1)

Further, they share that even when they find time, the advisor is sometimes not fully present. Another student reflects on how balancing school and work also makes it challenging for them to connect with peers or even attend office hours:

> *Also, not finding a lot of time to connect with people since I'm so busy trying to balance school/work. Since I don't know as many people yet, it's difficult to be able to get help*

> *from my peers when I have questions on assignments. I have to rely solely on professors' office hours, but it's not always feasible with my schedule*. (Group 1)

This additional stressor may be explained by master's students working part or full-time while pursuing their degree.These challenges may contribute to burnout.

Conclusion and Implications

Engineering graduate students encounter a variety of stressors and challenges that impact their educational experience. This study identified perceived stressors among the four groups of engineering graduate students (e.g., domestic master's, domestic doctoral, international master's, and international doctoral) and compared them to navigate similarities and differences in the identified stressors. By considering students' degree or citizenship status that are often overlooked in the literature on engineering graduate education, the findings illuminated both unique stressors for specific student groups and varied challenges that different groups face with regard to the same stressors, which couldn't be explored by simply interpreting the total mean scores.

First, according to the quantitative findings, among a total of 21 stressor variables (e.g., seven academic and 14 psychological stressors), the same six variables (two academic and four psychological variables) were perceived as stressors for Domestic master's (Group 1) and doctoral (Group 2) students. More stressors were identified by international students, and the number of perceived stressors was higher for international doctoral students (Group 4, three academic and nine psychological stressors) compared to those in their master's program (Group 3, two academic and five psychological stressors). Although the number of identified stressors should not be interpreted as the perceived level of stress, the findings suggest the need for acknowledging distinct or additional stressors for different student groups that are often associated with their degree or citizenship status.

Notably, more psychological stressors were identified by all groups of students regardless of their degree and citizenship. Even though none of the mean scores across the psychological stressor variables exceeded 2 (moderately), the relatively higher standard deviations for psychological stressor variables compared to those for academic stressors indicate that there possibly be students significantly suffering from multiple psychological stressors.

Next, incorporating the qualitative findings and students' demographic information in explaining the quantitative findings also helped generate a nuanced understanding of why or how different groups of students feel pressure from the identified stressors. For example, the qualitative findings on the challenges regarding the differences in the educational system or engineering content-related concepts or terminologies between the current and previous educations for international doctoral students explained why they perceive their *Teaching Responsibilities* as a stressor. The findings also provided insights that students in different groups may feel pressured by different aspects of the same stressors, which are often related to individual or institutional attributes associated with degree or citizenship. For example, financial stresses are manifested in different ways for domestic (e.g., *Burnout* due to work obligations)

and international (e.g., *Finances and debt, and reliable funding* due to the limited opportunities to work as an F1 visa holder) students. Although the findings only provided the qualitative analysis results relevant to the identified stressors, focusing on the voices of specific groups that identified those stressors, it was also noticed that the same or similar types of challenges were encountered by other student groups. For instance, emergent challenges on the conflicts or differences in language, culture, and social norms in relation to *Peer and Advisor Interactions* were also shown in the domestic students' responses on their interactions with their peers or advisor who are international.

The findings of this study consequently suggest engineering education researchers consider degree and citizenship status as well as the unique multicultural nature of the engineering graduate education learning environment when investigating the engineering graduate student's experience. The findings from this study also have the potential to help practitioners (e.g., faculty advisors, research supervisors, or academic coordinators) who frequently interact with engineering graduate students to be aware of and better respond to the varied stressors across the diverse student groups. Some of the findings provide insights into the institutional/program level support needed for different student groups, informing administrators' and graduate program chairs' decisions to develop support structures (e.g., funding structure, financial/social support, TA training, etc.).

Considering that the learning environment is an ecosystem where individual students - even if they are in different degree programs and have different citizenships - continue interacting and make mutual influences on one another, many issues may not be only for certain student groups but influencing all in that environment, but in different ways. Considering that acknowledgment is the first step towards making changes, the findings of this study on such differences will contribute to creating a more inclusive learning environment for students regardless of their degree and citizenship status.

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