Effects of Test Anxiety on Engineering Students' STEM Success

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Effects of Test Anxiety on First-Year Engineering Students' STEM Success

Abstract
In this research paper, we explore the impact of test anxiety on first-year engineering students' STEM success. Exams are a prevalent mechanism for evaluating student learning in engineering. However, when confronted with an exam, some students suffer from test anxiety, resulting in detrimental impacts to their performance in engineering. Outside of engineering education, test anxiety has been negatively correlated to GPA. However, there have been few test anxiety-GPA studies in engineering. Studies from other fields, like biology, indicate that there are persistent gender-based "grade anomalies" between women's performance in science courses compared to their overall GPA. Many studies indicate that these results are not due to group differences in ability, but rather structural challenges that differentially affect members of underrepresented groups. Based on this prior work, we investigate the previously studied role of gender and race/ethnicity on levels of test anxiety and performance in STEM; we also explore the role of neighborhood socioeconomic status and first-generation status. Test anxiety was measured using self-reported responses to the Motivated Strategies for Learning Questionnaire (MSLQ). We first used pairwise tests to examine between-group average differences. Then, we examined the relationship between test anxiety and first-year engineering students' grade point average (GPA) in science, mathematics, engineering, and in STEM courses overall as mediated by their group membership. Results suggest test anxiety positively (directionally), but problematically (experiencing anxiety), impacts performance for women in science, mathematics, and STEM overall. We discuss these findings in relation to the STEM “gender filter” further.

Introduction

Test anxiety can be described as "students’ worry and concern over taking exams” [1, pp. 119], and is “assumed to be an indication of the strength of the motive to avoid failure” [2, pp. 975] When given an exam, some students experience a great deal of test anxiety. However, exams remain a primary way by which students are assessed and graded in engineering. A recent study of five institutions indicated that women, marginalized racial/ethnic students, and first-generation college students perform worse in lecture-based STEM courses than they are expected to according to their GPAs in other courses and incoming academic preparation [3]. The results of that study indicate that structural issues in STEM courses may disadvantage groups already minoritized in engineering, especially women. The authors pointed specifically to evaluation in courses as one area for improvement, as grades have a significant impact on persistence [4]. They suggested that reducing time pressure or other sources of stress during testing could improve these disparities. These conclusions are consistent with other research that indicates that when women are in male-dominated STEM fields, they are more likely to have negative responses to low grades than their male peers, and are more likely to leave STEM majors [5]. Other studies also indicate that female students in STEM courses exhibit more test anxiety [6]. These results point to many potential issues in assessment, one issue being that assessments in STEM courses may not be equitably designed to help students properly manage test anxiety.

Test anxiety has two separate components: worry (cognitive; internal dialogue) and emotionality (affect; emotional arousal) [7]. For the purposes of this research, we focus on the emotionality component of test anxiety for two reasons. First, most of the existing literature (described below) connects performance in courses to this aspect of test anxiety, and second, the test anxiety measure most widely available and used with engineering student populations focusses on the affective component of test anxiety.

Many studies describe test anxiety in academic settings, from early childhood education through post-secondary education, and its potential linkages to other factors. In one study, higher levels of emotional test anxiety corresponded to poor exam performance when confidence in performance was low [7]. Similar findings were found in middle school settings where test anxiety increased when students aspired to perform better on a test than they expect to perform [8]. These students experienced higher levels of anxiety than students whose aspirations and expectations were aligned. In another study, higher test anxiety was correlated to lower exam performance, higher emotion-focused coping (seeking emotional and physical/instrumental support, and ventilation), and higher avoidance (disengagement and denial) for first-year undergraduates in social welfare and health sciences [9]. These studies highlight the complexity of and the relationship between test anxiety and other factors.

Theoretical Mechanism of Test Anxiety

Test anxiety is negatively correlated with academic performance, possibly due, in part, to the cognitive-interference of anxiety on performance. According to cognitive-interference theory, the experience of test anxiety diverts mental resources (e.g., short-term memory, cognitive processing, problem-solving), that are otherwise needed for test-taking [10]–[12], to other cognitive processes. An alternative view is the deficit model, which hypothesizes that test anxiety is a response to, not a cause of, expected poor student performance in testing situations [13]. As this work is centered on structural issues within engineering education rather than on student deficits, we utilize this alternative view in the work that we present.

Given that there is documented variability in the individual experience of test anxiety [14], [15], and that test anxiety has been demonstrated, in numerous studies, to negatively impact performance [13], [16]–[19], there is likely to be variability in how test anxiety affects assessment of students [20]. Consequently, exams may be measuring a student's ability to cope with test anxiety as much as, or instead of, the student's true cognitive ability or content mastery. Significantly, test anxiety may not be felt equally by all students, and its impacts may vary by student characteristics. For example, a study of neuroscience undergraduates indicated a moderate negative correlation between test anxiety and overall GPA ($r = -0.317$, $p < 0.001$) [21]. Additionally, the same study found that the relationship between first-generation college student status and GPA were mediated by test anxiety, motivation, and trait-anxiety (anxiety as a personal characteristic). Overall, these results suggest that not only can test anxiety influence academic performance, test anxiety can also act as a mediating variable in predicting first-generation college students' GPA.

Concerns with Test Anxiety

Research suggests students from marginalized groups in engineering see their competence as mathematicians, scientists, and engineers as an important determinant for whether they feel they belong in STEM contexts, including engineering [22]–[25]. Other literature also suggests marginalized students, such as those from socioeconomically marginalized backgrounds, are continually evaluating the risk of engineering in comparison to other pathways that might allow them and their families class mobility [26]–[28]. A culture of difficulty, including a focus on tests in STEM environments, puts continuous pressure on students to prove their competence in high-risk settings [29], [30]. Because mathematics backgrounds inform science backgrounds, and both inform engineering [23], [31], there are a multitude of opportunities for students to experience feelings of failure in engineering education, especially in the first two years of curricula. Fear of failure that comes with test anxiety, and the multi-faceted results that may come as a result of a failure, may in turn, push students to leave engineering.

Outside of STEM education contexts, the American Psychological Association suggests high generalized trait anxiety over long periods of time has been linked to poorer health conditions later in life including tumors, blood clotting issues, and others [32]. Marginalized students already experience heightened anxiety to perform in society without needing to be concerned about their place in engineering and the stress that comes with it [28], [33], [34]. Aside from the numerous mental health issues students engage with while enrolled in engineering [35], the additional anxiety of engineering likely puts students at risk of poorer health conditions later.

Research Questions

Based on the literature indicating that test anxiety may be a key factor in the differential impact of marginalized students' experiences in STEM classrooms, we explored differences in test anxiety for engineering students and the influence of that affective measure on STEM GPA. To explore the relationships between test anxiety and academic performance in the engineering education setting, we seek to answer the following research questions:

1. Are there differences in students' GPAs in science, engineering, mathematics, and STEM overall, and test anxiety, by gender, race/ethnicity, socioeconomic status, and first-generation status?
2. How are students' GPAs in science, engineering, mathematics, and STEM overall related to test anxiety?
3. To what extent do gender, race/ethnicity, socioeconomic status, and first-generation status mediate the relationship between GPA and test anxiety?

Research Methods

This study is part of a larger grant project (DUE-1626287, DUE-1626185, and DUE-1626148), which examines how non-cognitive and affective (NCA) factors affect students' success in engineering. In this research paper, we define student success as academic success through a proxy of grade point average (GPA).

Population

As part of the larger project, we surveyed a total of n = 2339 students at 17 institutions using a questionnaire of 28 NCA factors, the Studying Underlying Characteristics for Computing and Engineering Student Success (SUCCESS) survey [36], [37]. With student consent and approval from our Institutional Review Board, we have also gained access to the institutional records (transcript data, Dean of Student's records, and financial aid data) of students from three primary institutions in the study. In the results presented here, we focus on a sample of n = 561 first-year engineering students at a single large land-grant institution in the Midwest.In the SUCCESS survey, students were asked to provide information regarding their gender, race/ethnicity, first-generation status, and home ZIP code. Students could choose multiple options for their gender (including non-binary) and racial/ethnic identities. First-generation status was determined based on students' responses about their parent's education status. Students were considered first-generation college students if neither parent obtained a four-year college degree [38]. Neighborhood socioeconomic status was determined by first converting students' home ZIP code to its matching county code using the R package *noncensus* [39], and then matching that county code to Median Household Income information from the 2010 United States Census [40]. Socioeconomic classes; under $42,000 (low), $42,000 to $126,000 (middle), and $126,000 and higher (upper), were determined for the purpose of presenting demographics. These income ranges are based on federally recognized classifications of individual socioeconomic class [41]. More information about this process in the context of engineering education can be found in other work [42].

Students' self-reported demographic information is summarized in Table 1. Because students could choose more than one gender or racial/ethnic identity, or because of rounding error, percentages may add up to more than 100%. Additionally, while students could pick from a variety of gender identifications, for their protection, we have combined these identifications into a larger non-binary category.

Table 1. Demographics of the single-institution sample (n = 561).

	Counts	**Percentage of Total**
Gender		
Female	131	23.4%
Male	422	75.2%
Non-Binary	33	5.9%
Race/Ethnicity		
American Indian or Alaskan Native	2	0.4%
Asian	118	21.0%
Black or African American	19	3.4%
Hispanic, Latinx, or Spanish Origin	48	8.6%
Middle Eastern or North African	15	2.7%
Native Hawaiian or Other Pacific Islander	2	0.4%
White	382	68.1%
Another Identification	11	2.0%
Neighborhood Socioeconomic Status		
Low ($0 to $42,000)	38	6.8%
Middle ($42,000 to $126,000)	457	83.1%
High ($126,000 and up)	0	0.0%
Unknown	66	9.9%
First-Generation Status		
Yes	143	25.5%
No	409	72.9%
Unknown	9	1.6%

Due to small sample sizes, of those who did not identify as either women or men explicitly, these respondents were placed in one group to represent female and gender non-binary identifying students. While we intended to be able to explore more nuanced experiences of the LGBTQ+ community, we grouped women and non-binary together due to the general similarities in experiences of non-majority groups, and the male dominant presence and culture within engineering [43]. We acknowledge that our research population (primarily White, male, and of upper-middle class standing) remains a limitation of this work, and in opposition to the goals of diversity in engineering education more broadly [44].

STEM GPAs were calculated for each student by dividing the number of credits earned (weighted by grade) by the number attempted for each GPA type: science (i.e., chemistry and physics), engineering (i.e., first-year engineering courses, discipline-specific introductory courses including computer science), and mathematics (i.e., Calculus I, II, III; statistics). Additionally, an overall STEM GPA was created from all of the above courses.

Measures

In this study we use the test anxiety measure from the Motivated Strategies for Learning Questionnaire (MSLQ; Table 2) [45]. The MSLQ is a comprehensive survey instrument used to measure motivation in three separate but related overarching dimensions (value, expectancy, and affect), as well as different learning strategies. This survey instrument has been widely used in many contexts and languages. Validity evidence exists for the survey in Chinese [46], English [47]–[49], Estonian [50], Spanish [51], Turkish [52], as well as other languages. The MSLQ has wide usage throughout engineering education with validity evidence, specifically with engineering students in both English [53] and Spanish [51] language settings. In our previous work, we have documented validity evidence with our population, specifically with the Time and Study Environment, and the Test Anxiety factors within the MSLQ [36], [37]. The test anxiety items, shown in Table 2, were administered on an anchored, numeric scale from 1 to 7 where 1 = "Not at all true of me" and 7 = "Very true of me." Prior research has indicated that these items measure a single factor with a Cronbach's alpha of 0.80 [45].

Table 2. MSLQ Test Anxiety items developed by Pintrich and colleagues [45]

Prompt	*Q19: Please respond to the following items to the best of your ability.*
Q19a.	When I take a test, I think about how poorly I am doing compared to other students.
Q19b.	When I take a test, I think about items on other parts of the test I can't answer.
Q19c.	When I take tests, I think of the consequences of failing.
Q19d.	I feel my heart beating fast when I take an exam.
Q19e.	I have an uneasy, upset feeling when I take an exam.

Pairwise Group Comparisons

To investigate average differences by gender, race/ethnicity, and first-generation college student status, we used R [54] to conduct non-parametric tests on STEM GPAs. With the bounded nature of STEM GPA, the data were non-normal. Students' neighborhood socioeconomic status was also non-normal. However, Box-Cox Normality Tests suggested a linear transformation of neighborhood socioeconomic status was still the most appropriate to be used for this analysis.

We used Mann-Whitney-U Tests for pairwise comparisons across non-normal categorical demographics to explore differences in GPA and test anxiety. For continuous data, such as neighborhood socioeconomic status, we used correlation testing. Statistical significance for all tests in this study were conducted at the $\alpha = 0.05$ level.

Path Analysis

The GPA measures used in this study were linked to one another because performance in prior STEM courses influences current performance. Thus, we redirected our study to further explore multiple path differences all at once. To do so, we used all items with significant group differences in a larger path model to investigate the effect of group membership and test anxiety on STEM GPAs in a single model. This approach allowed us to understand which groups may have more grade disparities in particular subjects mediated by test anxiety. Path modeling was conducted using the R package *lavaan* [55] and a Weighted Least Squares Robust Means Robust Variance (WLSMV) estimator. Fit of the model was determined according to popularly accepted statistical measures for satisfactory fit: a Comparative Fit Index (CFI) > 0.95, a Tucker-Lewis Index (TLI) or Non-Normed Fit Index (NNFI) > 0.95, and a Root Mean Square Error of Approximation (RMSEA) < 0.08 with an upper tail < 0.06 [56]. Normally, a Square Root Mean Square Residual (SRMR) < 0.08 is suggested as well. However, because of the large number of categorical variables, we opted for a Weighted Root Mean Square Residual (WRMR) < 1.0 [57].

Results

In this section, we describe our results in the order of our research questions. First, we describe the results of group comparisons for GPAs. Thereafter, we report the results of group comparisons for test anxiety. The group comparisons were only used to identify which demographic groups differed significantly in GPA and/or Test Anxiety to inform the path analysis. Finally, we describe the results of the path analysis that followed.

Demographic differences in STEM GPAs

We first explored demographic differences in different STEM GPAs using a Mann-Whitney-U Test. We found no significant differences in science, mathematics, engineering, or combined STEM GPA by gender or first-generation status.

We tested for GPA differences by race/ethnicity in two steps. First, we compared students from underrepresented racial/ethnic backgrounds (i.e., American Indian or Alaskan Native, Black or African American, Middle Eastern or North African, Native Hawaiian or Pacific Islander) to majority students (i.e., White, Asian), as two groups. We found no significant GPA differences.

Second, we examined differences for individual underrepresented groups for which we had an adequate population size ($n \geq 30$; Asian and Latinx students). We found no significant differences for Asian and Latinx students in mathematics, engineering, or combined STEM GPA. However, we did find significant differences in science GPA for both Asian ($U = 30380$, $p = 0.007$) and Latinx ($U = 10166$, $p = 0.046$) students in comparison to all other students in the sample. We found no significant correlations (all $r < 0.005$) between students' neighborhood socioeconomic status and their GPAs in science, mathematics, engineering, or combined STEM.

Demographic differences in Test Anxiety
After examining GPA by demographic groups, we explored demographic differences in test anxiety. Using a Mann-Whitney-U Test, we found no significant differences in test anxiety by first-generation status, underrepresented race/ethnicity overall, or for Asian and Latinx students separately in comparison to all other students in the sample. However, we did find significant differences in test anxiety for female and non-binary students compared to their male peers (U = 22847, $p < 0.001$). Additionally, using regression correlation analysis, we explored relationships by neighborhood socioeconomic status. We found no significant differences.

In summary, answering RQ1, pairwise comparisons led us to find significant differences in mathematics GPA for first-generation students, and differences in science GPA for Asian and Latinx students. No differences in any GPA by gender or neighborhood socioeconomic status were found. However, we found there are significant gender differences in test anxiety.

Path modeling of demographics, STEM GPAs and, level of Test Anxiety
After noting the above group differences, we explored the effect of group membership on outcomes of STEM GPA as mediated by test anxiety. This approach allowed us to account for students at the intersections of multiple demographic groups, and to understand how test anxiety might explain the differences found for GPA. The results of this approach, shown in Figure 1 and Table 3, provide support for the hypothesis that structural issues, such as high stakes assessments where midterm tests and finals contribute to large portions of a student's grade (a common practice at the university in this study), may cause differential performance in STEM courses.

After the WLSMV estimator accounted for missing data through listwise deletion, 550 out of 561 responses (98.0%) were used for further analysis. The model indicated good fit with a CFI = 0.968, a TLI = 0.954, a RMSEA = 0.034 where the upper confidence interval tail was 0.052, a SRMR = 0.033, and a WRMR = 0.961. The individual regression path estimates are in Table 3. In the table, significance is denoted by $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***).

In relation to our second research question, we find that test anxiety plays a small but statistically significant role in students' GPAs in mathematics ($\beta = 0.065$, $p < 0.001$), and indirectly on students' GPAs in science ($\beta = 0.013$, $p = 0.008$), engineering ($\beta = 0.010$, $p = 0.017$), and STEM GPA overall ($\beta = 0.030$, $p < 0.001$). GPA in mathematics also had a significant relationship with science GPA ($\beta = 0.193$, $p < 0.001$) and engineering GPA ($\beta = 0.149$, $p = 0.002$). As expected, all three disciplinary GPAs (science GPA, mathematics GPA, and engineering GPA; $\beta = 0.224$, $p < 0.001$; $\beta = 0.373$, $p < 0.001$; and $\beta = 0.325$, $p < 0.001$; respectively) significantly predicted overall STEM GPA. Together, these results indicate that test anxiety impacts all first-year students' performance in science, mathematics, and engineering contexts.

In relation to our third research question, we found no significant differences relating race/ethnicity, neighborhood socioeconomic status, and first-generation college student status with test anxiety. However, we did find that test anxiety is an important mediator of science ($\beta = 0.009$, $p = 0.027$), mathematics ($\beta = 0.047$, $p = 0.004$), engineering ($\beta = 0.007$, $p = 0.036$), and overall STEM GPA ($\beta = 0.124$, $p = 0.023$) for female and non-binary students, specifically. These results, and their implications for engineering education practice are discussed below.

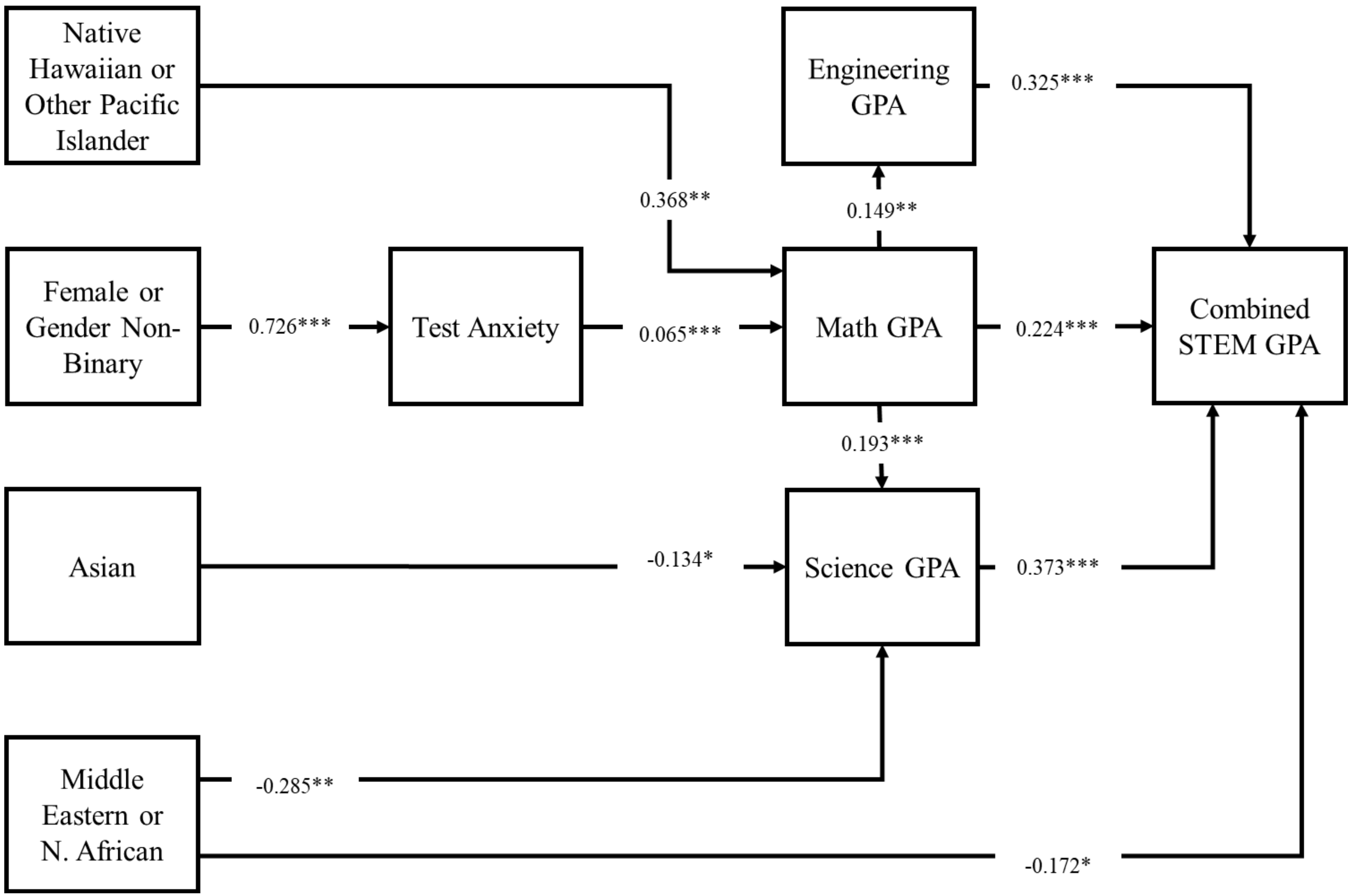

Figure 1. A path model showing the effects of test anxiety on undergraduate engineering students' STEM GPAs. Significance is denoted by $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***).

Table 3. Total effects in a path analysis of demographics, test anxiety, and GPAs in STEM.

Regressions	Standardized Estimate	Standard Error	*p*-value	Significance
Science GPA				
Asian	-0.134	0.061	0.028	*
Female or Gender Non-Binary	0.009	0.004	0.027	*
Mathematics GPA	0.193	0.047	< 0.001	***
Middle Eastern or North African	-0.285	0.106	0.007	**
Native Hawaiian or Other Pacific Islander	0.071	0.033	0.031	*
Test Anxiety	0.013	0.005	0.008	**
Engineering GPA				
Female or Gender Non-Binary	0.007	0.003	0.036	*
Native Hawaiian or Other Pacific Islander	0.055	0.029	0.057	n/s
Mathematics GPA	0.149	0.049	0.002	**
Test Anxiety	0.010	0.004	0.017	*
Mathematics GPA				
Female or Gender Non-Binary	0.047	0.016	0.004	**
Native Hawaiian or Other Pacific Islander	0.368	0.142	0.009	**
Test Anxiety	0.065	0.016	< 0.001	***
STEM GPA				
Asian	-0.030	0.014	0.031	*
Engineering GPA	0.325	0.016	< 0.001	***
Female or Gender Non-Binary	0.124	0.055	0.023	*
Mathematics GPA	0.373	0.014	< 0.001	***
Middle Eastern or North African	-0.172	0.085	0.044	*
Native Hawaiian or Other Pacific Islander	0.171	0.068	0.011	*
Science GPA	0.224	0.016	< 0.001	***
Test Anxiety	0.030	0.008	< 0.001	***
Test Anxiety				
Female or Gender Non-Binary	0.726	0.145	< 0.001	***

Discussion

In this study, we examined the effect test anxiety had on students' academic success as measured by GPA in science, mathematics, engineering, and STEM overall. Contrary to what has been observed within literature on test anxiety and academic performance, we found higher test anxiety was related to higher GPAs, We found that test anxiety positively (directionally), but problematically (experiencing anxiety), influenced students' GPAs in science, mathematics, engineering and STEM overall,. Further, we found that test anxiety was even more positively (directionally) related to female and non-binary students' success than their peers. Unlike a study by Gaudier-Diaz, Sinisterra, & Muscatell, which found that test anxiety was an important consideration for first-generation students in neuroscience settings [21], we found no such differences. We suspect that one reason for these first-generation differences may be that, in comparison to the authors who examined overall GPA in college, we looked at separate GPAs in science, mathematics, engineering and STEM overall. Additionally, we suspect that the differing contexts and cultures of engineering to neuroscience may also be explanatory.

Path coefficients suggest that higher test anxiety, especially for female and non-binary students, results in higher GPAs in science, mathematics, engineering, and STEM overall. This finding is counter to findings in other fields like biology, where women had higher test anxiety, but test anxiety negatively influenced performance. We hypothesize that engineering may attract a different type of student, and the environment may affect women differently than other STEM fields. Engineering is already recognized as a field with a "gender filter" [58]. In other words, women who enter engineering have significantly higher prior performance (as measured by high school GPA and standardized test scores) than their male peers. The women who choose engineering majors are already exceptionally talented and are more likely to succeed in their courses. So, we do expect that women may perform better in their college courses than their male peers. We hypothesize that higher test anxiety for this group may be reducing performance, but not enough to reverse the direction of the effect. That is, we believe our results may indicate that women overall perform better than men but also that women who have higher test anxiety than their female peers may do worse in STEM courses. Our future work will explore this possible mechanism for how test anxiety functions in engineering.

Implications

Our results highlight the need to consider how testing culture is affecting and putting at risk traditionally underrepresented groups in engineering. Constant contact with a culture of difficulty puts students in constant consideration of whether they should stay in, or leave, engineering [29], [30], [59]. Additionally, as described above, student anxiety is linked to many other health issues during undergraduate education, as well as later in life. To ensure students stay in, and succeed in engineering, it is imperative that engineering education researchers and practitioners seek to mitigate the anxiety that comes with testing in engineering education, as well as other aspects of performance. This consideration may include rethinking how assignments and tests are created, presented, and graded in engineering education. A larger change in these practices could lead to changes in the culture of engineering [29], [30], and ensure that students stay and succeed.

Limitations

Our sample size is a primary limitation of this study. While we did have a relatively large sample for analysis overall, we were still limited in analyses we could perform for finite marginalized groups in engineering education. This was especially the case for students of non-binary gender, students of color, students from non-heterosexual sexual orientations, and students from lower socioeconomic backgrounds. Larger sample sizes may have allowed us to learn more about students belonging to these groups. Beyond the number of students and the groups compared, a limitation of this study is our inability to represent more than one institution with different populations and different institutional contexts. Future work, amongst other analyses, should look at these differences as well as those limitations described before this.

Future Work

Future work first and foremost should seek to understand how these results replicate across institutions. Additionally, work should seek to examine additional variation for students from other marginalized groups, including at intersections that are not present in this analysis. Amongst this examination, it is necessary that more studies explore the positive connection between test anxiety and performance for female and non-binary students, and others.

Beyond replication, MSLQ has been described as a questionnaire which only captures the affective aspect of text anxiety [49]. The other theoretical component of anxiety, worry, as well as metacognition, have been documented in literature as a better, more nuanced, way to understand the effects of anxiety in daily life [60]. Studies that capture alternative points of view of anxiety in engineering education in and out of testing would be a valuable contribution to engineering education.

Conclusions

In this study, we examined the role test anxiety played in students' GPAs in STEM courses, particularly for marginalized groups to explore structural issues that cause differences in performance. We found that higher test anxiety results in a higher GPA for female and non-binary identifying students; there were no additional differences in test anxiety for any racial/ethnic or socioeconomic group. Regardless, anxiety is harmful to students' personal health and well-being. Therefore, although these students have higher GPAs, their increased level of anxiety and the testing culture of engineering could make them at risk to leave engineering. To ensure that students continue to succeed in engineering, especially students who are from traditionally marginalized groups, any and all efforts should be made to decentralize testing as a primary method of assessment in engineering education, or at least to lower the stakes of testing that are known and experienced in engineering education contexts.

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