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Examining Gender-Based Disparities in Students' Attitudes toward Engineering and Sociotechnical Understanding: A Structural Equation Modeling Study

Dr. Mohammad Meysami, Clarkson University

Mohammad Meysami is an Assistant Professor of Mathematics at Clarkson University. His research interests involve spatial statistics, data science, and machine learning. He utilizes mathematical and statistical structures to develop more robust and computationally feasible algorithms for analyzing data.

Felicity Bilow, Virginia Polytechnic Institute and State University

Felicity Bilow is a graduate student at Virginia Tech.

Jan DeWaters, Clarkson University

Dr. Jan DeWaters is an Associate Professor in the Institute for STEM Education with a joint appointment in the School of Engineering at Clarkson University, and teaches classes in both areas. Her research focuses on developing and assessing effective, inclusive teaching and learning in a variety of settings. An environmental engineer by training, Dr. DeWaters' work typically integrates environmental topics such as energy and climate into STEM settings.

Lucas Adams, Clarkson University

Current Senior at Clarkson University in Potsdam, NY majoring in Applied Mathematics and Statistics

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Abstract

This research study uses structural equation modeling (SEM) to explore the relationships among undergraduate engineering students' attitudes toward and perceptions of engineering and their understanding and appreciation of engineering's broad, sociotechnical aspects, with a particular focus on examining how these relationships vary with respect to student gender and exposure to sociotechnical engineering coursework. Subjects were 314 undergraduate students at one small technically-focused research university, who completed Likert-type surveys in spring 2022. A factor structure previously determined through exploratory and confirmatory factor analysis revealed five latent variables that align with a framework proposed by Fila et al. [1] for teaching engineering within a humanistic lens to help students develop a sense of belonging and their engineering identity. Our SEM analysis showed that for all students, *academic self-confidence and self-efficacy* and a *broad understanding of engineering* both have a significant positive influence on their s*ense of belonging*, which in turn has a significant influence on their attitudes toward *persisting and succeeding in engineering*. Appreciating the *importance of non-technical skills* in engineering had no significant influence on most students' *sense of belonging* with the exception of male students with more than one sociotechnical course, where the influence was negative. The relationships among the latent constructs varied according to student gender and exposure to sociotechnical coursework, and are described in detail in the study. In essence, the findings point to the important connections between students' sense of belonging and their attitudes toward persisting and succeeding in engineering, which was more important for female students compared to male students and was stronger for those female students who were exposed to more sociotechnical engineering coursework. Furthermore, providing students' educational opportunities to bolster their self-confidence and self-efficacy, and improve their understanding of the breadth of engineering, will positively influence their sense of belonging. The study findings are limited by the small sample sizes and the reliance on students' self-reported exposure to sociotechnical engineering coursework.

Introduction and Background

Today's complex and interdisciplinary challenges require an engineering workforce equipped with the ability to apply sociotechnical thinking [2],[3], which involves understanding and appreciating the social context of engineering and the broader societal implications of the engineer's work. These challenges also demand an engineering workforce comprised of a breadth of perspectives and diverse experiences [2],[4]-[6]. While these needs have been discussed and debated for years (e.g. [7]-[9]), little has changed among engineering curricula or within the engineering education culture [10].

The current landscape of undergraduate engineering curricula in the U.S. focuses on developing students' technical knowledge and skills, with less attention given to cultivating their understanding and appreciation of the societal implications of engineering work [4],[11]. This can create a culture of disengagement where students fail to grasp the importance of social responsibility in engineering [11],[12]; instead they "identify engineering as something that [is] more related to technical abilities than to a social purpose" [13], p. 5. It can also prevent students who do value the social aspects of engineering from identifying as engineers [14] and, worse, can keep them from persisting in their engineering studies [15],[16]. Moreover, students are often left to learn more of the social and cultural aspects of engineering organizations, including working on teams and communicating with others, as they transition into working in industry [17],[18].

Coursework that exposes students to the importance of engineering's broader social aspects can have multiple benefits. First, showcasing the social and contextual elements of engineering may help attract and retain female students in the field [16],[19],[20]. Relative to their male peers, female students tend to view the social aspects of engineering as more important [21],[22], understand the sociotechnical nature of engineering better [23], are more interested in solving social issues [24] and helping people [25], and are more likely to pursue engineering because of social motivations [5],[26]. Women are typically more interested in engineering disciplines that provide more real-world, contextualized learning opportunities [27], so engineering courses that highlight the social aspects of engineering may help female students to see engineering as a suitable career for them. Second, engineering graduates would better understand the importance of considering the social aspects of engineering and the societal implications of engineering work. This would better prepare them for a career industry where they will be (1) making decisions that impact people [1] and (2) interacting and collaborating with others [28]-[30].

One curricular strategy that has gained recent interest and attention for strengthening students' sociotechnical thinking is the incorporation of sociotechnical content into existing engineering coursework, where both technical and non-technical aspects of engineering are highlighted in the engineering curriculum. Sociotechnical material has been integrated into engineering science courses (e.g., [31]-[35]) as well as other more technical engineering courses, such as an introduction to computing course [36], a feedback systems control course [37], and a computer vision technology course [38]. Courses have also been created to focus on a sociotechnical engineering framework (e.g., [39],[40]), including first-year introduction to engineering courses (e.g., [41]-[43]) and second-year introduction to design courses [44]. Finally, senior design (capstone) courses, particularly those with real-world aspects, are known to incorporate sociotechnical dimensions [4],[45].

Previous research has shown that exposing students to sociotechnical engineering coursework can strengthen their sociotechnical thinking and their understanding of the broad nature of engineering [36],[38],[44],[46]-[49]. Yet few have investigated the influence of sociotechnical coursework on students' attitudes toward or perceptions of engineering, let alone the possible gender-related differences. Students' perceptions of the social and technical aspects of engineering can influence women's and men's sense of belonging in engineering differently [50]. Furthermore, students' attitudes toward engineering, including their sense of belonging and academic self-confidence, are key indicators of whether female students decide to stay in or leave engineering [51]. Thus, efforts to improve our understanding of the relationships among these factors, and the influence of sociotechnical engineering coursework - particularly with respect to male/female differences - will help foster educational experiences that benefit all students.

This paper explores relationships among undergraduate engineering students' attitudes toward and perceptions of engineering and their understanding and appreciation of engineering's broad, sociotechnical aspects, at one small research-based university. We examine in particular how these relationships vary with respect to student gender and exposure to sociotechnical engineering coursework. The study is guided by the following research questions:

1. What is the relationship between undergraduate engineering students' attitudes toward engineering (i.e., sense of belonging, academic self-confidence/self-efficacy, and persisting/succeeding in engineering) and their perceptions of the broader, non-technical aspects of engineering?
2. How do these relationships differ depending on students' gender identification and exposure to sociotechnical engineering coursework?

We quantitatively explore these research questions through SEM using student questionnaire responses. SEM is an analytical approach that allows us to examine complex relationships among multiple variables simultaneously and is commonly employed in social science research, including psychology, sociology, and education. The method involves both measurement and structural models, enabling the study of how variables are related to each other and how they contribute to the development of latent constructs or concepts. SEM is particularly useful for exploring intricate patterns and causal pathways within a theoretical framework [52]. The research presented in this paper is part of a larger on-going mixed-methods study exploring the relationships among students' attitudes toward and perceptions of engineering based on their gender and exposure to sociotechnical engineering coursework.

Conceptual Framework

Fila et al. [1] proposed a three-dimensional framework that situates engineering within a sociotechnical context called engineering *for*, *with*, and *as* people. This framework provides a lens to view and teach engineering humanistically. The engineering *for* people dimension acknowledges the non-technical aspects of engineering, including the importance of considering and serving society when making engineering design decisions [4],[41],[53]. Engineering *with* people recognizes the teamwork component of engineering work; engineers work with many others, including stakeholders, colleagues, and communities, when developing designs [28],[29],[54],[55]. The engineering *as* people dimension considers engineers as individuals who bring their own skills, values, beliefs, knowledge, and experiences (i.e. characteristics) to the engineering field [1]. A variety of characteristics are important for an engineering student. Of particular interest is a students' belief in their abilities to learn and perform well in their academics, also known as their academic self-efficacy [56]. Academic self-efficacy can play a vital role among engineering students' academic achievement and persistence in their studies [57]-[59]. Students' confidence in their academic abilities is also important, since a lack of academic self-confidence can contribute to students' decisions to leave their engineering major (e.g., [60],[61]. These characteristics can also influence students' sense of belonging in engineering [62]. A strong sense of belonging among students majoring in science, technology, engineering and math (STEM) disciplines has been shown to help advance academic persistence, success, and interest in the field [63],[64], while a decreased sense of belonging can weaken students' persistence in the field and ultimately lead them to leave engineering [65]-[67]. Thus, students' sense of belonging, academic self-confidence and self-efficacy, and attitudes toward persisting and succeeding in engineering are all linked to the engineering *as* people dimension.

According to Fila et al. [1], applying this framework to engineering education can foster an environment that enhances students' sense of belonging and non-technical skills. Given the framework's focus on a humanistic approach to engineering education, it is a suitable framework to evaluate the impact of sociotechnical engineering courses (i.e., a humanistic approach to engineering education) on students' attitudes toward and perceptions of engineering. Furthermore, this framework explicitly describes and explains the possible connections between students' attitudes toward and perceptions of engineering, making it appropriate for a study interested in exploring these relationships. The framework has been used to guide how we conceptualize sociotechnical engineering. The instrument used for this study included items and constructs that align with all three dimensions of Fila et al.'s [1] framework.

Methods

Survey responses collected from undergraduate engineering students were analyzed using exploratory factor analysis (EFA) to expose latent factors related to students' attitudes toward and perceptions of engineering, which align with the conceptual 'engineering *for*, *with*, *as* people' framework proposed by [1]. Building on that work, which is described briefly below and more fully in [68], SEM was used to examine the relationships among those latent factors, and to explore how these relationships may change depending on students' gender and exposure to sociotechnical engineering coursework. The subsequent sections detail the study's instrument, participants, analysis, and limitations.

Instrument

The instrument used in this study included Likert-type items from two previously validated instruments. Eight items asking students about the importance of various professional skills in engineering were selected from the Engineering Professional Responsibility Assessment (EPRA) tool [69]; these item responses were on a 7-point scale, ranging from "very unimportant" to "very important." Twenty-one items asking students about their attitudes toward feeling a sense of belonging, their academic abilities, and the engineering discipline were adapted from the Engineering Attitudes Questionnaire [46],[70]; these responses were based on a 5-point scale, ranging from "strongly disagree" to "strongly agree." Psychometric analysis was conducted on the instrument [68]. A six-factor structure that aligns with Fila et al.'s [1] engineering *for*, *with*, and *as* people framework was determined through exploratory factor analysis. Three factors align with the engineering *as* people dimension, describing students' attitudes related to their: (1) *sense of belonging in engineering* (6 items); (2) *academic self-confidence and self-efficacy* (6 items); and (3) *attitudes toward persisting and succeeding in engineering* (3 items). The other three factors captured students' perceptions of engineering. Two factors aligned with both the engineering *for* and *with* people dimensions, focusing on students': (4) *understanding of the broad nature of engineering* (3 items) and (5) *appreciation of the importance of non-technical skills in engineering* (9 items). The final factor focused on students' (6) *appreciation of technical skills in engineering* (2 items). Internal consistency reliability coefficient (i.e., Cronbach's alpha) values for the entire instrument (0.909) and all six factors (ranging from 0.751 to 0.878) were above the minimum acceptable level for social science questionnaires [71].

In addition to the Likert-type items, students were asked a series of demographic questions and were invited to complete several free-response questions, including one which described the definition of a sociotechnical course and asked them to self-report any courses they had previously or were currently taking that they believed were sociotechnical.

Participants

All undergraduate engineering students enrolled at a small, private, research-based technical university in the U.S. were invited to complete the questionnaire at the end of the spring 2022 semester. Once the data were cleaned using a procedure described by [72], 314 responses remained. Relevant sample characteristics are described in Table 1.

According to ABET requirements [73], engineering students at this university undergo exposure to sociotechnical engineering, either through specific courses or by encountering sociotechnical content in other engineering classes. A first-year engineering course that primarily focuses on sociotechnical themes is required for all engineering majors except those enrolled in the university's honors curriculum, which in and of itself addresses sociotechnical themes through a series of required courses. Notably, 221 students reported taking at least one sociotechnical engineering course, including senior capstone design, the first-year engineering course, and elective courses in specific subdisciplines, while 81 students responded that they had not taken any sociotechnical coursework. After examining these 81 questionnaires more closely, given the required first year sociotechnical engineering course, a decision was made to assume that all had misunderstood the question and had, indeed, been exposed to one sociotechnical course. For analysis, two exposure levels were established: those with one course (S=1), including the 81 misreporting students (n = 279: 94 female, 179 male), and those with more than one course (S>1; n = 35: 13 female, 21 male).

Table 1: Sample Characteristics - Gender and Exposure to Sociotechnical Engineering Courses

Gender (total)	Exposure to Sociotechnical Courses		
	S=1	S>1	S>1 upsampled*
Male (200)	179	21	50
Female (107)	94	13	60
Prefer not to say (7)**	**	**	**
Total (314)	279	35	

Table notes:
*Given the large difference in sample size between students who took one and those who took more than one sociotechnical engineering course, a statistical procedure called 'Synthetic Minority Over-sampling Technique' was used to artificially increase the sample size. This procedure is described and justified below.
**Because so few students were in this category, we confined our study to those who described themselves as either male or female.

Upsampling:

After filtering the data for male or female students with more than one sociotechnical course, the number of observations becomes fewer than the number of variables. This prevents us from utilizing SEM for these two subgroups. To address this limitation, we used the Synthetic Minority Over-sampling Technique (SMOTE) [74] to enlarge the size of the data in each of these subgroups. SMOTE generates synthetic samples by interpolating between the minority cases and their nearest neighbors to upsample the existing data. More comprehensive illustrations of SMOTE and its application in social sciences and biological studies can be found [75]-[78]. In this study SMOTE was utilized to adjust the sample sizes for both subgroups of male and female students with more than one sociotechnical course and increased the size of each group to 50 and 60 students, respectively. Technically speaking, we upsampled more than the minimum number required for a SEM analysis to ensure that our analysis not only meets the foundational prerequisites for SEM but also provides a greater margin of confidence in the structural relationships observed within the male and female groups.

SMOTE is a well-accepted method for upsampling in machine learning and data science, but it's important to note that it adds some artificial observations into the dataset. While generating some "fake" data allows for the effective utilization of SEM in this study and we can still interpret the results, SMOTE may not precisely represent true observations. Therefore, we should be mindful of the inherent artificial nature of the added data.

Analysis

EFA is a common technique in multivariate statistics to discover the latent (unobserved) components and correlations between observed data to better understand the underlying structure of the model. EFA classifies observed variables into groups (unobserved variables), such that these groups influence the observed variables as shown in Figure 1. As we can see in Figure 1, these relationships exist between the unobserved variables and the observed variables [79]. The first step in EFA is identifying the number of unobserved variables (i.e., factors). The estimated number of factors is determined through the scree plot. The scree plot is created by computing the eigenvalues of the correlation matrix sorted from largest to smallest. The second step is identifying the relationship between each unobserved variable and the observed variables and are computed by their regression coefficients. These relationships between each unobserved variable and observed variable are depicted as arrows, and they can be quantified by their regression coefficients.

EFA assumes that unobserved variables do not influence each other. This may not be an appropriate assumption since the latent variables may exhibit some interconnection in real-world problems. To address this limitation, we can utilize SEM, which extends the capabilities of EFA by not only considering the factor loadings in the measurement model but also estimating the relationships among the unobserved variables [80]. SEM provides the estimation of relationships between latent variables, as well as an evaluation of the overall model fit, along with the statistical evidence for the validity of the hypothesized relationships [81]. This extension enables hypothesis testing and model validation in a single analytical framework to dig deeper than through an entire exploratory analysis.

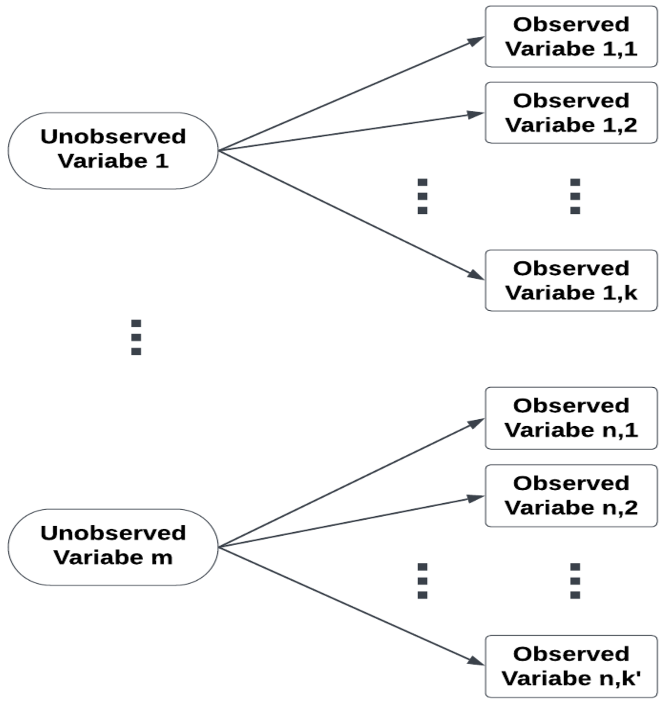

Figure 1: EFA model. Each unobserved variable influences the observed variable by a loading factor, shown as an arrow. There are no interrelationships between the unobserved variables.

SEM is a system of equations that expresses the relationships between observed variables and also unobserved variables. Let Y be a vector of observed variables, X be a matrix of latent variables, B be a vector of coefficients, and E be a vector of error terms. Mathematically, the structural model is represented as $Y = BX + E$ and is characterized by two key components: (i) the measurement model, which shows the relationships between unobserved and observed variables by factor loadings, and (ii) the structural model, which defines the relationships among unobserved variables [80]. The model is estimated through iterative procedures that involve techniques such as the maximum likelihood estimation [81]. The flexibility of SEM makes it a powerful statistical method to specify intricate relationships and validate complex theoretical substructure in many fields [82].

In this study, five of the six latent factors underlying different facets of students' perceptions and attitudes toward engineering and sociotechnical understanding that were extracted previously through EFA, listed below and described more fully in [68], provided the starting point for the SEM analysis.

- f1 Importance of Non-Technical Skills in Engineering
- f2 Sense of Belonging in Engineering
- f3 Academic Self-Confidence and Self-Efficacy
- f4 Understanding of the Broad Nature of Engineering
- f5 Attitudes toward Persisting and Succeeding in Engineering
- f6 Importance of Technical Skills in Engineering

Factor 6, Importance of Technical Skills in Engineering, was omitted from the SEM analysis primarily because only two survey items loaded onto this factor. While there is no strict rule for the minimum number of items that should be in each factor, a commonly suggested guideline is to have at least three items per factor to ensure more stability and reliability in factor analysis, which helps to retain more robust and interpretable results [83]. Moreover, the topic of factor 6, a students' recognition of the importance of technical skills in engineering, was deemed somewhat superfluous to this current study.

Recognizing the complexity inherent in these factors, we have utilized SEM for a more sophisticated analytical framework to examine not only the interrelations among latent constructs but also to dig deeper into the differences that may exist between male and female students in their attitudes toward engineering and sociotechnical understanding. This transition is motivated by a goal to move beyond purely descriptive analysis and gain a more comprehensive understanding of the factors influencing how both male and female students perceive engineering and its sociotechnical aspects. We first applied SEM to the entire sample of 314 student responses, to develop a model that aligned with our conceptual framework and other theoretical understandings. We subsequently fit this model to subgroups of our sample to examine the differences between limited and more expansive sociotechnical exposure on both male and female students. The analysis would reveal unique patterns of associations that characterized how students of different genders interpret, internalize, and respond to the complex interplay of factors shaping their perspectives on engineering.

Limitations

We recognize this study involves a few limitations. First, this study is limited by the case-based nature of the data that were used; data were collected from only one university, which limits the generalizability and replicability of our findings. Second, the procedure used to determine students' exposure to sociotechnical engineering coursework was somewhat ambiguous because of students' unfamiliarity with the term "sociotechnical" and its definition; a more robust approach should be used in future research. Third, due to the instrument's design, we were not able to capture possible relationships involving students' perceptions of the technical aspects of engineering; this should be addressed in future research, considering the potential insight that could be obtained from gathering this information, including how students' perceptions of the technical aspects of engineering fare in relation to the non-technical aspects of engineering when considering these constructs' relationships with students' attitudes. Finally, since the sample sizes were low for both groups who took more than one sociotechnical engineering course, we needed to adjust the sample sizes using an oversampling technique in order to be able to create the models given the requirements for SEM. Thus, the results should be interpreted with this caveat in mind.

Results and Discussion

Figure 2 presents the path diagram that provides a visual representation of our SEM model, derived using the entire sample of 314 responses. Computed fit-indices, which are indicators for evaluating the goodness of fit in the SEM to assess the extent of agreement between the model and the observed data, are provided below:

- Comparative Fit Index (CFI), 0.866;
- Tucker-Lewis Index (TLI), 0.852;

- Root Mean Square Error of Approximation (RMSEA), 0.071;
- Standardized Root Mean Square Residual (SRMR), 0.072.

Interpretation of the goodness-of-fit measures of SEM involves consideration of commonly accepted thresholds. While the absence of universal standards makes these thresholds somewhat context-dependent, some established guidelines offer a basis for the model assessment. In terms of CFI and TLI, our model falls just below the minimum value of 0.95 which is generally considered indicative of a well-fitting model. However, an RMSEA often suggests acceptable fit when below 0.08, and an SRMR below 0.08 is commonly deemed acceptable [84]-[86]. Thus, while conventional guidelines propose specific recommended values for goodness-of-fit measures, it is pivotal to consider these recommendations as adaptable benchmarks rather than rigid criteria [81]. Despite a slight deviation of CFI and TLI from the suggested levels, they still fall within reasonable bounds. Moreover, our attention should pivot towards the broader context of our study. Acknowledging the intricate nature of real-world data, our emphasis is placed on the primary objective of our study – comparing male and female students – rather than fixating excessively on precise fit values.

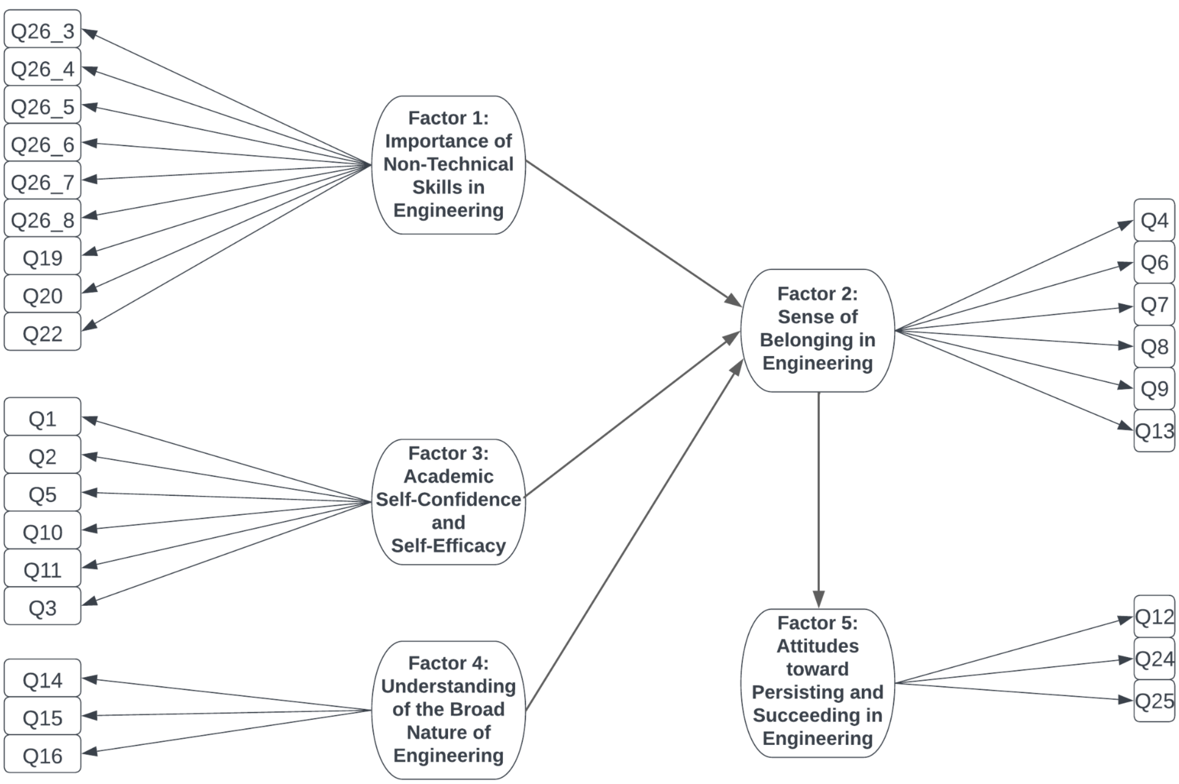

Figure 2. The diagram visually represents the relationship among latent factors and questionnaire items. Each latent factor — Importance of Non-Technical Skills in Engineering (f1), Sense of Belonging in Engineering (f2), Academic Self-Confidence and Self-Efficacy (f3), Understanding of the Broad Nature of Engineering (f4), and Attitudes toward Persisting and Succeeding in Engineering (f5) — is depicted as an oval, and the relationships between them are indicated by directional arrows.

The path diagram in Figure 2 illustrates the relationships among the five latent factors derived from the EFA, and highlights the relationships between these latent factors and the observed items. It provides a comprehensive visual representation of the intricate network of associations underpinning students' perceptions and attitudes in engineering. As shown in Figure 2, students' sense of belonging in engineering (factor 2) is influenced by their perceptions of engineering (factor 1), academic self-confidence and self-efficacy (factor 3), and understanding of the broad nature of engineering (factor 5). Students' attitudes toward persisting and succeeding in engineering (factor 5) are subsequently impacted by their sense of belonging in engineering (factor 2).

Table 2 shows the regression coefficients and p-values for each relationship, allowing us to make comparisons between various groups of students, including all male (M) vs all female (F) students, and then each gender who took one sociotechnical course (S=1) vs those who took more than one (S>1).

Table 2: Regression coefficients between latent factors for the four groups: female students who have taken one sociotechnical course (F,S=1), female students who have taken more than one sociotechnical course (F,S>1), male students who have taken one sociotechnical course (M,S=1), and male students who have taken more than one sociotechnical course (M,S>1).

Factors	**Estimate (p-value)**					
	All students		**Female Students**		**Male Students**	
	Female n=107	**Male n=200**	**=1 n=94**	**S>1 n*=60**	**S=1 n=179**	**S>1 n*=50**
Sense of Belonging in Engineering (f2) ~						
Importance of Non-Technical Skills in Engineering (f1)	0.047 (0.738)	0.101 (0.166)	0.043 (0.774)	**-0.128** (0.296)	0.105 (0.200)	**-0.583** (0.000)
Academic Self-Confidence and Self-Efficacy (f3)	0.636 (0.000)	0.509 (0.000)	0.644 (0.000)	0.900 (0.000)	0.495 (0.000)	1.438 (0.000)
Understanding of the Broad Nature of Engineering (f4)	0.387 (0.001)	0.359 (0.000)	0.371 (0.003)	**0.314** (0.007)	0.335 (0.000)	**0.998** (0.000)
Attitudes toward Persisting and Succeeding in Engineering (f5) ~						
Sense of Belonging in Engineering (f2)	0.403 (0.000)	0.556 (0.000)	**0.366** (0.000)	**0.780** (0.000)	**0.595** (0.000)	**0.173** (0.002)

Table notes:
n* denotes the sample size after up-sampling
The pairs with statistically significant differences at the 0.10 level are distinguished by different colors, in bold, for clarity and emphasis. These differences are explained as follows and discussed in context below:
– Among students who took more than one sociotechnical course, there was a significant male/female difference regarding the influence of the "Importance of Non-Technical Skills" on their "Sense of Belonging" and their "Understanding of the Broad Nature of Engineering."
– Regardless of their exposure to sociotechnical coursework, the difference between male and female students was significant regarding the influence of their "Sense of Belonging" on their "Attitudes toward persisting and succeeding in Engineering."

The results of the SEM analysis indicate that *academic self-confidence and self-efficacy* and *understanding of the broad nature of engineering* significantly influenced all students' *sense of belonging in engineering.* Compared to their male counterparts, female students' sense of academic confidence and self-efficacy has a stronger impact on fostering a sense of belonging in engineering. The larger estimate for female students implies that academic self-confidence and self-efficacy may play a particularly pivotal role in shaping the sense of belonging for women in engineering. This implies that efforts to bolster self-confidence and self-efficacy among female students may help them feel more welcome in the classroom. Similarly, female students may derive a slightly higher sense of belonging from their understanding of the broad nature of engineering compared to their male counterparts, although the difference is only slight. Faulkner [50] also found that gender-related differences in how engineers perceive the social and technical aspects of engineering could influence their sense of belonging in engineering differently.

For both male and female students, the effect of *academic self-confidence and self-efficacy* on their *sense of belonging* was greater for students who took more than on sociotechnical course (S>1) compared to those who took only 1 (S=1). This difference between S=1 and S>1 was larger for male students than female students, although the difference was not significant. Also interesting to note is that, among students who took only one sociotechnical course, the relationships were stronger for the female group, yet the opposite was true for students who took more than one sociotechnical course. Our findings overall suggest that as students are exposed to greater amounts of sociotechnical engineering coursework, their sense of belonging is more strongly impacted by their academic self-confidence and self-efficacy. In light of previous research demonstrating increases in students' self-confidence after taking a sociotechnical engineering course [43],[46],[87], we might expect that exposure to sociotechnical engineering coursework would in turn positively influence students' sense of belonging in the field, for both male and female students.

Differences in the relationship between students' *understanding of the broad nature of engineering* and their *sense of belonging* as students are exposed to more sociotechnical coursework seems to differ according to gender, with the effects increasing for male students and slightly decreasing for female students. In fact, among students who took more than one sociotechnical course, the effects of students' understanding of engineering's breadth on their sense of belonging was significantly greater for male vs female students. Previous research has shown that sociotechnical engineering courses can improve students' understanding of the broad nature of engineering (e.g., [36],[44],[46],[47]). With this in mind, the male students in our study who took more than one sociotechnical course may have gained a better understanding of the broader aspects of engineering, helping them to obtain a more holistic view of engineering, which leads to an increase in their sense of belonging in engineering. However, among female students in our study, *sense of belonging in engineering* was not influenced as much by their *understanding of the broad nature of the field*. This finding is surprising given that other researchers have determined that female students tend to place more importance on the social and contextual aspects of engineering than their male peers [21]-[23],[50]. Thus, we would expect that as female students are made more aware of the broader, social aspects of engineering through their coursework, it would strengthen the positive influence their sense of belonging in the field. Nevertheless, the positive relationship between students' understanding of engineering as a broad field, and their sense of belonging in the field, is indisputable, regardless of their gender or their exposure to sociotechnical coursework.

The impact of students' appreciation of the *importance of non-technical skills* on their *sense of belonging* in the field is somewhat variable. The relationship is negative for both male and female students who have taken more than one sociotechnical course, although the effect for female students is not significant, while the negative effect for their male counterparts is significant, and significantly stronger than for the female group. The negative effect for students with more sociotechnical coursework may result, in part, to the relative age of the two groups of students - by default, the sample of students who took more than one sociotechnical course was more heavily comprised of upperclassmen, compared to those who took only one sociotechnical course. It is known that students' awareness of and concern for the societal aspects of engineering decreases over the course of their engineering education [11],[16],[88], which may be a result of the technical focus of their curriculum (e.g. [4],[11],[89]). Thus, they likely believe that engineers perform more technical engineering work from the nature of their coursework. As they develop a greater appreciation of the importance of non-technical skills (teamwork, communication, writing) in engineering, their sense of belonging decreases because this does not align with their perception of engineering as a highly technical profession. The fact that the effect is so much more pronounced for male students could speak to the generally accepted, albeit stereotypical understanding that men tend to be drawn to the technical aspects of engineering (see for example [50]) with less appreciation for the societal context (e.g., [23]), while women are known to have more prosocial motivations for studying engineering [5],[26].

Finally, the influence of students' *sense of belonging in engineering* on their *attitudes toward persisting and succeeding in engineering* was significant for all students. This suggests that a positive sense of belonging will contribute toward a positive mindset towards persistence and success in the field, a finding that aligns with previous research (e.g. [63]-[67]). Interestingly, the impact of exposure to sociotechnical courses on this relationship is opposite for male students compared to female students. *Sense of belonging* had a stronger influence on *attitudes toward persisting in engineering* for female students who took more than one sociotechnical engineering course compared to those who only took one, while the opposite was true for male students. Moreover, the strength of the relationship between these two latent factors was significantly different across all groups: for students who took only 1 sociotechnical course, the influence was significantly greater for male vs female students; for students with more than one sociotechnical course, the influence was significantly greater for female vs male students. Sociotechnical coursework, which aligns with Fila et al's [1] engineering *as*, *for*, *with* framework for engineering education, fosters an environment that enhances students' sense of belonging - in part by providing opportunities to improve their academic self confidence. These findings suggest that for women, greater amounts of exposure to coursework that emphasizes the sociotechnical aspects of engineering may further strengthen their attitudes toward persisting and succeeding in engineering.

Given the strong and significant relationship between students' sense of belonging and their attitudes toward persisting and succeeding in engineering, the implications for the engineering education community point to the importance of providing welcoming educational experiences that foster students' sense of belonging, both in the classroom as an engineering student, and potentially as a practicing professional in the field. The results of this study indicate that providing opportunities to improve students' academic self-confidence and self-efficacy, and help them understand the broad nature of engineering, will contribute toward a positive sense of belonging in engineering for all students, regardless of gender. Sociotechnical coursework can help strengthen the connections between all students' sense of belonging and their academic self-confidence and self-efficacy, and for male students, can help strengthen the relationship between their sense of belonging and their understanding of engineering's broad nature. In effect, this study has demonstrated that students who are given multiple opportunities to engage in sociotechnical engineering coursework experience benefits that contribute toward a greater sense of belonging and positive attitude toward persisting and succeeding in engineering.

Conclusions and Future Work

This study used SEM to explore the relationships among undergraduate engineering students' attitudes toward and perceptions of engineering, as well as how these relationships differ given students' gender and exposure to sociotechnical engineering coursework. Not surprisingly, our model shows that students' *sense of belonging in engineering* contributes positively toward their *attitudes to persist and succeed in engineering*. Their sense of belonging, in turn, is influenced by their *academic self-confidence and self-efficac*y, their *understanding of the broad nature of engineering*, and to a lesser extent by their *recognition of the importance of non-technical skills in engineering*. As students experience greater amounts of sociotechnical coursework, their recognition of the importance of non-technical skills appears to negatively impact their sense of belonging, especially among male students.

Differential impacts according to gender and exposure to sociotechnical coursework were somewhat mixed. For example, *sense of belonging* had a stronger influence on *attitudes toward persisting in engineering* for female students who took more than one sociotechnical engineering course compared to those who only took one, while the opposite was true for male students. The influence of *academic self-confidence and self-efficacy* on *sense of belonging* was stronger for female vs male students, and was stronger for students who took greater amounts of sociotechnical coursework regardless of their gender. Although students' *understanding of the broad nature of engineering* significantly impacted their *sense of belonging* across all groups, the impact of more extensive sociotechnical coursework varied by gender – for female students, the strength of relationship between these two latent factors was fairly constant, while for male students it was was much stronger, and significantly greater than for their female counterparts. Thus as male students are exposed to more sociotechnical coursework, a thorough understanding of the breadth of engineering will contribute greatly to their sense of belonging, perhaps even more so than for female students. Gender differences were also found in the relationship between students' *appreciation of non-technical skills* in engineering and their *sense of belonging*. The relationship between these two factors is significantly negative for male students with more exposure to sociotechnical coursework, suggesting that as they become more aware of the importance of non-technical skills (i.e. professional skills such as communication, writing, creativity) they may feel less like they belong in the engineering profession.

Previous findings have indicated that coursework highlighting the broader social aspects of engineering can help attract and retain women, who view the social aspects of engineering as more important than do their male peers. While we found strong positive relationships among self-confidence, understanding the broad nature of engineering, sense of belonging in engineering, and attitudes toward persisting and succeeding in engineering for all students regardless of their exposure to sociotechnical coursework, our findings suggest that more extensive exposure increases the influence of academic self-confidence on their sense of belonging and, for female students, the influence of sense of belonging on attitudes to persist in engineering.

The findings of this study are limited by the study group, which consisted of undergraduate students at one university during one academic semester. Also limiting was the relatively small sample size for students who enrolled in more than one sociotechnical course, which required implementation of statistical procedures to artificially increase sample sizes so a reliable analysis could be performed. These circumstances no doubt hampered our ability to achieve a 'well-fitting' SEM model. Nevertheless, the study sheds light on initial relationships among these variables. Future work will involve a revised questionnaire with additional items to improve the model fit, as well as a more straightforward and reliable method of collecting information regarding students' exposure to sociotechnical engineering coursework. Combining this quantitative analysis with a thematic analysis of students' free responses to open-ended questions in this same survey will provide a deeper understanding of the various factors shaping students' attitudes and perceptions toward engineering.

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