2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering
Education for 130 Years
Paper ID #37724

Development of a Questionnaire to Measure Students' Attitudes and Perceptions of Sociotechnical Engineering

Felicity Bilow, Clarkson University

Felicity Bilow is a graduate student at Clarkson University.

Mohammad Meysami, Clarkson University

I am an Assistant Professor of Mathematics at Clarkson University. My research interests lie in statistics, particularly in spatial statistics and machine learning. Through my work, I aim to deepen our understanding of the intricate connections between data points in space, and to devise novel techniques for analyzing and interpreting large datasets.

Dr. Jan DeWaters, Clarkson University

Jan DeWaters is an Associate Professor in the Institute for STEM Education at Clarkson University, in Potsdam, New York. She teaches in the School of Engineering and her research area is engineering and STEM education.

Development of a Questionnaire to Measure Students' Attitudes and Perceptions of Sociotechnical Engineering

Abstract
This research paper describes the development and initial validation of a questionnaire to assess students' attitudes toward engineering and their appreciation of the sociotechnical nature of engineering. The questionnaire was developed in light of the increasing need for a diverse engineering workforce that is adequately prepared with a range of skills required to solve complex, interdisciplinary, sociotechnical engineering problems. Questionnaire data from 314 undergraduate engineering students at a small private university were used for psychometric analysis. Exploratory factor analysis (EFA) revealed a six-factor structure. Three factors relate to students' attitudes: (1) academic self-confidence and self-efficacy; (2) sense of belonging in engineering; and (3) attitudes toward persisting and succeeding in engineering. The other three factors focus on: (4) students' understanding of the broad nature of engineering; and how they appreciate the importance of (5) non-technical and (6) technical skills in engineering. Internal consistencies for each of the six subscales, measured by Cronbach's α, ranged from 0.751 to 0.878; average discrimination indices ranged from 0.509 to 0.688. The development of this questionnaire affords researchers the opportunity to more deeply explore students' attitudes toward and perceptions of engineering, as well as the relationship among these two phenomena.

Introduction and Background

A diverse pool of engineering graduates who can apply sociotechnical thinking – considering both technical and non-technical factors (social, economic, cultural, political, etc.) [1, 2] – is needed to solve complex, interdisciplinary problems that have a significant impact on society at both local and global levels (e.g., climate change, access to clean water, etc.) [3-5]. Despite calls from several professional engineering organizations and engineering educators to address these needs [5-8], engineering education has been slow to change.

Current engineering curricula in the U.S. generally focus on developing students' technical skills and knowledge [e.g., 9-14], with little emphasis on helping students recognize and fully appreciate the social implications of engineering work [9, 15-17]. Recent research has shown that students undervalue non-technical skills in engineering [17], and their sense of social responsibility and concern for public welfare decreases during their time as an engineering student [9, 18]. This is problematic given the significant societal impacts of engineering design [17, 19]. With evidence that technical engineering courses fail to raise students' awareness of the social and ethical context of engineering design [16, 20], efforts have been made to increase students' understanding of the sociotechnical nature of engineering by integrating engineering courses that highlight this relationship into the curriculum [e.g., 1, 21, 22].

Emphasizing the societal context of engineering may also help broaden participation among students from underrepresented groups, given previous research suggesting that marginalized students' attitudes toward engineering and sense of belonging may be positively impacted by integrating societal relevance into engineering coursework [23-25]. Students' attitudes (e.g., sense of belonging, self-confidence, etc.) play a major role in their decision to persist in or leave engineering [26-29]. Female-identified students' sense of belonging and self-confidence have a significant impact on their persistence [24, 30]. Engineering identity also strongly contributes to students’ desires to stay in the field [31-33]. Students who are more interested in and motivated by the social impact of engineering do not always identify as engineers [25] because of the emphasis on technical engineering work [13]. This is especially concerning in light of recent evidence suggesting that female-identified students place more importance on the sociotechnical dimensions of engineering than their male-identified peers [23, 34]. Providing students with more opportunities to engage with socially driven engineering may help broaden participation in the field because students who enter engineering with more social and altruistic motivations – oftentimes women and minority students [23-25, 35] – would develop a better understanding of engineering as a sociotechnical profession [11, 23, 36].

Knowing students from underrepresented groups often struggle with finding a sense of belonging [24, 30], and recognizing that a large majority of their coursework does not place importance on the social context of engineering [16, 20], researchers are beginning to question how we can develop engineering curricula that promotes diversity, equity, and inclusion in the classroom while simultaneously preparing students to solve complex sociotechnical problems [37]. Given the likely complex interactions between students’ attitudes toward engineering, their understanding of the sociotechnical nature of engineering, and their tendencies to persist in the field, efforts to understand the relationship among these phenomena may aid in the development of curricular approaches to make engineering education both inclusive and socially relevant. Despite recent interest in understanding students’ perceptions of the sociotechnical nature of engineering and how those perceptions relate to their engineering identity [38, 39], very little research has been done to understand how students’ attitudes are impacted by their perception of the sociotechnical nature of engineering and vice versa. Some researchers have used the terms “engineering identity” and “belonging in engineering” analogously [33, 40, 41]. However, Rohde et al. [42] investigated how design experiences – which can be considered sociotechnical – impacted first-year electrical and computer engineering students’ sense of belonging and identity and found that students do not discuss their identity and belonging in engineering as the same thing. Therefore, more research is needed to explore the relationship between how students perceive the sociotechnical nature of engineering and their general attitudes toward the field, rather than focusing narrowly on their identity.

A questionnaire has been developed to measure engineering students’ attitudes toward the field, as well as their perceptions of the sociotechnical nature of engineering problem solving and design. The questionnaire uses items from two previously vetted instruments [43-45], and builds on previous work by expanding the population of students responding to the questionnaire and analyzing the combination of items to yield a broader interpretation of student attitudes and perceptions. This paper presents the psychometric analysis used to determine the instrument’s reliability and construct validity, which was performed with exploratory factor analysis (EFA). We then investigate the degree to which the factor structure aligns with the engineering *for*, *with*, and *as* people framework developed by Fila et al. [19].

Exploratory Factor Analysis as an Analysis Tool

EFA is a commonly used technique that reduces the dimensionality of data by investigating the underlying structure of a large number of variables, such as characteristics or attributes of people that can be observed and measured. The technique has been used in a wide range of applications in the social sciences, for example, to explore relationships among socioeconomic factors and

COVID 19 [46], risk of chronic diseases [47], and aspects of child behavior [48]. It has also been used in studies measuring entrepreneur satisfaction [49], transportation studies [50], evaluating quality of work life [51], or describing the movement of free-ranging animals [52].

EFA identifies patterns of correlation among a set of observed variables to estimate underlying factors, or latent variables, that cannot be measured directly, such as depression, anxiety, and quality of life [53, 54]. The procedure ultimately specifies a number of latent variables or factors that account for the majority of variance in the data. When applied to questionnaires, individual items are associated with each factor according to a "factor loading." Calculated as standardized regression weights between items and factors, factor loadings quantify the contribution of a common factor, or latent variable, to an observed or measured variable.

Factor rotation improves interpretability of the factors by aligning them with the original variables in the questionnaire. Rotation methods vary depending on whether the factors are independent or related to each other. If the factors are independent, orthogonal rotation is used, whereas, if the factors are correlated, oblique rotation is utilized. Oblique rotation takes into account the correlation coefficients between each item and factor and the regression coefficients for each item on each factor, thus the correlations between items and factors differ from the corresponding regression coefficients. In contrast, orthogonal rotation assumes that the factor loading is equal to the correlation between the factor and the variable, which is the same as the regression coefficients [53].

The factor structure provides a way to focus on specific groups of variables, in order to identify patterns that may be obscured when analyzing all variables together. Furthermore, when applied to questionnaires, EFA provides a more in-depth understanding of the underlying dimensions in each factor group and the extent to which each factor is related to the questionnaire items. This can be useful for identifying specific areas of improvement in the questionnaire or for understanding unique characteristics of different subpopulations.

Conceptual Framework

Fila et al. [19] developed a framework that applies a humanistic lens to engineering and engineering education, placing people as the centerpiece of engineering work. The framework views engineering *for*, *with*, and *as* people. Engineering *for* people recognizes the societal context in which engineering takes place; engineering designs and solutions serve society, and social (non-technical) factors cannot be separated from the technical [1, 2, 55]. Engineering *with* people refers to the collaboration and teamwork integral to engineering work, since engineers work with others – stakeholders, colleagues, communities, etc. – to design solutions [e.g., 56, 57]. Engineering *as* people acknowledges the fact that engineers are individuals who have their own set of "knowledge, skills, beliefs, and values" [19, p. 1], which impact their experiences in engineering and the design solutions they develop. Throughout students' education, they are learning what is/is not accepted in the culture of engineering, while also developing their own engineering identities and feelings of belonging based on these experiences [31, 58]. Fila et al.'s three-dimensional framework provides a structure for understanding the sociotechnical nature of engineering. The questionnaire developed in this research addresses students' perceptions across all three dimensions.

Methods

Survey Items

The questionnaire was adapted from two previously vetted instruments: the Engineering Attitudes Questionnaire [43, 44] and the Engineering Professional Responsibility Assessment (EPRA) tool [45]. The Engineering Attitudes Questionnaire has been used to explore first-year engineering students' attitudes toward and understanding of engineering, and how those change over the first months of their university experience [43, 59-61]. We extracted 25 Likert-type statements that focused on students' feelings toward their academic performance, their sense of belonging in engineering, and their attitudes about engineering. The items used a 5-point response scale ranging from "strongly disagree" to "strongly agree." The EPRA tool is a multidimensional instrument that was designed to investigate students' social responsibility, and has been used to examine changes over time [18] and differences among various subgroups, including gender, student major, and engineering discipline [62, 63]. We adapted eight items from the EPRA tool that asked students to rate the importance of a variety of engineering skills, using a 7-point Likert-type response scale ranging from "very important" to "very unimportant."

Sample

A sample of 468 undergraduate engineering students enrolled at a small private research-based technical university completed the questionnaire at the end of the Spring 2022 semester. After cleaning the dataset using a process described by Leiner [64], 314 responses were retained for analysis. Participant characteristics are included in Table 1. Among the participants, 227 (72%) reported that they had taken a sociotechnical engineering course. Most engineering students are required to take a first-year sociotechnical engineering course at the university this study was conducted at, which is likely contributing to the high percentage of students reporting taking a sociotechnical engineering course.

Table 1. Participant Characteristics

Category	**n**	**%**
Gender		
Females	107	34.1
Males	200	63.7
Non-binary	1	0.3
Prefer not to say	6	1.9
Class Year		
First-year	76	24.2
Sophomore	60	19.1
Junior	79	25.2
Senior	96	30.6
Super Senior	3	0.9
Major		
Civil Engineering	50	15.9
Environmental Engineering	20	6.4
Civil & Environmental Engineering	9	2.9
Chemical Engineering	52	16.6
Mechanical Engineering	97	30.9

Table 1 (continued)

Aeronautical Engineering	15	4.8
Mechanical & Aeronautical Engineering	22	7.0
Electrical Engineering	24	7.6
Computer/Software Engineering	24	7.6
Engineering Studies	1	0.3

Item Analysis

Student responses to each item were assigned numerical codes to enable the calculation of summated rating totals for each subscale or factor group. Codes were assigned according to a preferred response direction, ranging from 1 (least preferred) to 5 (most preferred) for the Attitude items and from 1 (least preferred) to 7 (most preferred) for the Skills items.

The item analysis included a combination of statistical analysis with qualitative evaluation of each item's contribution to the overall objectives of the questionnaire. Statistical procedures, performed with IBM's Statistical Package for Social Sciences (SPSS), involved evaluation of each items' discrimination index, as specified by the corrected item-total correlation coefficient, and each item's contribution to the scale's internal consistency reliability, as indicated by Cronbach's alpha. SPSS was also used to assess the internal reliability (Cronbach's α) of each subscale or factor, since it is critical to compute and report the internal consistency reliability of both the scale and subscales when using Likert-type surveys [65].

Factor Analysis

We performed exploratory factor analysis (EFA) according to a series of steps, including data preparation, factor extraction, and factor rotation. The statistical software R version 4.1.2 was used for the analysis, along with the following libraries in our coding: tidyverse, ggfortify, cluster, RcmdrMisc, and psych. We began by checking for missing data and ensuring all variables were suitable for factor analysis. A correlation check revealed that there were no pairs with a correlation larger than 0.90. Two tests were performed to ensure that the data were suitable for EFA: the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of Sphericity. The KMO test evaluates how well the factors explain each other, producing a number between 0 and 1 to represent the sampling adequacy of each variable in the model and the full model. A score between 0.80 and 1 indicates that the sampling adequacy is satisfactory, while a score less than 0.5 is considered unacceptable; our analysis yielded a value of 0.91. Bartlett's test, on the other hand, compares the correlation matrix to an identity matrix to evaluate the sphericity of the correlation matrix, that is, H_0: correlation matrix = identity matrix, vs. H_1: correlation matrix ≠ identity matrix. A significant statistical test is desired, indicating some correlation among items. For our analysis, the p-value associated with Bartlett's test was extremely small ($p < 0.001$), $\chi^2 = 3300$, indicating there are correlations among items.

Factor extraction was then used to identify the factors that explain the most variance in the data. Eigenvalues, which indicate the relative importance of each factor, can be used to decide how many factors should be retained in the model. EFA only uses factors with the highest eigenvalues, typically greater than one. Alternatively, Catell [66] proposed using a scree plot – which is a scatterplot showing the eigenvalue of each factor on the y-axis vs. the factor number on the x-axis. The ideal number of factors to retain in the model is revealed by the "elbow point" of the curve, where the relative change in eigenvalue with each increasing number of factors diminishes rapidly. This indicates that adding an additional factor to the model contributes only minimally to explaining the variance of the data. In our analysis, based on information from both the eigenvalues and the scree plot, we chose to compare the relative usefulness and fit of a range of models with 3, 4, 5, and 6 factors. The adequacy of each model was investigated with a combination of statistical measures as well as qualitative evaluation of the relative contribution of each additional factor to improving our ability to interpret and use information from the instrument. Best fit statistics included root mean square error of approximation (RMSEA), Tucker Lewis Index (TLI), and a Comparative Fit Index (CFI).

Factors were rotated prior to aligning them with the original questionnaire items. Oblique rotation was used as we believed that the underlying factors are not independent and have some relationships among them; a suspicion that was confirmed with our results. The result yielded a factor solution that represents the underlying dimensions of the questionnaire and provides a clear understanding of the relationship among the items in the questionnaire. These findings are presented as a factor loading matrix and the path diagram of the model. The technical aspects of these steps are explained in the next section.

Results

Item Analysis

Each item was evaluated for its individual value as well as its consistency with the rest of the instrument and, ultimately, its contribution to the instrument's overall objectives. The items as a whole were found to be internally consistent (Cronbach's $\alpha = 0.889$), satisfying the minimum acceptable value for social science surveys (>0.7) [67]. Four Attitude items did not perform well and were removed; all four failed to contribute favorably to the overall scale's reliability, and three did not discriminate well among the sample group (corrected item-total correlation coefficient was below the acceptable value of 0.20 suggested by Kline [68]). The decision to remove these four items was confirmed by results from the EFA. Three of these items were negatively worded; the inconsistency of negatively worded Likert-type items is an artifact that has been previously documented [69, 70]. The fourth item that was removed, which had a corrected item-total correlation coefficient of -0.030, asked students to indicate their agreement with the importance of two components of the engineering process simultaneously: collaboration and teamwork. We suspect that the low discrimination index resulted from students responding to one or the other of the aspects inconsistently.

The remaining 29 items yield an overall average discrimination index of 0.498 (corrected item-total correlation coefficients ranged from 0.262 to 0.656), with Cronbach's $\alpha = 0.909$. Only one item did not contribute favorably to the overall scale reliability. We decided to retain the item with low reliability (Cronbach's α when deleted = 0.910) because it provided important and useful insight into students' perceptions of engineering otherwise not covered by the other items – the importance of fundamental skills (i.e., math and science). Thus, the set of items retained for factor analysis included 21 Attitude and 8 Skills items (29 items in total).

Factor Structure

EFA was conducted in an iterative process to determine the overall most suitable factor model for the questionnaire. We sought a factor structure that used a reasonably small number of factor groupings, while still ensuring that the items in each factor group were consistently aligned with a logical instrument construct. At each point in the analysis we considered the results of the item analysis for examining the relative value of retaining or rejecting each questionnaire item. Our analysis determined that a 6-factor model was most suitable for the items after comparing goodness of fit indices and the conceptual underpinnings among the four structures we explored. Details of the analysis are presented and discussed below.

The scree plot shown in Figure 1 suggests two possible models, indicated by the elbow points after factor 3, where the slope changes rapidly, and again after factor 6, where the line becomes almost flat. Alternatively, the blue dashed line, located at an eigenvalue equal to one, suggests that three factors should be considered in the model. Based on this information, we performed EFA with three, four, five, and six factors and compared them to select the most adequate model.

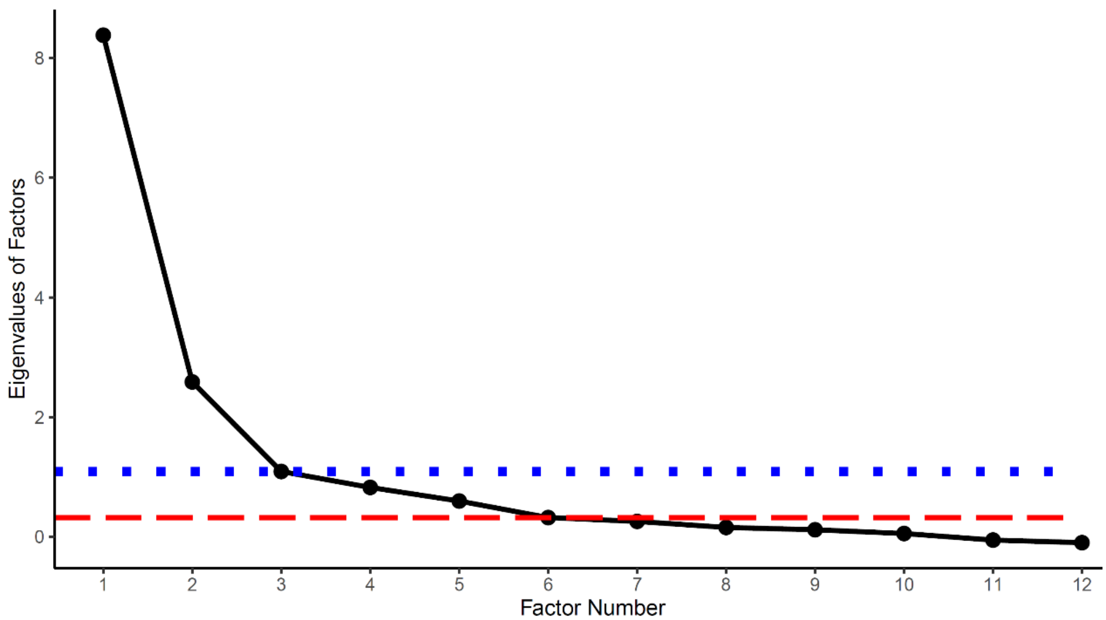

Figure 1. Scree plot. Red dotted line (longer dash length) indicates inflection point where line becomes nearly flat; blue dotted line (shorter dash length) is at eigenvalue equal to 1.

Table 2 compares the four models based on their best fit statistics. As the number of factors increases, so does the model fit. RMSEA values between 0.5 and 0.8 specify an acceptable model fit [71], which the 4-, 5-, and 6-factor models meet. A TLI of 0.9 or greater [72] and a CFI of 0.95 or greater indicate a good model fit [72, 73]; only the 6-factor model satisfies both of these requirements. From a statistical point of view, the 6-factor model is the most suitable.

Table 2. Model Fit Statistics Comparisons

Model	χ^2	**df**	**p-value**	**RMSR**	**TLI**	**RMSEA**	**CFI**
3-factor	1081.51	322	8.15E-83	0.059	0.767	0.087	0.820
4-factor	780.41	296	2.65E-45	0.048	0.838	0.072	0.886
5-factor	608.40	271	5.74E-28	0.036	0.876	0.063	0.921
6-factor	457.04	247	1.03E-14	0.033	0.915	0.052	0.951

Figure 2 displays the distribution of items among three, four, five, and six factors, respectively. Item numbers are colored to correspond with the factor grouping in the 6-factor model, to more easily demonstrate how the items and factors shifted throughout the iterative analysis. For the 3-factor model, items related to students' attitudes, such as their academic self-confidence and self-efficacy (Q1, Q2, Q5, Q10, Q11), sense of belonging in engineering (Q4, Q6, Q7, Q8, Q9), and attitudes toward persisting/succeeding in engineering (Q12, Q24, Q25), grouped together in Factor 1. Factor 2 included items related to students' attitudes toward the broad nature of engineering (Q19, Q20, and Q22), along with eight items that asked students to rate the importance of various skills to engineering (Q26_1 through Q26_8). Factor 3 contained one item that focused on students' problem solving knowledge (Q3), one that addressed students' ability to picture themselves as an engineer (Q13), and a group of items about their understanding of the broad nature of engineering (Q14, Q15, Q16). Adding a fourth factor separated Factor 1 so the sense of belonging in engineering items moved into Factor 3 along with Q13, which made sense since "picturing yourself as an engineer" is related to having a sense of belonging in the field. The remaining items in Factor 3 related to problem solving knowledge and understanding the broad nature of engineering were shifted into Factor 4. The 5-factor model subsequently separated the skills items in Factor 2 that focused on the importance of technical skills in engineering (Q26_1 and Q26_2, now in Factor 5) from those that focused on the importance of non-technical skills (Q26_3 through Q26_8), which remained together with the items related to students' attitudes toward the broad nature of engineering in Factor 2. Adding a sixth factor managed to distinguish the items in Factor 1 related to students' attitudes toward persisting and succeeding in engineering from those focusing on students' academic self-confidence and self-efficacy (Factor 5 and Factor 3, respectively, in the 6-factor model). Q3, which loaded onto two different factors in the 6-factor model - Factor 4 (0.46) and Factor 3 (0.40) - was placed in Factor 3 because of the similarities between students' self-perceived problem solving capabilities and their academic self-confidence and self-efficacy. Ultimately, we determined the 6-factor model was the most appropriate for the data, not only because of the statistical best fit indices, but also because it aligned with our conceptual understandings. The model places the questionnaire items into six factor groups according to the following topics:

1. How students appreciate the importance of non-technical skills in engineering (9 items)
2. Students' sense of belonging in engineering (6 items)
3. Students' academic self-confidence and self-efficacy (6 items)
4. Students' understanding of the broad nature of engineering (3 items)
5. Student attitudes toward persisting and succeeding in engineering (3 items)
6. Students' perception of the importance of technical skills in engineering (2 items).

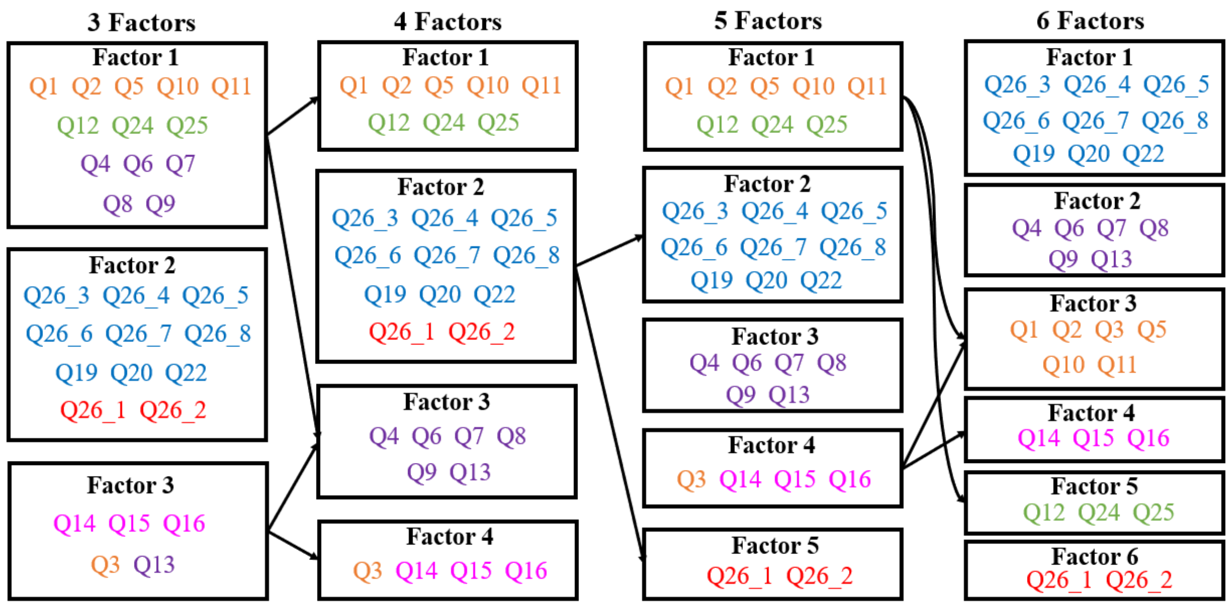

Figure 2. Distribution of questionnaire items among the factor groups, according to the 3-, 4-, 5-, and 6-factor EFA analyses.

Factor loadings for each item are presented in Figure 3. Factor 1 assesses students' *appreciation of the importance of non-technical skills in engineering* (i.e., professional, social, cultural awareness, ethics, creativity, etc.). Factor 2 focuses on students' *sense of belonging in engineering*, related to their satisfaction with their decision to study engineering, and their beliefs on if engineering is a career where they would be able to use their talents, feel like they belong, and look forward to working in. Factor 3 depicts students' *academic self-confidence and self-efficacy*, in terms of their confidence in their engineering problem solving abilities, academic performance, and confidence in succeeding in a college curriculum. Factor 4 characterizes students' *understanding of the broad nature of engineering*, with respect to how they understand the relationship between engineering and society and how engineers work with others. Factor 5 describes students' *attitudes toward persisting and succeeding in engineering*, in regard to students' beliefs about their engineering capability, their confidence in succeeding in an engineering curriculum, and maintaining their engineering major throughout their education. Finally, Factor 6 examines students' *appreciation of the importance of technical skills in engineering*, in terms of how they value fundamental (math and science) and technical skills in engineering.

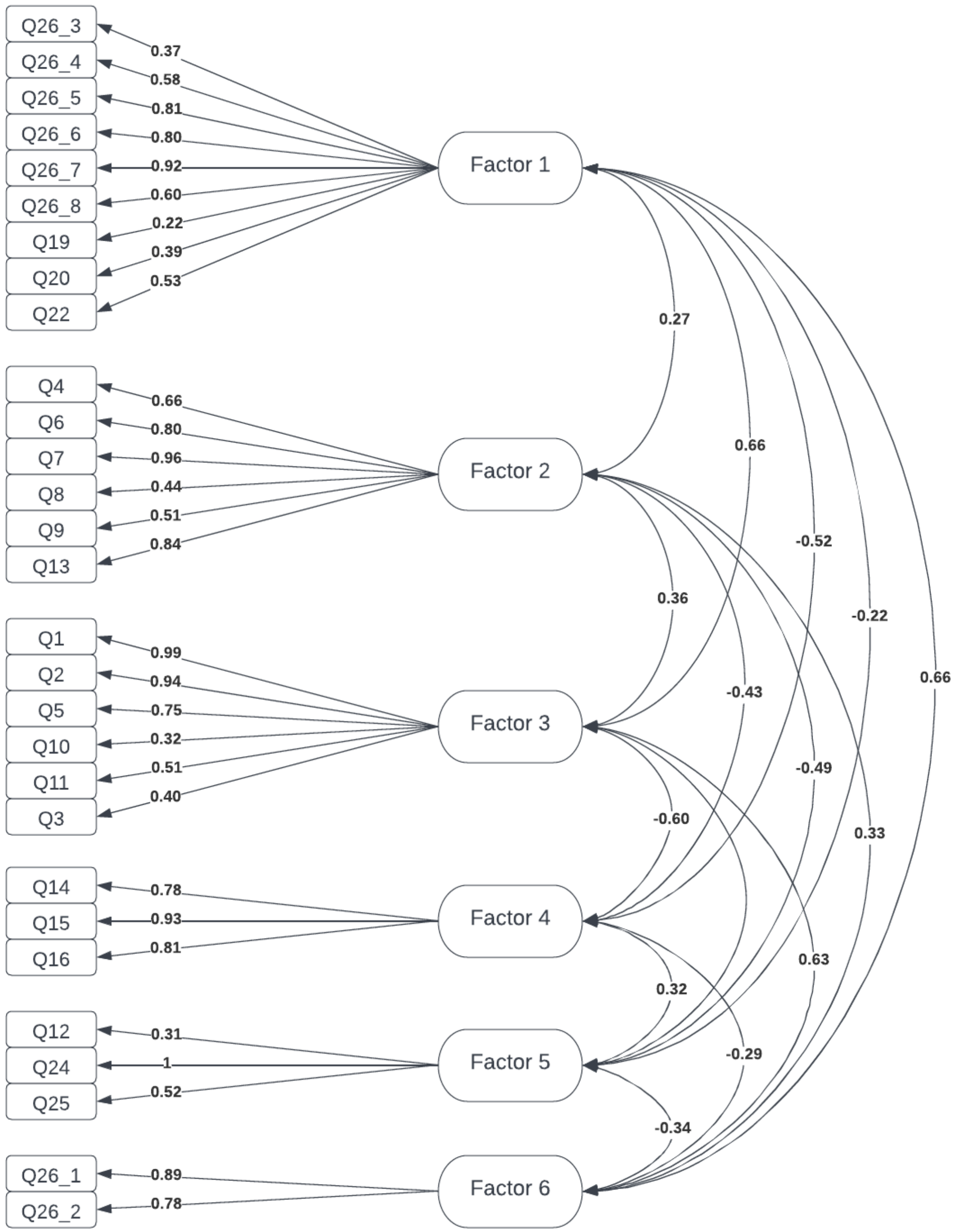

Figure 3. Path diagram of the 6-factor EFA model. Values indicate factor loadings (on the left) and factor correlation coefficients (on the right).

Table 3 provides the internal consistency reliability (i.e., Cronbach's α) and discrimination indices for each factor. Cronbach's α values exceed minimum acceptable criteria with values ranging from 0.751 to 0.878 [67]. Discrimination indices, measured by the corrected item-total correlation coefficient, were all well above acceptable values [68].

Table 3. Item Reliability Statistics by Factor

Item #	**Item Text**[a]	**Corrected Item-Total Correlation Coefficient**	**Cronbach's α if Item Deleted**
Factor 1: Importance of Non-Technical Skills in Engineering		**0.562**	**α = 0.839**
Q19	Creativity is important to the engineering process.	0.414	0.836
Q20	Engineering decisions are influenced by the societal context in which they take place.	0.418	0.836
Q22	Ethical problem solving is an important part of engineering design.	0.526	0.827
Q26_3	Business Skills (i.e., Business Knowledge, Management Skills, & Professionalism)	0.466	0.832
Q26_4	Professional Skills (i.e., Communication, Contemporary Issues, Creativity, Leadership, Life-Long Learning, & Teamwork)	0.612	0.817
Q26_5	Cultural Awareness/Understanding (i.e., of your culture, and those of others)	0.643	0.815
Q26_6	Ethics (i.e., ensuring all of your work follows professional codes of conduct)	0.679	0.808
Q26_7	Societal Context (i.e., how your work connects to society and vice versa)	0.763	0.797
Q26_8	Volunteerism (for professional and personal reasons)	0.534	0.829
Factor 2: Sense of Belonging in Engineering		**0.688**	**α = 0.878**
Q4	At the present time, I am satisfied with my decision to study engineering.	0.681	0.857
Q6	A degree in engineering will allow me to get a job where I can use my talents and creativity.	0.703	0.854
Q7	I look forward to a career in engineering.	0.741	0.847
Q8	I feel confident working as a member of a team.	0.633	0.865
Q9	I will feel "part of the group" (i.e., I will fit in or feel like I belong to the community of engineering) if I get a job in engineering.	0.624	0.870
Q13	I can picture myself working as an engineer.	0.743	0.848
Factor 3: Academic Self-Confidence and Self-Efficacy		**0.614**	**α = 0.835**
Q1	On the whole, I am pleased with my performance as a student.	0.648	0.800
Q2	I feel confident that I will succeed in a college curriculum.	0.692	0.794
Q3	I know a lot about using different methods to solve a new problem or tackle a challenge.	0.495	0.829

Table 3 (continued)

Q5	I feel that I am at least as capable as other students in my classes.	0.668	0.796
Q10	I feel confident about applying a systematic process to solve an unfamiliar problem.	0.564	0.817
Q11	I have a positive attitude toward myself and my abilities.	0.614	0.810
Factor 4: Understanding of the Broad Nature of Engineering		**0.509**	**α = 0.826**
Q14	I understand how engineering decisions are made.	0.659	0.784
Q15	I understand how engineers work with other professionals and technicians to solve problems.	0.727	0.716
Q16	I understand the relationship between engineering and the society in which it is practiced.	0.664	0.779
Factor 5: Attitudes toward Persisting and Succeeding in Engineering		**0.653**	**α = 0.802**
Q12	At the present time, I feel confident that I will keep my chosen engineering major throughout college.	0.501	0.877
Q24	I am capable of becoming an engineer.	0.740	0.633
Q25	I can succeed in an engineering curriculum.	0.719	0.652
Factor 6: Importance of Technical Skills in Engineering		**0.606**	**α = 0.751**
Q26_1	Fundamental Skills (i.e., Math & Science)	0.606	N/A
Q26_2	Technical Skills (i.e., Conducting Experiments, Data Analysis, Design, Engineering Tools, & Problem Solving)	0.606	N/A

Note:
[a]Attitude items Q1 through Q25 asked students to indicate their level of agreement with each statement; Skills items Q26_1 through Q26_8 asked them to indicate the level of importance of each skill to the engineering profession.

Discussion

We developed a questionnaire to measure student attitudes toward and perceptions of engineering using items adapted from two previously vetted questionnaires. The instrument's reliability and validity were confirmed through item analysis and an iterative EFA in which we explored four models, with the number of factors ranging from three to six. Most adequate was the 6-factor structure, which assesses students': (1) academic self-confidence and self-efficacy; (2) sense of belonging in engineering; (3) attitudes toward persisting and succeeding in engineering; (4) understanding of the broad nature of engineering; and perceptions of the importance of (5) non-technical and (6) technical skills in engineering.

Although the scree plot (Figure 1) conveniently suggested a 3-factor model, the three factors aligned only partially with the three dimensions of Fila et al.'s [19] engineering *for*, *with*, and *as* people framework. The first factor, which contained items focused on students' general engineering attitudes (i.e., sense of belonging in engineering, academic self-confidence and self-efficacy, and attitudes toward persisting and succeeding in engineering), fits well with the engineering *as* people dimension. This dimension takes into account that engineers are individuals who have their own skill sets and experiences in engineering, which contributes to their feelings of belonging because there are certain values and skills that are more acceptable than others [31, 58]. A diminished sense of belonging has been found to substantially influence students' decisions to leave engineering [27, 29, 74], and within STEM majors, a strong sense of belonging can lead to academic success, persistence, and interest in the field [75, 76]. Thus, students' academic self-confidence and self-efficacy, sense of belonging, and attitudes toward persisting and succeeding in engineering all align with the engineering *as* people dimension. The second factor included items that assessed students' perceptions of the sociotechnical nature of engineering, including the importance of both non-technical and technical aspects of engineering as well as the importance of teamwork and communication, thus spanning both *for* and *with* dimensions of Fila et al.'s [19] framework. Fila et al. note that all three dimensions have features that overlap with one another; for instance, engineers work *with c*ustomers, communities, and other stakeholders to design solutions *for* these communities and customers that meet their needs. The overlap of these two dimensions in the second factor reflects this dynamic. The third factor's items, collectively, represent all three dimensions of Fila et al.'s framework. Items that address students' understanding of the broad nature of engineering fit both the *for* and *with* dimensions, for example asking, "how engineering decisions are made" and "how engineers work with other professionals." Items that address students' self-perceived problem solving capabilities and the degree to which they picture themselves as engineers align with the *as* dimension.

Adding a fourth factor provided a bit more structural alignment with Fila et al.'s [19] framework. The new model pulled some of the items from Factor 1 together with one item from Factor 3 into a new factor that focused more narrowly on students' sense of belonging, leaving behind the items related to academic self-confidence and self-efficacy and persisting and succeeding in engineering. Both of these new factors still fit the *as* dimension. Factor 2 was unchanged, and Factor 3, although somewhat less diverse, still contained items spread across all three dimensions of the framework. The 5-factor model further separated items in Factor 2 related to students' perceived importance of various engineering skills into two groups: non-technical vs. technical. As such, the non-technical items in Factor 2 still spanned both the *for* and *with* dimensions of the model, while the two items related to the importance of technical skills, placed into a new Factor 5, did not truly align with the humanistic framework proposed by Fila et al. Nevertheless, we viewed the 5-factor model as an improvement because we were interested in a model that would allow us to compare and contrast students' perceived importance of both skill types.

Introducing a sixth factor into the model split Factor 1 items into two factors that more narrowly focused on students' attitudes toward persisting and succeeding in engineering (Factor 5) and academic self-confidence and self-efficacy (Factor 3). One item that addresses students' problem solving knowledge also shifted into this new Factor 3. These two factors, together with items related to sense of belonging in engineering (Factor 2), all align with the *as* dimension of the framework. The other factors in the 6-factor model include two that align with both the *for* and *with* dimensions of the framework: Factor 4, understanding the broad nature of engineering, and Factor 1, which addresses the importance of non-technical skills in engineering. It is interesting to note that a previous analysis of Canney's and Bielefeldt's [45] EPRA tool, which is the source of all eight Skills items, yielded one factor related to the importance of an engineer's "base skills," including ethics and technical, fundamental, business, and professional skills, while the other three Skills items were distributed among other factors in their model. Yet when we combined the EPRA skills items with items from the Engineering Attitudes Questionnaire, the Skills items were distributed between two distinct factors: the importance of non-technical skills in engineering (i.e., societal context, cultural awareness/understanding, professional, ethics, business, and volunteerism) in Factor 1, and the importance of technical skills in engineering (i.e., fundamental and technical) in Factor 6. Although Factor 6 does not really fit within Fila et al.'s [19] humanistic engineering framework, distinguishing this construct from the appreciation of non-technical skills helps us understand students' perceptions of the relative value of technical vs. non-technical aspects of engineering - factors that often contribute to students' interest in the field, engineering identity, and sense of belonging [e.g., 24, 25, 32].

Details provided in Table 3 allow us to explore the degree to which the questionnaire items align with the conceptual underpinnings of the 6-factor structure. <u>Factor 1</u> items all ask students about the importance of non-technical factors in engineering that are typically associated with contextual and social factors in the literature, such as teamwork, societal context, cultural awareness/understanding, ethics, and creativity [55, 77, 78]; all six items related to non-technical skills from the EPRA tool are included. The EFA revealed a few redundancies in Factor 1 among items adapted from the two different instruments that we used – for instance, Q20 and Q26_7 both ask students about the influence societal context has on engineering, Q22 and Q26_6 question the importance of ethics in engineering, and the importance of creativity is mentioned twice (Q19 and Q26_4). These redundancies will be eliminated in future iterations of the questionnaire. Items in <u>Factor 2</u> generally work together to describe students' sense of belonging in engineering, including their satisfaction with engineering, their sense of fit, and their ability to picture themselves as an engineer. One item in this factor relates to students' confidence while working in a team. Although intuitively, and despite statistical results, we might have pushed this item into Factor 3 with the other self-confidence items, the alignment with a sense of belonging makes sense given the expectations that engineering work involves collaboration - working on teams and communicating with other stakeholders [56, 57, 79, 80]. Thus, a person's confidence working as a member of a team will no doubt impact their sense of belonging in this teamwork-oriented field [40, 81, 82]. <u>Factor 3</u> items all focus on students' academic self-confidence and self-efficacy. The three items in <u>Factor 4</u> would conceptually fit within Factor 1 – they all discuss the broad nature of engineering. They may have been separated into a different factor because they all begin with the statement "I understand." Given the conceptual overlap, these items will be reworded in the next iteration of the questionnaire, to remove this clause. The three items in <u>Factor 5</u> all focus on students' attitudes toward persisting and succeeding in engineering. Finally, the two items in <u>Factor 6</u> both target students' appreciation of the importance of technical skills in engineering.

This analysis revealed several opportunities to improve the questionnaire, as summarized in the following points:

1. All items should use the same Likert-type response scale, either 5-point or 7-point. This may improve the overall internal consistency reliability of the questionnaire, although the Cronbach's α values are already sufficient with the mixed scales. More importantly, a consistent scale will better facilitate the calculation and comparison of average mean

factor scores when the survey is implemented.

2. Several items can be improved with better rewording:
    a. Q18 - separate the terms "teamwork" and "collaboration" into individual items. This may help improve the item's low discrimination index.
    b. Re-write negatively worded items to be the exact opposite, or antonym, of a positively worded item [83], thereby creating positive/negative item pairs. For example, positively worded item: "Engineering decisions are influenced by the societal context in which they take place"; negatively worded antonym: "Engineering decisions are **not** influenced by the societal context in which they take place."
    c. Items in Factor 4, understanding the broad nature of engineering, all begin with "I understand." Rewording these items may give a more accurate breakdown of students' sense of engineering's broad, sociotechnical nature, and the specific nontechnical skills included in Factor 1 (e.g., Q20). The relatively strong correlation between these two factors supports this recommendation ($r = 0.52$).
3. The addition of more items related to non-technical factors, such as environmental and political context, may help develop an even deeper understanding of how students perceive the non-technical, contextual, and social aspects of engineering.
4. The addition of more items related to the technical side of engineering [e.g., 55] would increase the number of items in Factor 6; guidelines recommend having more than two items in one factor [84, 85].
5. Redundancies between some of the skills questions and the corresponding attitude items should be eliminated:
    a. Q22 and Q26_6 both concern the importance of ethics in engineering.
    b. Q20 and Q26_7 both concern the influence of societal context in engineering.
    c. Q19 asks students about the importance of creativity in engineering and one of the skills included in Q26_4 (Professional Skills) is creativity.

This questionnaire has potential applications in a variety of educational contexts, including those that explore attitudes and perceptions among a given population as well as those that measure the impact of an educational intervention. For instance, it could be used to investigate the impact of a sociotechnical course, or a case study highlighting the sociotechnical context of engineering, on students' general attitudes toward and perceptions of engineering. The questionnaire could also be applied to a longitudinal study examining the relationship between students' attitudes toward and perceptions of engineering and how those change over the course of their engineering education.

Conclusions and Future Work

Our findings suggest that this questionnaire has the potential to be a valid and reliable instrument for measuring and understanding the relationship between students' general attitudes toward and perceptions of engineering. After performing EFA, we found that the items focus on students': (1) academic self-confidence and self-efficacy; (2) sense of belonging in engineering; (3) attitudes toward persisting and succeeding in engineering; (4) understanding of the broad nature of engineering; and appreciation of the importance of (5) non-technical and (6) technical skills in engineering. We determined that some of these six factors align with the three dimensions described in Fila et al.'s [19] engineering *for*, *with*, and *as* people framework. A few revisions to the questionnaire would lead to a more robust instrument. There are several applications in which this questionnaire could be used, including a pre-/post-study for a sociotechnical course. Gaining a deeper understanding of the relationship between engineering students' attitudes and how they perceive engineering has the potential to help create a more inclusive engineering curriculum and educational experience for all students, while possibly having far-reaching impacts on the culture of engineering in general.

This questionnaire is a part of a larger on-going mixed-methods study that explores the relationship between student exposure to sociotechnical coursework and their general attitudes toward and sense of belonging in engineering. Future research will examine differences among various subgroups displayed in Table 1 using questionnaire and semi-structured interview data. The questionnaire data will be used in confirmatory factor analysis and other structural equation modeling techniques to further validate the instrument and analyze the relationships among the constructs. We also plan to include another iteration of data collection and analysis using a revised questionnaire, based on improvements noted in this current exploratory analysis.

References

[1] G. D. Hoople, D. A. Chen, S. M. Lord, L. A. Gelles, F. Bilow, and J. A. Mejia, "An Integrated Approach to Energy Education in Engineering," *Sustainability,* vol. 12, no. 21, 2020.

[2] B. Cohen, J. S. Rossmann, and K. L. S. Bernhardt, "Introducing Engineering as a Socio-technical Process," in *Proceedings of the Annual ASEE Conference & Exposition*, Indianapolis, IN, USA, 2014.

[3] United Nations. "The 17 Goals." United Nations. https://sdgs.un.org/goals (accessed: February 22, 2023).

[4] B. Amadei, "Engineering for the Developing World," in *The Bridge*, vol. 34, no. 2, Washington, DC, USA: National Academies Press, 2004, pp. 24-31.

[5] National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington DC, USA: The National Academies Press, 2004.

[6] Accreditation Board for Engineering and Technology. "Criteria for Accrediting Engineering Programs, 2022-2023." Accreditation Board for Engineering and Technology. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2022-2023/ (accessed: January 22, 2023).

[7] W. A. Wulf. "2003 Annual Meeting - President's Remarks." National Academy of Engineering. https://www.nae.edu/8647/page2003AnnualMeeting-PresidentsRemarks (accessed: January 21, 2023).

[8] A. L. Pawley, "'Asking questions, we walk': How should engineering education address equity, the climate crisis, and its own moral infrastructure?," *Journal of Engineering Education,* vol. 108, no. 4, pp. 447-452, 2019.

[9] E. A. Cech, "Culture of Disengagement in Engineering Education?," *Science Technology Human Values,* vol. 39, no. 1, pp. 42-72, 2014.

[10] E. A. Cech and H. M. Sherick, "Depoliticization and the Structure of Engineering Education," in *International Perspectives on Engineering Education*, S. H. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham and B. Newberry, Eds., Cham, Switzerland: Springer, 2015, pp. 203-216.

[11] N. P. Gaunkar, N. Fila, and M. Mina, "Broadening Engineering Perspectives by Emphasizing the Human Side of Engineering," in *Proceedings of the Annual IEEE Frontiers in Education (FIE) Conference*, Virtual Conference, 2020.

[12] W. Faulkner, "Dualisms, hierarchies, and gender in engineering," *Social Studies of Science,* vol. 30, no. 5, pp. 759-792, 2000.

[13] W. Faulkner, "'Nuts and Bolts and People': Gender-Troubled Engineering Identities," *Social Studies of Science,* vol. 37, no. 3, pp. 331-356, 2007.

[14] J. A. Leydens and J. C. Lucena. *Engineering Justice: Transforming Engineering Education and Practice*. Piscataway, NJ, USA: IEEE Press, 2018.

[15] W. E. Kastenberg, G. Hauser-Kastenberg, and D. Norris, "An approach to undergraduate engineering education for the 21st century," in *Proceedings of the Annual IEEE Frontiers in Education (FIE) Conference*, San Diego, CA, USA, 28-31 Oct., 2006.

[16] M. C. Loui, "Ethics and the development of professional identities of engineering students," *Journal of Engineering Education,* vol. 94, no. 4, pp. 383-390, 2006.

[17] S. Niles, S. Contreras, S. Roudbari, J. Kaminsky, and J. L. Harrison, "Resisting and assisting with public welfare in engineering education," *Journal of Engineering Education,* vol. 103, no. 3, pp. 491-507, 2020.

[18] A. R. Bielefeldt and N. E. Canney, "Changes in the Social Responsibility Attitudes of Engineering Students Over Time," *Science and Engineering Ethics,* vol. 22, no. 5, pp. 1535-1551, 2016.

[19] N. D. Fila, J. Hess, A. Hira, C. H. Joslyn, D. Tolbert, and M. M. Hynes, "The People Part of Engineering: Engineering For, With, and As People," in *Proceedings of the Annual IEEE Frontiers in Education (FIE) Conference*, Oklahoma City, OK, USA, Oct. 2014.

[20] J. C. Lucena and J. A. Leydens, "From Sacred Cow to Dairy Cow: Challenges and Opportunities in Integrating of Social Justice in Engineering Science Courses," in *Proceedings of the Annual ASEE Conference & Exposition*, Seattle, WA, USA, 2015.

[21] D. DiBiasio, C. Hill, and N. Mello, "Work in Progress: Crossing Technical, Social and Cultural Borders within the Engineering Classroom," in *Proceedings of the Annual IEEE Frontiers in Education (FIE) Conference*, San Diego, CA, USA, 28-31 Oct., 2006.

[22] J. A. Leydens, K. E. Johnson, and B. M. Moskal, "Engineering student perceptions of social justice in a feedback control systems course," *Journal of Engineering Education,* vol. 110, no. 3, pp. 718-749, 2021.

[23] D. Kilgore, C. J. Atman, K. Yasuhara, T. J. Barker, and A. Morozov, "Considering Context: A Study of First-Year Engineering Students," *Journal of Engineering Education,* vol. 96, no. 4, pp. 321-334, 2007.

[24] I. J. Busch-Vishniac and J. P. Jarosz, "Can Diversity in the Undergraduate Engineering Population Be Enahnced Through Curricular Change?," *Journal of Women and Minorities in Science and Engineering,* vol. 10, no. 3, pp. 255-281, 2004.

[25] K. Litchfield and A. Javernick-Will, ""I Am an Engineer And": a Mixed Methods Study of Socially Engaged Engineers," *Journal of Engineering Education,* vol. 104, no. 4, pp. 393-416, 2015.

[26] L. J. Shuman, C. Delaney, H. Wolfe, and A. Scalise, "Engineering Attrition: Student Characteristics and Educational Initiatives," in *Proceedings of the Annual ASEE Conference & Exposition*, Charlotte, NC, USA, 1999.

[27] B. N. Geisinger and D. R. Raman, "Why They Leave: Understanding Student Attrition from Engineering Majors," *International Journal of Engineering Education,* vol. 29, no. 4, pp. 914-925, 2013.

[28] M. Meyer and S. Marx, "Engineering Dropouts: A Qualitative Examination of Why Undergraduates Leave Engineering," *Journal of Engineering Education,* vol. 103, no. 4, pp. 525-548, 2014.

[29] R. M. Marra, K. A. Rodgers, D. Shen, and B. Bogue, "Leaving Engineering: A Multi-Year Single Institution Study," *Journal of Engineering Education,* vol. 101, no. 1, pp. 6-27, 2012.

[30] S. G. Brainard and L. Carlin, "A six-year longitudinal study of undergraduate women in engineering and science," *Journal of Engineering Education,* vol. 87, no. 4, pp. 369-375, 1998.

[31] K. L. Tonso, "Engineering Identity," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds., New York, NY, USA: Cambridge University Press, 2014, pp. 267-282.

[32] D. Chachra, D. Kilgore, H. Loshbaugh, J. McCain, and H. Chen, "Being and Becoming: Gender and Identity Formation of Engineering Students," in *Proceedings of the Annual ASEE Conference & Exposition*, Pittsburgh, PA, USA, 2008.

[33] K. L. Meyers, M. W. Ohland, A. L. Pawley, S. E. Silliman, and K. A. Smith, "Factors relating to engineering identity," *Global Journal of Engineering Education,* vol. 14, no. 1, pp. 119-131, 2012.

[34] M. Swartz, J. A. Leydens, J. D. Walter, and K. Johnson, "Is Sociotechnical Thinking Important in Engineering Education?: Survey Perceptions of Male and Female Undergraduates," in *Proceedings of the Annual ASEE Conference & Exposition*, Tampa Bay, FL, USA, June 2019.

[35] A. Godwin and G. Potvin, "Fostering Female Belongingness in Engineering through the Lens of Critical Engineering Agency," *International Journal of Engineering Education,* vol. 31, no. 4, pp. 938-952, 2015.

[36] C. Swan, K. Paterson, and A. R. Bielefeldt, "Community Engagement in Engineering Education as a Way to increase Inclusiveness," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds., New York, NY: Cambridge University Press, 2014, pp. 357-372.

[37] C. Schimpf and J. Swenson, "Reimagining faculty, student and community interactions in capstone: A synthesis of liberative pedagogies, citizen engineering, and human-centered design," in *Proceedings of the Annual IEEE Frontiers in Education (FIE) Conference*, Uppsala, Sweden, 2022.

[38] S. Claussen, J. Y. Tsai, K. Johnson, J. Blacklock, and J. A. Leydens, "Exploring the Nexus Between Students' Perceptions of Sociotechnical Thinking and Construction of their Engineering Identities," in *Proceedings of the Annual ASEE Conference & Exposition*, Virtual Conference, 2021.

[39] M. H. Hwang, E. Trueblood, and S. A. Claussen, "Engineering Identity, Perceptions of Sociotechnical Education, and Views of Engineering Practice in Undergraduate Students," in *Proceedings of the Annual IEEE Frontiers in Education (FIE) Conference*, Uppsala, Sweden, 2022.

[40] K. L. Tonso, "Teams that Work: Campus Culture, Engineer Identity, and Social Interactions," *Journal of Engineering Education,* vol. 95, no. 1, pp. 25-37, 2006.

[41] K. L. Tonso. *On the Outskirts of Engineering: Learning Identity, Gender, and Power via Engineering Practice*. Rotterdam, Netherlands: Sense Publishers, 2007.

[42] J. Rohde, B. B. Musselman, D. Verdin, A. Godwin, A. Kirn, L. Benson, and G. Potvin, "Design Experiences, Engineering Identity, and Belongingness in Early Career Electrical and Computer Engineering Students," *IEEE Transactions on Education,* vol. 62, no. 3, pp. 165-172, 2019.

[43] J. E. DeWaters, J. Halfacre, J. Moosbrugger, E. Chapman, and E. Wultsh, "Enhancing the Experience of First-Year Engineering Students with an Entry-Level STS Course," in *Proceedings of the Annual IEEE Frontiers in Education (FIE) Conference*, El Paso, TX, USA, October 2015.

[44] J. E. DeWaters, J. C. Moosbrugger, and P. Sharma, "Development and Application of a Questionnaire to Measure Student Attitudes Toward and Understanding of Engineering," in *Proceedings of the Annual ASEE Conference & Exposition*, Columbus, OH, USA, June 2017.

[45] N. E. Canney and A. R. Bielefeldt, "Validity and Reliability Evidence of the Engineering Professional Reponsibility Assessment Tool," *Journal of Engineering Education,* vol. 105, no. 3, pp. 452-477, 2016.

[46] A. A. Syed, S. Gupta, and D. Rai, "Psychological, social and economic impact of COVID 19 on the working population of India: Exploratory factor analysis approach," *International Journal of Disaster Risk Reduction,* vol. 66, 2021.

[47] C. d. Marsola, L. M. Cunha, J. P. d. Carvalho-Ferreira, and D. T. da Cunha, "Factors Underlying Food Choice Motives in a Brazilian Sample: The Association with Socioeconomic Factors and Risk Perceptions about Chronic Diseases," *Foods,* vol. 9, 2020.

[48] E. R. P. Altafim, D. C. McCoy, and M. B. M. Linhares, "Relations between parenting practices, socioeconmoic status, and child behavior in Brazil," *Children and Youth Services Review,* vol. 89, pp. 93-102, 2018.

[49] D. Iskamto, P. L. Ghazali, A. Afthanorhan, J. Jasman, Sukono, and A. T. Bon, "Exploratory Factor Analysis (EFA) To Measure Entrepreneur Satisfaction," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Detroit, MI, USA, 2020.

[50] R. D. Ledesma, P. J. Ferrando, M. A. Trógolo, F. M. Póo, J. D. Tosi, and C. Castro, "Exploratory factor analysis in transportation research: Current practices and recommendation," *Transportation Research Part F: Traffic Psychology and Behaviour,* vol. 78, pp. 340-352, 2021.

[51] A. S. M. M. Hoque, B. A. Siddiqui, Z. B. Awang, and S. M. A. T. Baharu, "Exploratory Factor Analysis of Entrepreneurial Orientation in the Context of Bangladeshi Small and Medium Enterprises (SMEs)," *European Journal of Management and Marketing Studies,* vol. 3, no. 2, pp. 81-94, 2018.

[52] D. R. Brillinger, H. K. Preisler, A. A. Ager, and J. G. Kie, "An exploratory data analysis (EDA) of the paths of moving animals," *Journal of Statistical Planning and Inference,* vol. 122, no. 1-2, pp. 43-63, 2004.

[53] A. Field, J. N. V. Miles, and Z. Field. *Discovering statistics using R*. London: Sage Publications, 2012.

[54] M. Alavi, D. C. Visentin, D. K. Thapa, G. E. Hunt, R. Watson, and M. Cleary, "Exploratory factor analysis and principal component analysis in clinical studies: Which one should you use?," *Journal of Advanced Nursing,* vol. 76, no. 8, pp. 1886-1889, 2020.

[55] J. A. Leydens, K. Johnson, S. Claussen, J. Blacklock, B. M. Moskal, and O. Cordova, "Measuring Change over Time on Sociotechnical Thinking: A Survey/validation Model for Sociotechnical Habits of Mind," in *Proceedings of the Annual ASEE Conference & Exposition*, Salt Lake City, UT, USA, 2018.

[56] J. Trevelyan, "Technical Coordination in Engineering Practice," *Journal of Engineering Education,* vol. 96, no. 3, pp. 191-204, 2007.

[57] J. Trevelyan, "Reconstructing Engineering from Practice," *Engineering Studies,* vol. 2, no. 3, pp. 175-195, 2010.

[58] B. S. Benedict, D. Verdin, R. A. Baker, A. Godwin, and T. Milton, "Uncovering Latent Diversity: Steps Towards Understanding 'What Counts' and 'Who Belongs' in Engineering Culture," in *Proceedings of the Annual ASEE Conference & Exposition*, Salt Lake City, UT, USA, 2018.

[59] E. Chapman, E. Wultsch, J. DeWaters, J. Moosbrugger, K. Buckle, P. Turner, M. Ramsdell, and R. Jaspersohn, "Innovating engineering curriculum for first-year retention," in *Proceedings of the Annual ASEE Conference & Exposition*, Seattle, WA, USA, 2015.

[60] J. E. DeWaters, E. Chapman, E. Wultsch, K. Buckle, and J. C. Moosbrugger, "Engineering and Society: A Course for First-Year Engineering Students and Non-Majors," in *Proceedings of the 5th Annual First Year Engineering Experience (FYEE) Conference*, Pittsburgh, PA, USA, 2013.

[61] J. Moosbrugger, J. DeWaters, E. Chapman, and M. Richards, "A Course on Engineering and Society for First-Year Engineering Students and Non-Majors," in *Proceedings of the Annual ASEE Conference & Exposition*, San Antonio, TX, USA, June 2012.

[62] Q. Kreth, D. S. Schiff, J. Lee, E. Zegura, and J. Borenstein, "Social responsibility attitudes among undergraduate computer science students: an empirical analysis," in *Proceedings of the Annual ASEE Conference & Exposition*, Minneapolis, MN, USA, 2022.

[63] N. E. Canney and A. R. Bielefeldt, "Differences in Engineering Students' Views of Social Responsibility between Disciplines," *Journal of Professional Issues in Engineering Education and Practice,* vol. 141, no. 4, 2015.

[64] D. J. Leiner, "Too Fast, too Straight, too Weird: Non-Reactive Indicators for Meaningless Data in Internet Surveys," *Survey Research Methods,* vol. 13, no. 3, pp. 229-248, 2019.

[65] J. A. Gliem and R. R. Gliem, "Calculating, Interpreting, and Reporting Cronbach's Alpha Reliability Coefficient for Likert-type Scales," in *Midwest Research-to-Practice Conference in Adult, Continuing, and Community Education*, The Ohio State University, Columbus, OH, USA, 2003.

[66] R. B. Cattell, "The scree test for the number of factors," *Multivariate Behavioral Research,* vol. 1, no. 2, pp. 245-276, 1966.

[67] J. Benson and F. Clark, "A guide for instrument development and validation," *American Journal of Occupational Therapy,* vol. 36, no. 12, pp. 789-800, 1982.

[68] P. Kline, "Item trials," in *A Handbook of Test Construction: Introduction to Psychometric Design*, London: Methuen & Co. Ltd., 1986, ch. 6, pp. 133-149.

[69] D. A. Harrison and M. E. McLaughlin, "Exploring the cognitive processes underlying responses to self-report instruments: Effects of item content on work attitude measures," in *Proceedings of the 1991 Academy of Management Annual Meetings*, Miami, FL, USA, 1991.

[70] M. Roszkowski and M. Soven, "Shifting gears: Consequences of including two negatively worded items in the middle of a positively worded questionnaire," *Assessment & Evaluation in Higher Education,* vol. 35, no. 1, pp. 117-134, 2010.

[71] L. R. Fabrigar, R. C. MacCallum, D. T. Wegener, and E. J. Strahan, "Evaluating the use of exploratory factor analysis in psychological research," *Psychological Methods,* vol. 4, no. 3, pp. 272-299, 1999.

[72] L. Hu and P. M. Bentler, "Cutoff criteria for fit indexes in covariance structure analysis: Convential criteria versus new alternatives," *Structural Equation Modeling: A Multidisciplinary Journal,* vol. 6, no. 1, pp. 1-55, 1999.

[73] S. G. West, A. B. Taylor, and W. Wu, "Model fit and model selection in structural equation modeling," in *Handbook of Structural Equation Modeling*, R. H. Hoyle, Ed., New York, NY: Guilford Press, 2012, pp. 209-231.

[74] B. A. Danielak, A. Gupta, and A. Elby, "Marginalized Identities of Sense-Makers: Reframing Engineering Student Retention," *Journal of Engineering Education,* vol. 103, no. 1, pp. 8-44, 2014.

[75] K. Rainey, M. Dancy, R. Mickelson, E. Stearns, and S. Moller, "Race and gender differences in how sense of belonging influences decisions to major in STEM," *International Journal of STEM Education,* vol. 5, 2018.

[76] A. Master and A. N. Meltzoff, "Cultural Stereotypes and Sense of Belonging Contribute to Gender Gaps in STEM," *International Journal of Gender, Science and Technology,* vol. 12, no. 1, pp. 152-198, 2020.

[77] H. K. Ro, L. R. Lattuca, D. Merson, and P. T. Terenzini, "Measuring Engineering Students' Contextual Competence," in *Proceedings of the Annual ASEE Conference & Exposition*, San Antonio, TX, USA, 2012.

[78] R. P. Loweth, S. R. Daly, L. Paborsky, S. L. Hoffman, and S. J. Skerlos, "'You Could Take 'Social' Out of Engineering and Be Just Fine:' An Exploration of Engineering Students' Beliefs About the Social Aspects of Engineering Work," in *Proceedings of the Annual ASEE Conference & Exposition*, Virtual Conference, 2021.

[79] H. J. Passow and C. H. Passow, "What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review," *Journal of Engineering Education,* vol. 106, no. 3, pp. 475-526, 2017.

[80] K. J. B. Anderson, S. S. Courter, T. McGlamery, T. M. Nathans-Kelly, and C. G. Nicometo, "Understanding Engineering Work and Identity: A Cross-Case Analysis of Engineers Within Six Firms," *Engineering Studies,* vol. 2, no. 3, pp. 153-174, 2010.

[81] B. D. Jones, C. M. Epler, P. Mokri, L. Bryant, and M. C. Paretti, "The effects of a collaborative problem-based learning experience on students' motivation in engineering capstone courses," *The Interdiscplinary Journal of Problem-based Learning,* vol. 7, no. 2, pp. 34-71, 2013.

[82] H. E. Rodriquez-Simmonds, N. S. Pearson, J. A. Rohde, K. P. Vealey, A. Kirn, and A. Godwin, "Forget diversity, our project is due," in *Proceedings of the Annual ASEE Conference & Exposition*, Columbus, OH, USA, 2017.

[83] P. G. Curran, "Methods for the detection of carelessly invalid responses in survey data," *Journal of Experimental Social Psychology,* vol. 66, pp. 4-19, 2016.

[84] H. W. Marsh, K. T. Hau, J. R. Balla, and D. Grayson, "Is More Ever Too Much? The Number of Indicators per Factor in Confirmatory Factor Analysis," *Multivariate Behavioral Research,* vol. 33, no. 2, pp. 181-220, 1998.

[85] W. F. Velicer and J. L. Fava, "Effects of Variable and Subject Sampling on Factor Pattern Recovery," *Psychological Methods,* vol. 3, no. 2, pp. 231-251, 1998.