

Incorporating an Education Module on Diversity, Equity, and Inclusion into Undergraduate and Graduate Curricula Has No Positive Effect on Women's Perception of Biomedical Engineering

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Introduction

Women are substantially underrepresented within engineering at all levels in academia and industry. For example, while women earn 58% of undergraduate degrees across all disciplines, they account for only 24% of undergraduate students in engineering [1], [2]. Research suggests that this is partly due to women voluntarily choosing not to pursue an engineering education because their main motivators (e.g., personal fulfillment, societal benefit) do not match their perception of engineering careers [3], [4]. Consistent with these assertions, women earn an equal proportion of undergraduate degrees in certain engineering subfields that have an explicit goal of improving societal outcomes (e.g., biomedical engineering) [2]. Nevertheless, even in biomedical engineering, there is a steep decline in female representation at the graduate student and tenure-track faculty level (Fig. 1A) [2], [5]. This decline in female representation at the faculty level is also observed broadly throughout science, technology, engineering, and mathematics (STEM) fields in general (Fig. 1B) [6], [7]. Furthermore, this lack of representation is not limited to academia; while 46% of STEM doctoral degrees are awarded to women, only 32% of STEM positions in government and industry are occupied by women [7]. Therefore, even in cases where women eagerly pursue a STEM education, they disproportionately choose not to utilize this education after graduation. This is not only detrimental to the women themselves, but also to maximizing the potential of the national STEM workforce.

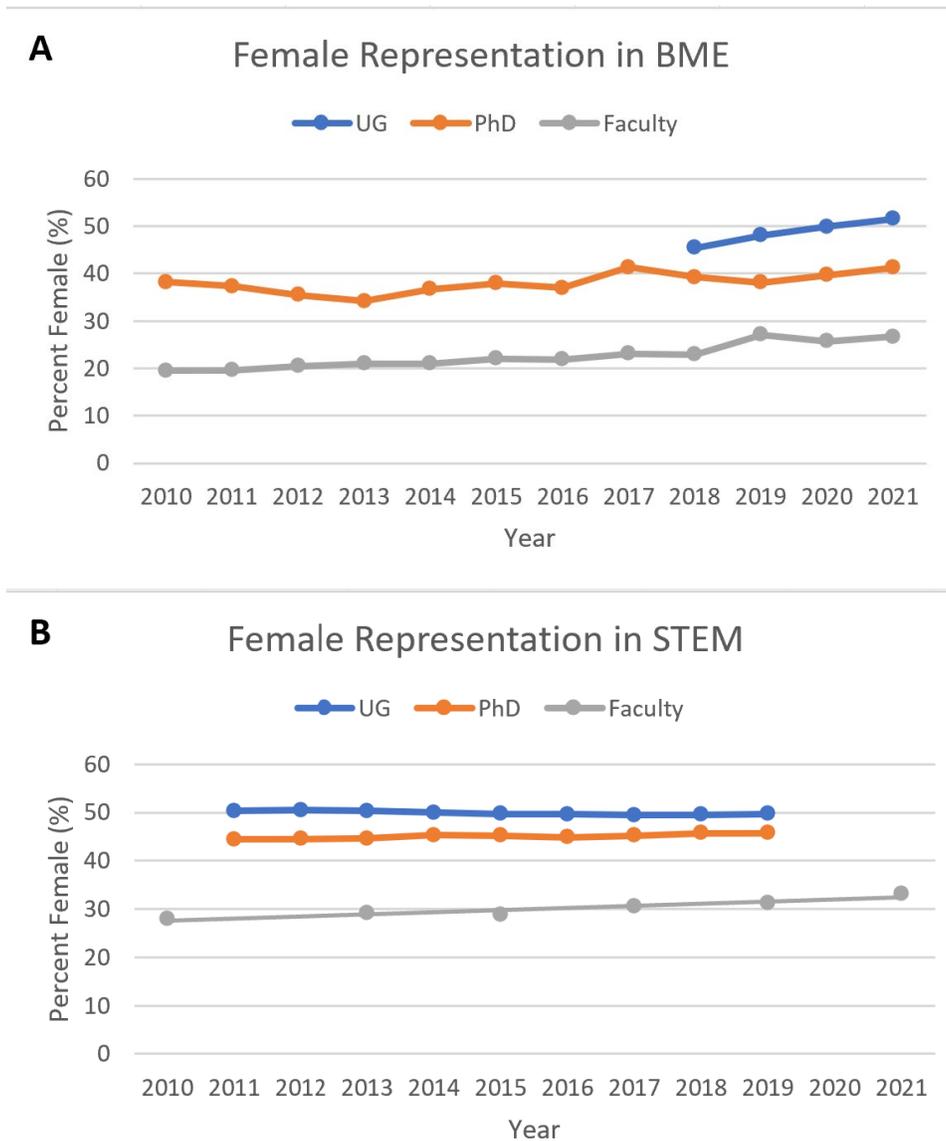


Figure 1: Female Representation in Biomedical Engineering (BME) and STEM.

Undergraduate (UG) and PhD: degrees awarded in that year. Faculty: tenured or tenure-track faculty. Sources: Engineering by the Numbers, ASEE EDGE Graphic Explorer, NCSSES Survey of Earned Doctorates, NCSSES Science and Engineering Indicators, NCSSES Diversity and STEM: Women, Minorities, and Persons with Disabilities

Several societal pressures and personal experiences are responsible for women’s decision not to remain in biomedical engineering and other STEM professions. Women turn away from engineering often because of social expectations/pressure, perceptions that they don’t belong, and a hostile learning environment [3], [8]–[11]. In addition to this “chilly climate,” societal factors (e.g., family responsibility) are also significant obstacles for women [8], [12]–[14]; single women with STEM doctoral degrees are significantly more likely to be working fulltime as scientists/engineers compared to women with small children (93% vs. 71%), while the opposite effect is seen for men (94% vs 98%) [15]. Finally, implicit and explicit bias/discrimination create

additional obstacles for women that erode their confidence in themselves (e.g., imposter phenomenon) and their drive to persist [8], [12], [16]–[19]. Therefore, in addition to empowering women, institutional changes in the educational and professional climate are necessary to correct gender disparities in engineering [20].

The objective of this study was to determine whether improving the climate for women in biomedical engineering would increase their interest in pursuing further education or a career in engineering after graduation. To test this, we added lectures, assignments, and active-learning modules into required seminar courses at the undergraduate and graduate levels that explicitly dealt with gender inequalities and implicit bias in engineering. We hypothesized that the acknowledgement and open discussion of these issues for women would enhance their sense of belonging within biomedical engineering and increase their intention to persist in engineering. Additionally, we investigated whether a resource intensive small-group discussion enhanced the impact of the educational modules.

Methods

In the fall semesters of 2021 and 2022, an anonymous survey was administered to students at the beginning and end of a 4th-year undergraduate seminar course within the Biomedical Engineering Department at the Pennsylvania State University (PSU). The same survey was administered at the beginning and end of a seminar course for first- and second-year graduate students (MS and PhD) in the spring 2022 semester. All surveys were identical and included validated scales of intrinsic engineering interest, identification with engineering, extrinsic engineering utility, engineering self-efficacy, and intention to pursue a career in engineering [21], [22]. Scales from prior surveys within the College of Engineering at PSU were used to assess student perception of compatibility between their gender and engineering, perception of compatibility between their race and engineering, sense of belonging in the department, and lack of experience of discrimination (Appendix). Comparisons between the pre- and post-surveys using the same measurement scales enabled us to determine if there was any change in student attitudes over the duration of the semester. Students that took both surveys were identified using a unique anonymous identification number to enable individual (rather than aggregate) differences in perceptions over time. All procedures were approved in advance by the Institutional Review Board at PSU.

We decided to implement our surveys and educational modules on diversity, equity, and inclusion into these seminar courses for three reasons. First, all 4th-year undergraduate and first- and second-year graduate students in the biomedical engineering program were enrolled in these seminar courses since they are required to complete a degree (BS/MS/PhD) in biomedical engineering at PSU. Second, these seminar courses provide professional development for biomedical engineering students by presenting current research and career opportunities through weekly invited speakers. The overall professional development learning objectives of the courses were compatible with our education modules designed to increase student understanding and competency of topics related to diversity, equity, and inclusion. Third, the format of the courses (i.e., weekly invited speakers) made it easy to insert our content into the curriculum.

During each semester and in-between the administration of the pre- and post-surveys, we engaged the students on the topic of gender and racial inequality in engineering as well as the causes of these inequalities through lectures, assignments, and active-learning modules. All the content and assignments used for this study were the same for both the undergraduate and graduate courses. At the beginning of the semester, one of the authors (SES) provided an in-class lecture presenting data demonstrating the level of racial and gender underrepresentation in engineering. In this same lecture, students were exposed to research identifying the causes of these inequalities (i.e., bias, gendered career interests, gendered career expectations and family obligations, racial disparities in educational opportunities) [3], [8], [10]–[14], [16], [17], [19], [23]. Following this lecture, the students further engaged with the material outside of class by viewing the movie “Picture a Scientist” and listening to a recording of an episode from *This American Life* entitled “The Problem We All Live With.” These multimedia resources were chosen since they reinforced the topics discussed in the in-class lectures through emotive personal examples and provided supporting data on gender and racial barriers in education and science. The students additionally processed the information presented in the lecture as well as the multimedia material by submitting a reflection on the content as a course assignment. Approximately midway through the semester, SES presented a second in-class lecture focusing on implicit bias. This lecture presented data on the presence and impact of bias in science [17]–[19] as well as the definition and measurement of implicit bias through the Implicit Association Test [24]. The lecture also included instruction on how to mitigate implicit bias through active witness training as well as reflective, slow, and anonymized decision making. Finally, emphasis during the lecture was placed on research demonstrating that all people (including those that are marginalized) are prone to have negative implicit biases of women and racial minorities. To help reinforce this idea and encourage students to become active participants in addressing bias, the students were required to complete and reflect upon the results of two implicit association tests performed on their own through Project Implicit [25]. An additional third assignment required the students to catalogue and reflect on instances of bias or discrimination that they observed throughout the remaining half of the semester. At the end of the semester, SES led a final summary and in-class discussion of the content and reflections related to our educational module. Additionally, the importance of moving beyond individual bias and addressing systemic bias within institutional policies was communicated [20], [26] followed by an in-class brainstorming activity asking students to identify academic policies at PSU that they believe maybe contribute to lack of diversity, equity, or inclusion.

In addition to the above standardized content provided in all three courses, students in the undergraduate and graduate courses during the 2021-2022 academic year met immediately following the submission of their first assignment to discuss the course content together in small groups. These small group discussions were led by trained undergraduate facilitators through the World in Conversation program at PSU. This small-group discussion was omitted from the fall 2022 undergraduate class to determine whether this time and resource intensive element had a meaningful impact on student outcomes.

Successful student engagement with the content of our educational modules was assessed by grading the completeness of the three assignments (e.g., did the student provide a meaningful reflection on the content of the lecture, movie, and podcast episode). Grades of zero, one, and two were given for no submission, superficial/poor reflection, and meaningful/satisfactory

reflection, respectively. Baseline differences in each scale between men and women were assessed for undergraduate and graduate students using Mann-Whitney tests. Additionally, Mann-Whitney tests were used to assess any changes in each scale between the pre- and post-surveys. Since the surveys were voluntary and the respondents were not the same in both the pre- and post-surveys for a given class, we also used Mann-Whitney tests to determine if the paired pre/post differences in survey responses for individuals who took both surveys was different from zero. All data are presented using box plots with the whiskers indicating the max/min data. Statistical significance was determined by $p < 0.05$ and a statistical trend by $p < 0.10$.

Results

In fall 2021, a total of 63/72 (pre/post) undergraduate students (58% women) completed the surveys and 95% of the students submitted meaningful/satisfactory reflections. In fall 2022, a total of 65/58 (pre/post) undergraduate students (64% women) completed the surveys and 97% of the students submitted meaningful/satisfactory reflections. In spring 2022, a total of 41/55 (pre/post) graduate students (35% women) completed the surveys and 79% of the students submitted meaningful/satisfactory reflections. We found that the survey results for women undergraduate and graduate students were the same as men for nearly every measurement scale at the beginning of the semester (Fig. 2). The only difference was that women perceived their gender as less compatible with engineering at both the undergraduate and graduate levels. Additionally, there was minimal difference between the two undergraduate cohorts at the beginning of the semester with only a slight increase in sense of belonging in the fall 2022 semester (Fig. 2C).

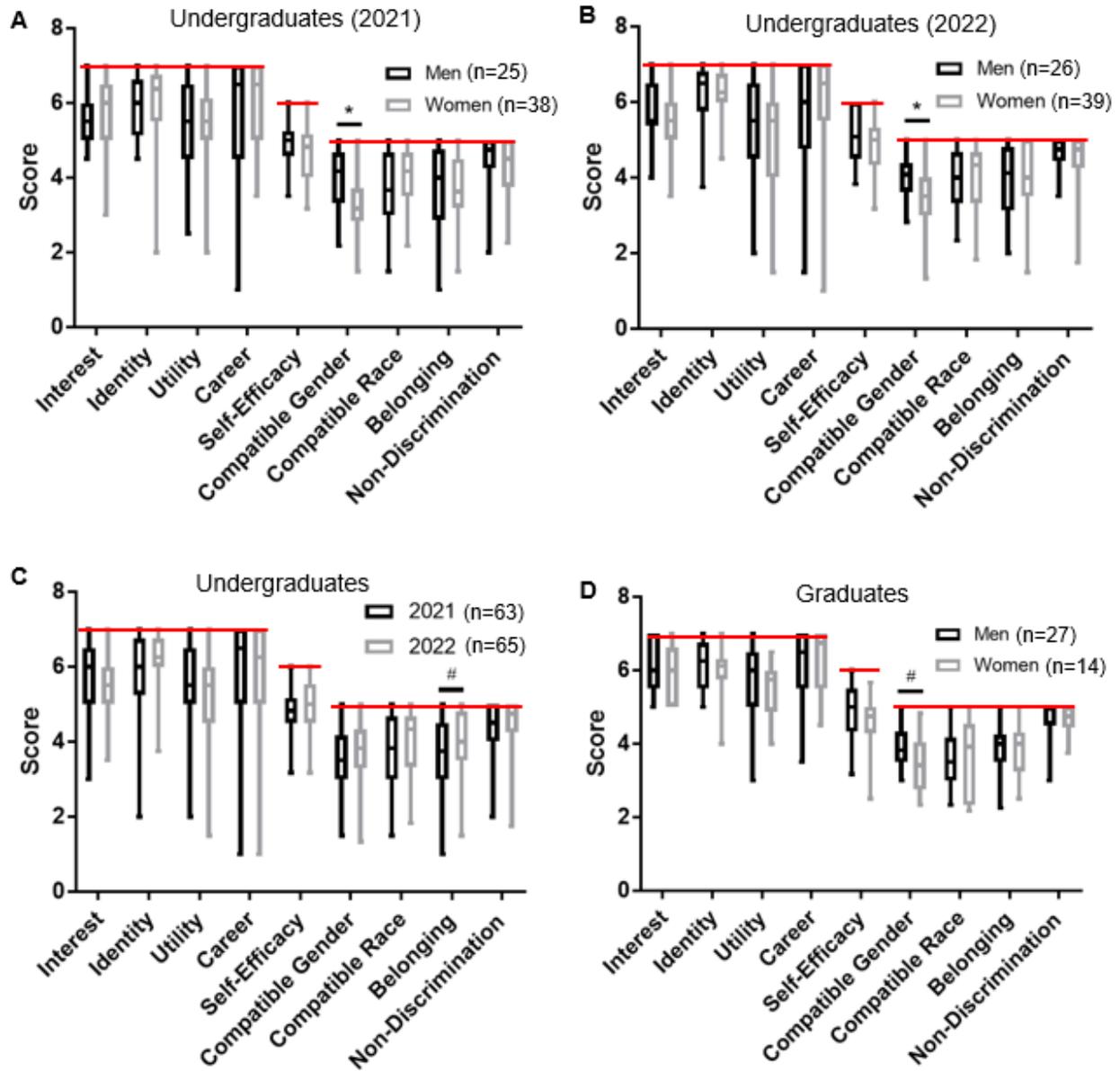


Figure 2: Baseline Data at the Beginning of Each Semester. (A,B) Scores for each scale for undergraduate students in (A) fall 2021 and (B) fall 2022. (C) Comparison of baseline scores for undergraduate students between fall 2021 and fall 2022. (D) Scores for each scale for graduate students in spring 2022. Red line indicates maximum score for each scale. * $p < 0.05$, # $p < 0.10$.

Comparisons of the aggregate pre/post data at the undergraduate level demonstrated that there was no change in any of the scales over time during the fall 2021 semester (Fig. 3A-C). Paired comparisons for students that took both surveys showed a slight decrease in engineering interest for women (Fig. 3D).

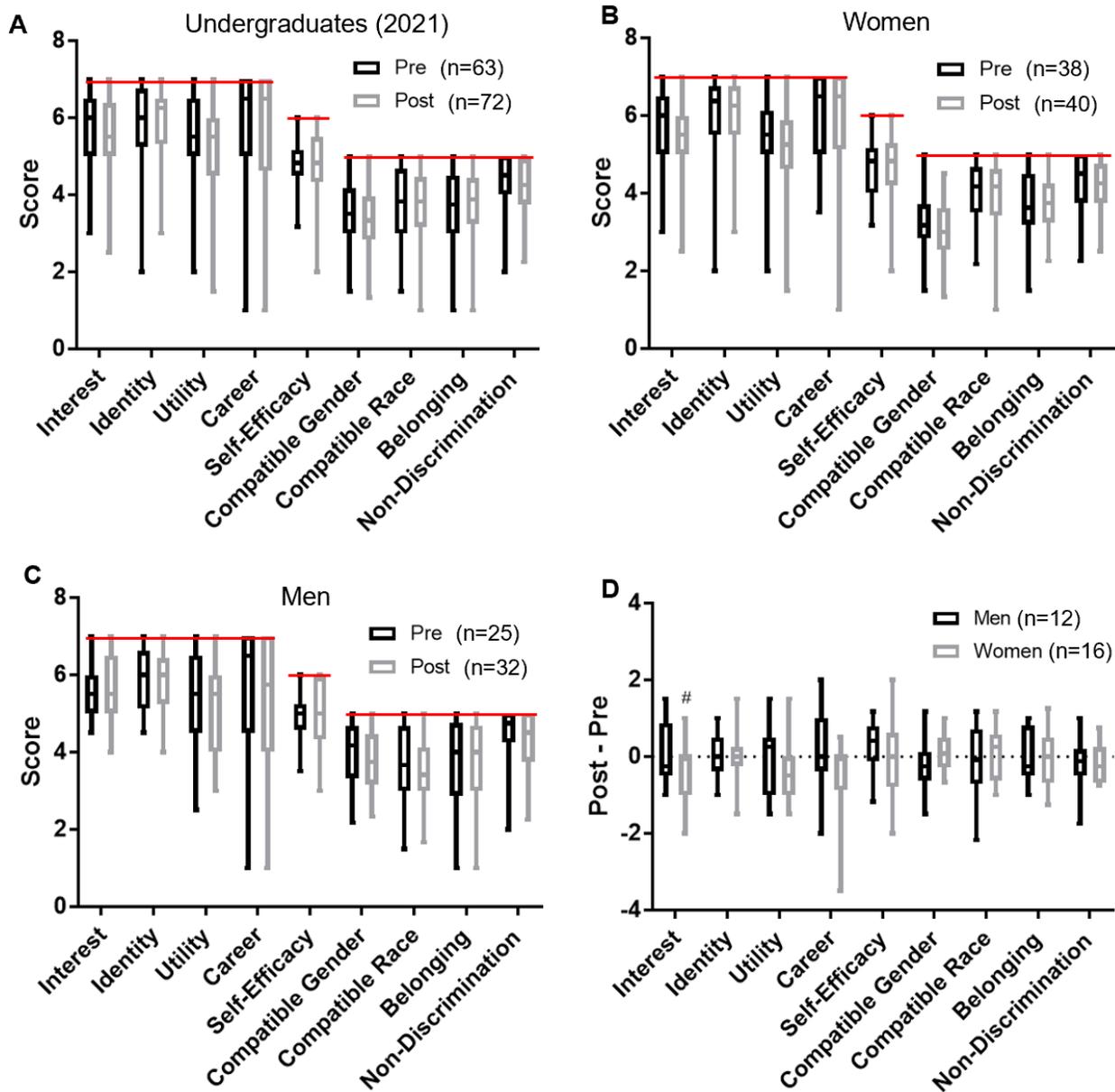


Figure 3: Change in Undergraduate Student Perceptions During Fall 2021 (with small-group discussion). (A) Comparison of pre/post data in aggregate. (B,C) Comparison of pre/post data for (B) female and (C) male undergraduate students. (D) Paired difference in pre/post data for students that took both surveys. Red line indicates maximum score for each scale. * $p < 0.05$, # $p < 0.10$.

In the fall 2022 semester, which lacked the small-group discussion, the female students exhibited a decrease in sense of belonging and experienced an increase in discrimination (i.e., decrease in non-discrimination) (Fig. 4A-C). The decrease in sense of belonging for women was also observed in the pairwise comparisons (Fig. 4D). For men that took both surveys in fall 2022, there was an increase in the perceived utility of engineering.

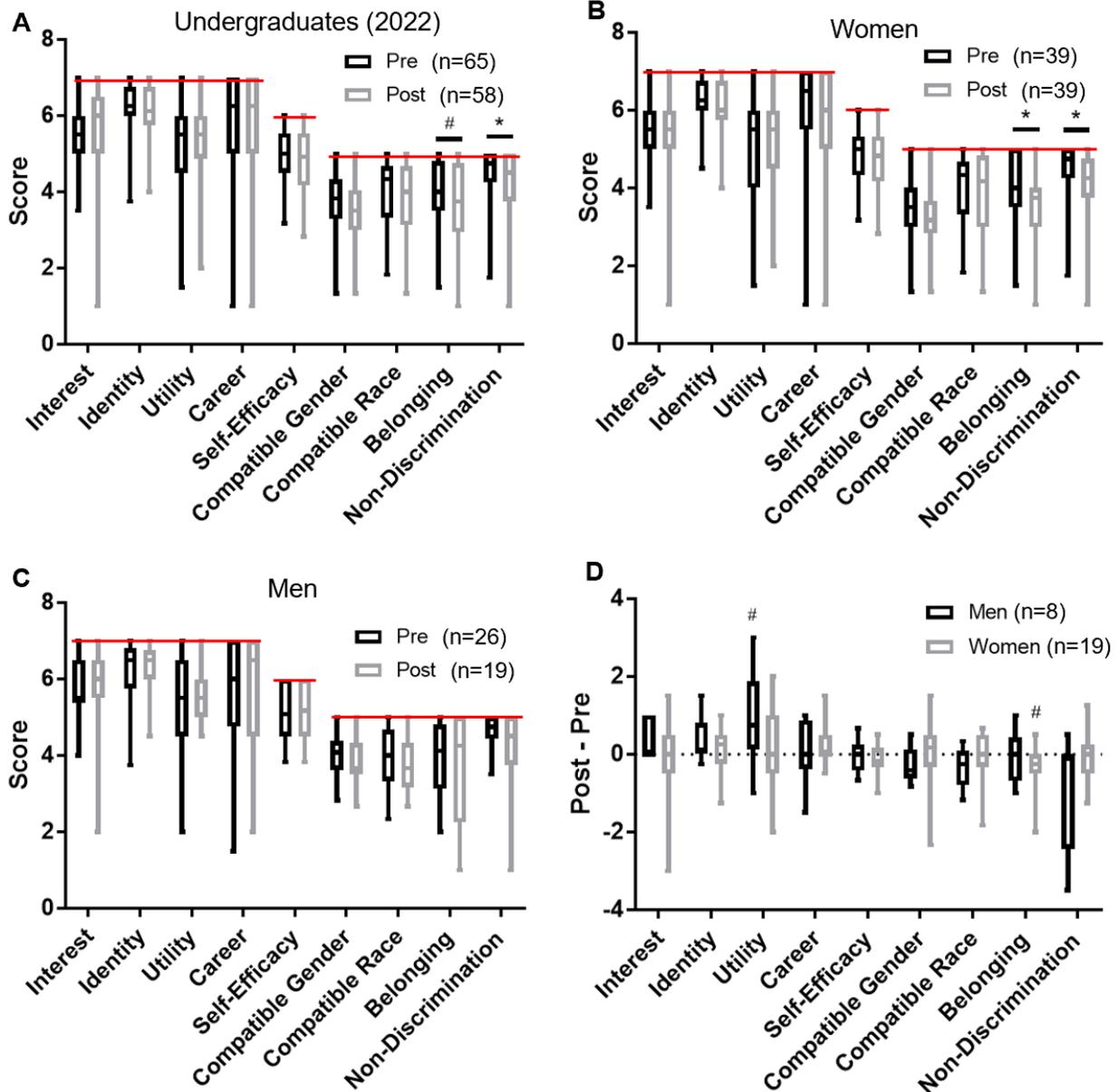


Figure 4: Change in Undergraduate Student Perceptions During Fall 2022 (without small-group discussion). (A) Comparison of pre/post data in aggregate. (B,C) Comparison of pre/post data for (B) female and (C) male undergraduate students. (D) Paired difference in pre/post data for students that took both surveys. Red line indicates maximum score for each scale. * $p < 0.05$, # $p < 0.10$.

At the graduate level, there was a significant increase in interest in engineering over time; however, there was also a decrease in perceived compatibility of gender with engineering and an increase in the experience of discrimination over the semester (Fig. 5A). Disaggregating the data by gender found that both men and women experienced the same increase in discrimination over time (Fig. 5B-C). Finally, similar findings were observed in the pairwise comparison for female graduate students (Fig. 5D).

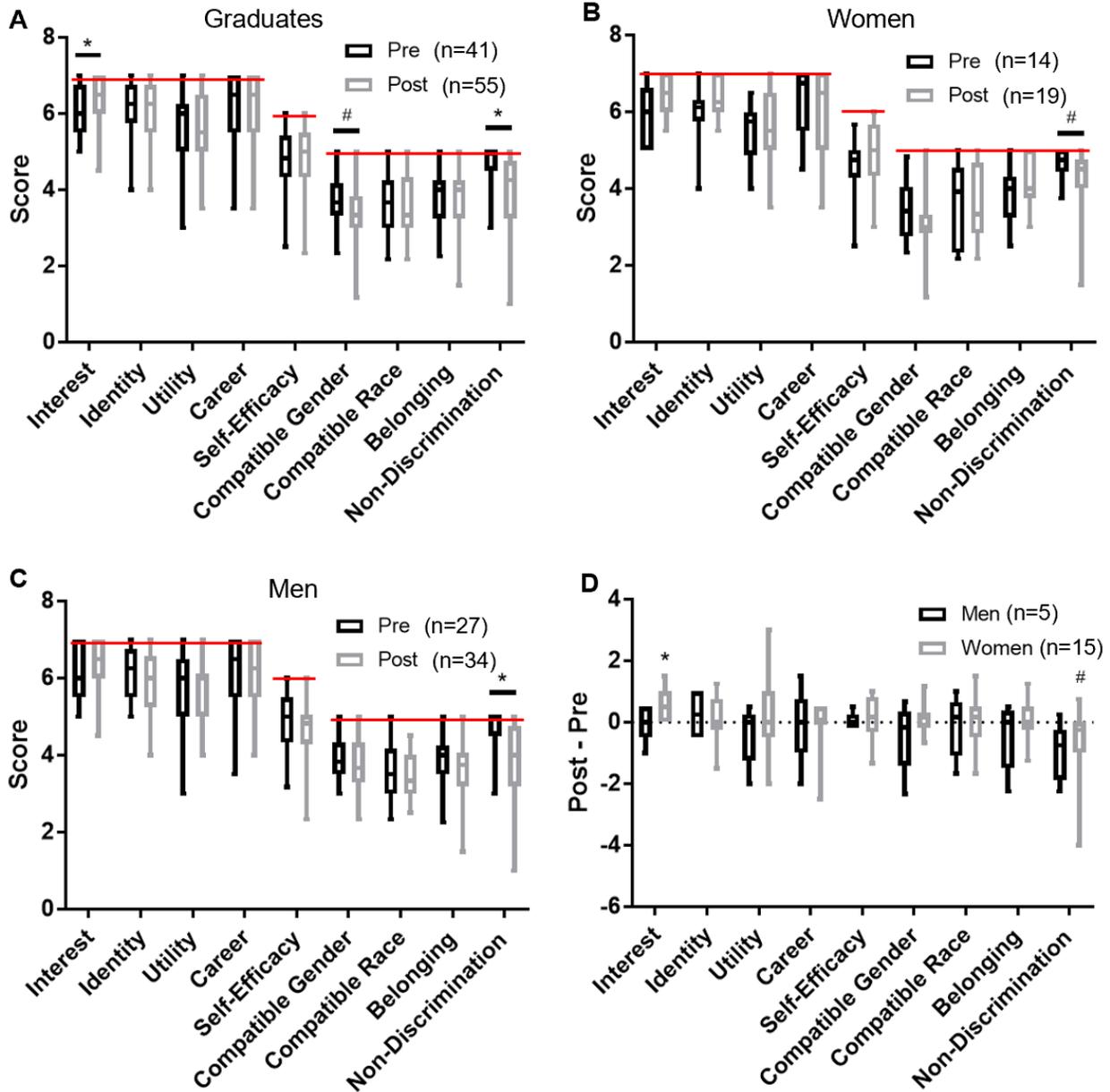


Figure 5: Change in Graduate Student Perceptions During Spring 2022 (with small-group discussion). (A) Comparison of pre/post data in aggregate. (B,C) Comparison of pre/post data for (B) female and (C) male graduate students. (D) Paired difference in pre/post data for students that took both surveys. Red line indicates maximum score for each scale. * $p < 0.05$, # $p < 0.10$.

To ease comparison between semesters, the paired differences between pre- and post-survey results for each student (panel D from Figs. 3-5) were replotted in Fig. 6. Focusing on the female undergraduate students (Fig. 6A-B), there was a decrease in engineering interest in the fall 2021 semester (which included small group discussions) and there was a decrease in sense of belonging in fall 2022 (no small group discussions). Male undergraduate students experienced an increase in perceived engineering utility only in fall 2022. In contrast to the female undergraduate students who engaged in small group discussions (Fig. 6A), the female graduate students who also engaged in small group discussions experienced an increase in engineering interest (Fig. 6C); however, they experienced an increase in discrimination.

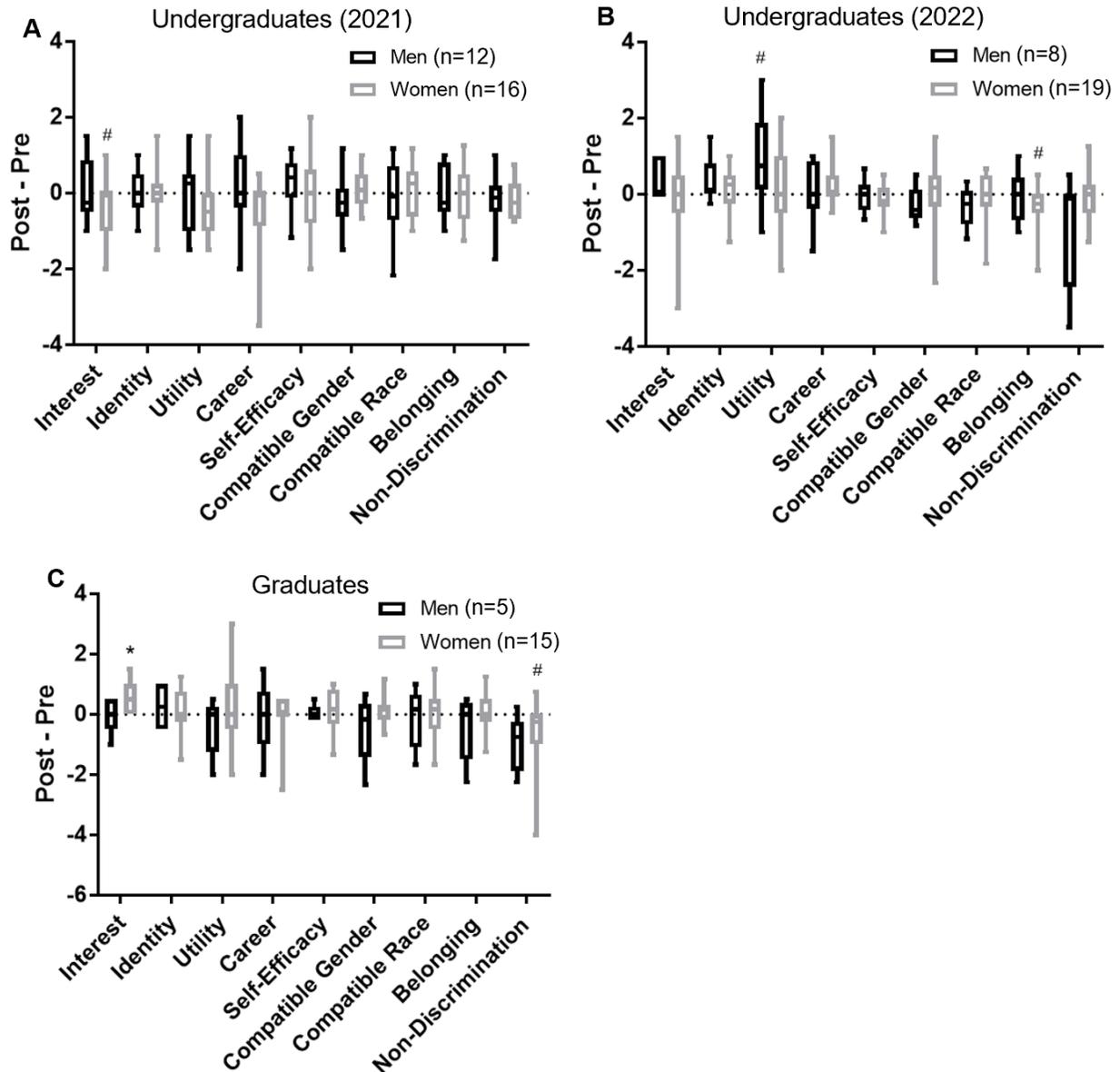


Figure 6: Comparison of Change in Student Perceptions Across All Semesters. (A) Paired difference in pre/post data for undergraduate students in fall 2021 (with small group discussion). (B) Paired difference in pre/post data for undergraduate students in fall 2022 (without small

group discussion). (C) Paired difference in pre/post data for graduate students in spring 2022 (with small group discussion). * $p < 0.05$, # $p < 0.10$.

Discussion

The objective of this study was to determine whether improving the climate for women in biomedical engineering through education on diversity, equity, and inclusion would increase their interest in pursuing a career in engineering after graduation. Consistent with prior literature [10], female undergraduate and graduate students perceived their gender to be less compatible with engineering than men. However, there was no difference between men and women at baseline for any other metrics, including sense of belonging in the department, intention to pursue an engineering career, and experience of discrimination. Contrary to our hypothesis, we found that there was no positive change over the semester in sense of belonging or intention to pursue an engineering career for female undergraduate or graduate students. Surprisingly, we found that female undergraduate students experienced a decrease in engineering interest and sense of belonging as well as an increase in experience of discrimination during the semester. Similarly, there was an increase in the experience of discrimination for female (and male) graduate students. Together, these data suggest that our educational modules on diversity, equity, and inclusion did not improve women's sense of belonging or increase their intention to remain in engineering.

The lack of a positive effect for our educational modules is likely due to several reasons. First, the survey scores for student interest in engineering careers, sense of belonging, and lack of discrimination were already relatively high at baseline. Therefore, there was little improvement that was even possible for our education modules. Still, there was no positive benefit observed for the one metric that was different between male and female students (i.e., perceived compatibility of gender with engineering). This is likely because the weight of a lifetime of experiences that convey to female students that their gender is not compatible with engineering is likely too large to be counterbalanced by a few educational lessons in a single class [27]. Indeed, research shows that meaningful improvements in women's perception of engineering are only possible with systemic changes throughout all levels within the hierarchy of an academic institution [20]. Second, it is possible that the decreased sense of belonging for female undergraduate students in fall 2022 could be due to the lack of a small-group discussion to aid in processing the content as a cohort. This may have led them to feel more isolated than the undergraduate students in the fall 2021 semester who did collectively engage with the material. Finally, it is worth noting that the increase in discrimination observed by students may not be negative. On the one hand, it would obviously be a problem if discrimination against women increased due to discussion of inequality in engineering. On the other hand, one of the goals of the educational modules was to make students more aware of bias and discrimination. Indeed, one of the assignments was to have students record observations of bias throughout the semester in a journal. Therefore, the increased discrimination reported by the students may be due to an increase in awareness of the existing levels of bias around them. A handful of salient submissions for this assignment are transcribed below to help illustrate this point.

“I often find myself experiencing gender bias when I am walking alone or at night. I noticed this more often after this assignment and noticed it on multiple occasions. When I am walking home,

as I pass people on the street, I find myself walking faster or moving farther away from them on the sidewalk. I typically find myself doing this when passing a group of males... I am timid and scared whenever passing males on the street at night or alone because I am afraid one will do something to me. As I was thinking more about this after the lecture, I also realized that I do not have this bias when I pass other females on the street. And I personally do not think that other females would do something to hurt me as I pass them on the street. Additionally, I spoke with some of my male friends, and they are never scared passing anyone on the street.”

“I worked at a new CVS location and had not met any of the employers beforehand, so I was unsure who to go introduce myself to. I ran into a young Asian woman, and the first thing that I asked her was “are you a pharmacy technician?”. She said, “no, I am the pharmacist”. I felt terrible as I had mistaken her for a pharmacy technician based on her looks alone. The interaction would have been different if the pharmacist was a different race, and even a different gender. I would have most likely asked if they were the pharmacist and not the pharmacy technician if the pharmacist had a different identity. After my comment, I immediately apologized for my assumption and explained that I didn’t know any of my coworkers yet and wasn’t sure who to talk to.”

“In my engineering entrepreneurship class, we were tasked with creating a product or service and creating a business plan that we would be pitching to actual leaders in businesses. This project included financials, marketing, and prototyping. I found myself leaning towards the prototyping phase of this project as it had more design and creative aspects to it. The one other girl in the group also decided to help me with this aspect of the project. After leaving class, I realized how we had both showed an implicit bias of women participating in more creative and “artsy” pieces while leaving the technical and financials to the men in the group. I may have been more inclined to attempt the financials and technical pieces of this project if it had been a group of all girls, however I was very willing to let the men take over these aspects. This made me feel kind of guilty as I caught myself participating in my implicit bias that almost looks down upon girls. This made me feel kind of helpless with the thought process of, if I am a girl and cannot hide my implicit bias, how will things ever change? I think that moving forward I can try to identify this bias earlier and try to act to go against it in the moment, even if it makes me feel slightly uncomfortable.”

“One time that I was biased was when having to pick a partner for a group project. I had the option to pick between a male and a female, in which I found myself choosing the male. Subconsciously, I found myself believing that the male was smarter and would be more helpful as a partner. Additionally, I stereotyped the female by thinking she would cause drama and be difficult to work with. If my gender was different, I may have decided to go with the other partner... I believe that over time, people have subconsciously learned to associate men with the STEM field. Hence, I believe that growing up in this society caused me to choose the male as my partner for the engineering project. Since this instance, I have been trying to change this way of thinking. Instead of partnering with someone based on their gender, I will be sure to not let any biases affect my decision. I will attempt to partner with someone who I may not have thought to partner with in the past. By doing this, I might even learn many valuable lessons.”

“Several times I saw a woman at the entrance of the building at work and, until now, I always assumed that she was an administrative employee. I realized that I do not know anything about her, therefore, I should not assume anything about her position at the university. The fact that I assume her being an administrative employee and not a faculty or other different position could be an implicit bias of mine based on gender discrimination, as was discussed in the seminar. Reflecting on that, probably I would not assume that if that person was not a woman, independent of his race. This is something that I have to work on, so I do not propagate and validate this kind of bias anymore even when it is not expressed as an explicit act.”

“As a white native English speaker I have noticed a bias in myself across this semester against non-native English speakers in classes. One of my classes required us to score in class presentations each week and I constantly had to stop myself from scoring people lower for struggling to present the paper due to a language barrier despite the content of their presentations being fully comprehensive. To combat this I focused more on the content of the presentations for scoring opposed to how it was presented. Despite working in a non-American dominated lab for over 3 years now I still have to stop myself from letting bias influence me in many daily situations.”

There are a few limitations to this study that are worth noting. First, there were no control groups that took the pre/post surveys but did not receive the educational modules. This makes it difficult to interpret whether differences in the pre/post survey results were due to the education modules or some other experiences that occurred during the semester. Additionally, it is possible that the lack of effect of the educational modules was due to poor design and implementation of the modules rather than intransigence of student perceptions. While it is possible that a more experienced educator on the topic of diversity, equity, and inclusion may have greater success in influencing student opinions, prior data support the idea that systemic incorporation of equity-focused initiatives throughout an educational institution are important for improving the experience of marginalized students [20], [27]. Another limitation is that the baseline student scores may have been influenced by the COVID pandemic, especially for the students in the fall 2021 semester. While this may limit the generalizability of our findings, it is worth noting that course instruction at PSU had returned to a fully in-person format by the fall 2021 semester, so there was no difference in the delivery of the educational modules between semesters. Finally, there were small sample sizes for the paired analyses, which decreased the power of the longitudinal comparisons. This was partly due to the fact that there was also a selection bias in terms of which students completed the surveys. That is, at the undergraduate level, more women completed the surveys than men even though the student population had roughly equal proportions of men and women. Additionally, even though there were more men than women in the graduate class, substantially more women took both surveys, making longitudinal analysis of the men difficult. Despite these limitations, these data suggest that a single educational module on diversity, equity, and inclusion is not sufficient on its own to improve a sense of belonging or retention in engineering for women.

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Appendix

Survey Questions/Scales:

- 1) Please enter a code number so that the responses between this survey and the one at the end of the semester can be paired.
 - a. Code Number: numeric date of your birthday (i.e. 30 if your birthday is November 30), the last 4 digits of your phone number, and the last two letters of your middle name (if you have one). Example: 301234an
- 2) Gender (Male/Female/Non-Binary)
- 3) Race
 - a. Asian
 - b. Black
 - c. Hispanic
 - d. White Non-Hispanic
 - e. American Indian
 - f. Pacific Islander

g. Multiracial

4) Engineering Intrinsic Interest Value (Jones 2010 J Eng Ed)

a. 7-point Likert

- In general, I find working on engineering-related assignments (very boring, very interesting)
- How much do you like engineering? (not very much, very much)

5) Identification with Engineering (Jones 2010 J Eng Ed)

a. 7-point Likert (1 = strongly disagree; 4 = neutral; and 7 = strongly agree)

- Being good at engineering is an important part of who I am.
- Doing well on engineering tasks is very important to me.
- Success in engineering school is very valuable to me.
- It matters to me how I do in engineering school.

6) Engineering Extrinsic Utility Value (Jones 2010 J Eng Ed)

a. 7-point Likert

- How useful is learning engineering for what you want to do after you graduate and go to work? (not very useful, very useful)
- How useful is what you learn in math, science, and engineering courses for your daily life outside school? (not at all useful, very useful)

7) Engineering Career (Jones 2010 J Eng Ed and Mamaril 2016 J Eng Ed)

a. 7-point Likert

- I intend to practice engineering for at least 3 years after I graduate (strongly disagree, strongly agree)
- How likely is it that your eventual career after graduation will directly pertain to engineering? (not at all likely, very likely)

8) Engineering Self-Efficacy (Mamaril 2016 J Eng Ed)

a. 6-point Likert (completely uncertain, completely certain)

- I can master the content in the engineering-related courses I am taking this semester.
- I can master the content in even the most challenging engineering course.
- I can do a good job on almost all my engineering coursework.
- I can do an excellent job on engineering-related problems and tasks assigned this semester.
- I can learn the content taught in my engineering-related courses.
- I can earn a good grade in my engineering-related courses.

9) Perceived Identity Compatibility between Gender and Major

Please indicate how much you agree or disagree with each of the following statements:

Perceived Identity Compatibility Between Gender and Major (6 Items)

1. I don't think that my gender will affect how others view me in my major
2. I don't think that my gender will affect how well I do in my major
3. I think my gender and my major are very compatible
4. I think I may experience difficulties in my major because of my gender (R)
5. I think my gender will be an important factor in the type of career I decide to pursue (R)
6. I don't think I would pursue certain fields because of my gender (R)

Response options: 5-point Likert scale from 1=Strongly disagree to 5=Strongly agree
(R) = Reverse Coded

10) Perceived Identity Compatibility between Race and Major

Please indicate how much you agree or disagree with each of the following statements:
Check one for each statement using the scale that ranges from "Strongly disagree" to "Strongly agree"

Perceived Identity Compatibility Between Gender and Major (6 Items)

1. I don't think that my race/ethnicity will affect how others view me in my major
2. I don't think that my race/ethnicity will affect how well I do in my major
3. I think my race/ethnicity and my major are very compatible
4. I think I may experience difficulties in my major because of my race/ethnicity (R)
5. I think my race/ethnicity will be an important factor in the type of career I decide to pursue (R)
6. I don't think I would pursue certain fields because of my race/ethnicity (R)

Response options: 5-point Likert scale from 1=Strongly disagree to 5=Strongly agree
(R) = Reverse Coded

11) Sense of Belonging in College of Engineering

Please indicate the extent which you disagree or agree with the following statements about the

College of Engineering at Penn State:
[Check one for each statement using the scale that ranges from "Strongly disagree" to "Strongly agree"]

Sense of Belonging at the College of Engineering (4 Items)

1. I feel that I am a member of the College of Engineering
2. I see myself as part of the College of Engineering
3. I feel a sense of belonging to the College of Engineering
4. If asked, I would recommend the College of Engineering to others

Response options: 4-point Likert scale from 1 =Strongly disagree to 4 = Strongly agree

12) Discrimination and Bias

Please indicate how often you have personally experienced the following forms of bias/ discrimination during these first weeks at this college:

Discrimination and Bias (7 Items)

1. Verbal comments
2. Cyberbullying (e.g., emails, texts, social media)
3. Exclusion (e.g., from gatherings, events)
4. Offensive visual images or items

During these first weeks at this college, how often have you:

5. Heard insensitive or disparaging remarks from faculty
6. Heard insensitive or disparaging remarks from staff
7. Heard insensitive or disparaging remarks from students

Response options: 5-point Likert scale from 1=Very often to 5=Never