Examining Student Responses and Gender Differences to a First-Year Sociotechnical Engineering Course

Felicity Bilow
Department of Civil & Environmental Engineering
Clarkson University
Potsdam, NY, USA
bilowf@clarkson.edu

Jan DeWaters
Institute for STEM Education
Clarkson University
Potsdam, NY, USA
jdewater@clarkson.edu

***Abstract*—This research full paper explores first-year engineering (FYE) students' attitudes toward and understanding of engineering, investigating differences among male and female students in two different courses: *Engineering and Society* (ES110), a sociotechnical course, and *Physics I* (PH131). A pre/post survey was used to understand how student attitudes toward and understanding of engineering were affected after taking these courses. Four cohorts of students over three fall semesters (2018-2020) were examined: males in ES110; females in ES110; males in PH131; and females in PH131. Our results confirmed previous findings - compared to the control group, ES110 students showed more positive outcomes in terms of academic and engineering self-confidence and their understanding of engineering. Male/female comparisons revealed some interesting findings. Compared to their male counterparts, female PH131 students experienced a greater drop in academic and engineering self-confidence. In ES110, females showed a greater increase in engineering self-confidence, but a greater drop in their engineering sense-of-fit, yet they began with higher pre-scores - across all cohorts - and ended with post-scores similar to their male peers for this subscale. All student scores dropped in the sense-of-fit subscale, although the post-scores for ES110 students were slightly higher than for PH131. ES110 females' post-scores were the highest across all cohorts for two subscales (engineering self-confidence; understanding of engineering) and were the second highest for the other two subscales. PH131 females' post-scores were the lowest across all cohorts for three subscales (academic and engineering self-confidence; satisfaction with engineering/sense of fit). Overall, our results indicate that first-year students benefit from taking a sociotechnical engineering course in their first semester, compared to a strictly technical curriculum, and those benefits are even greater for female students.**

Keywords—student attitudes, sociotechnical course, gender impacts, first year programs

I. INTRODUCTION AND BACKGROUND

As the world continues to change and the problems faced by society continue to become increasingly complex, the demand for a more diverse engineering workforce has become more and more pressing [1]. A broad range of talent is needed to tackle the wide array of complex, interdisciplinary problems that have far reaching societal consequences. Engineering graduates who can apply sociotechnical thinking – which considers both technical and nontechnical factors (social, economic, cultural, political, etc.) [2, 3] – are needed to solve these "wicked" global problems (e.g., access to clean water, failing infrastructure, climate change, etc.) [1, 4]. Current engineering curricula generally highlight the technical side of engineering and focus on developing students' technical skills and knowledge rather than on the social, cultural, and political context of engineering [e.g., 5-9]. This narrow technical focus decreases engineering students' sense of social responsibility over the course of their engineering education [5, 10, 11], failing to prepare them to think sociotechnically when they begin working in industry. Courses that contextualize engineering within a sociocultural and economic framework help students understand the social implications of engineering and expose them to sociotechnical problem solving needed for the future [3, 12-14].

Engineering curriculum that is narrowly focused on technical aspects fails to contextualize students' lived experiences in their coursework, causing some students to lose interest and motivation to continue in their engineering studies [15, 16]. The retention rate of undergraduate students in engineering is low, with a large percentage of students leaving after their first year [17, 18]. Research has found that some engineering students leave because they do not feel like they belong, they may experience poor teaching styles and advising at the school, lack of confidence, lack of motivation, loss of interest, and/or a lack of context in the curriculum [17, 19-21]. Introductory courses can help retention, bridging the gap between students' perceptions and expectations of engineering and engineering curricula, and dispelling many of the generalizations students carry with them into the start of their engineering degree [18, 22-24]. These courses also provide the opportunity to introduce first-year students to the human or social side of engineering, helping a broader range of students to find a sense of belonging in the field early on, thereby increasing their persistence in engineering.

Changes in engineering curricula and instruction practices are effective strategies to improve retention and to provide a more welcoming educational environment for students from historically excluded groups in engineering [15, 25]. In particular, integrating more social relevance and context, as well as students' lived experiences, tends to increase female students' participation in the field [26, 27]. Women and female-identified individuals are more apt to pursue engineering because of social and altruistic aspirations compared to their male peers [15, 28-30]. They are also more likely to have a stronger sense of social responsibility [10, 11] and to think about the sociotechnical dimensions of engineering [31]. Students' attitudes, including their sense of belonging and self-confidence, are integral to whether female students persist in their engineering studies [15, 32]. Sociotechnical courses may allow students to find social relevance to the field [29, 31, 33], helping females find a sense of belonging in engineering, ultimately leading to an increase in the retention rate of women in engineering.

In an attempt to improve first-year engineering (FYE) students' experiences, Clarkson University implemented a course that exposes FYE students to engineering, with particular emphasis on the social implications of engineering and technology. *Engineering and Society* (ES110) is a one-semester course that introduces students to "engineering as a sociotechnical endeavor" [3, p. 3]. All FYE students take ES110 during their first or second semester at the university.

This paper builds on previous research [34] and explores female and male FYE students' attitudes toward and understanding of engineering over the course of their first semester, comparing students who took ES110 to a control group enrolled in introductory physics (PH131). Based on existing literature and our own previous research, we hypothesized that overall pre-/post-changes would be greatest for female ES110 students and least for females taking PH131.

II. Methodology

A. Courses and Curriculum

The university created ES110 in 2011, and in 2014 the course was incorporated into the required first-year curriculum for engineering students [35]. ES110 introduces students to engineering ethics, the history of technology and engineering, and the connection between society, technology, and engineering [34, 35]. FYE students are enrolled into either ES110 or PH131 during their first semester at the university based on their performance on physics and math readiness exams that they take the summer before beginning their undergraduate studies [35]. Besides either of these two courses, all FYE students take calculus, chemistry, and a freshman writing course during their first semester. This curriculum design prevents PH131 students from taking an engineering course, while ES110 students are introduced to engineering within a sociotechnical framework during their first semester. FYE students who are not enrolled in ES110 during their first semester, take ES110 during their second semester (spring semester of their first year).

B. Sample Group

This paper uses data from three fall academic semesters: fall 2018 through fall 2020. Students were combined into four cohorts: males in ES110 (n = 181); females in ES110 (n = 83); males in PH131 (n = 156); and females in PH131 (n = 47). Students enrolled in ES110 are the treatment group, while PH131 students serve as the control.

C. Survey

An Engineering Attitudes Survey [34, 36] was administered to students before (pre-) and after (post-) taking their respective course. The survey included a set of 25 Likert-type items about students' understanding of engineering, as well as their confidence and sense of fit in engineering. Versions of this survey have been distributed to FYE students at the university since fall 2011. Survey items, available by request, were focused on four key areas, and were divided into four subscales: academic self-confidence (4 items); engineering self-confidence (6 items); satisfaction with engineering/sense of fit (6 items); and understanding of engineering (9 items) [34, 36]. The internal consistency reliability coefficients (Cronbach's α value) for all four subscales, were above minimum acceptable levels for educational surveys [37, 38]. Values ranged from 0.769 to 0.872.

D. Analysis

Surveys were retained for analysis based on a variety of criteria. After removing unmatched pre- or post-data, surveys were examined and retained if the responses were at least 85% complete, included responses across the range of response options (i.e., not all 4s or 5s), and included different responses to two identical but opposite items (i.e., one positively and one negatively worded). Retained survey responses were analyzed using the statistical software packages R and SPSS. The 5-point Likert-type responses were recoded to numerical values (strongly disagree = 1 to strongly agree = 5), with higher numbers indicating the preferred direction of response. Students' scores were analyzed separately for each of the four subscales. Pre-post changes by item and subscale mean score, by cohort, were compared using a Wilcoxon signed rank test. Pre-post changes to items that did not receive a 100% response rate were compared using a Mann-Whitney U test. A non-parametric ANCOVA, with pre-score as the covariate, post-score as the dependent variable, and cohort as the fixed factor was used to analyze the differences in students' pre/post gains (or losses) among the four cohorts, by subscale mean and by item [39-41]. Significant differences between the pre- and post-scores across the four cohorts were determined using a series of Mann-Whitney U tests. A statistically significant difference for all comparisons was justified with a p-value ≤ 0.05.

III. Results and Discussion

Overall findings, by subscale, are summarized in Table 1. In general, we found that all four cohorts' understanding of engineering significantly increased, and the increase was significantly greater for ES110 students relative to the control group. Among the control students, the increase in females' understanding of engineering was more pronounced than their male peers. All cohorts' academic self-confidence and satisfaction with engineering/sense of fit decreased, to a varying degree, over the course of the semester. Results for the engineering self-confidence subscale were mixed. ES110 females' scores increased substantially, while control females' scores decreased considerably, ES110 males' scores increased slightly, and control males' scores were unaffected. The results are examined in more detail in the following sections, arranged according to the four topical subscales.

A. Academic Self-Confidence

Although all student cohorts showed a drop in academic self-confidence scores, student scores were relatively stable for ES110 students over the course of the semester, while corresponding scores for the control students taking PH131 declined, most notably for females (Table 1, Fig. 1). In fact, a significant difference was found between the combined males and females in ES110 vs. those in PH131 for this subscale ($p < 0.05$, data not shown). Among all cohorts, scores for control females decreased the most, followed in decreasing order by control males, ES110 males, and finally ES110 females, whose scores only dropped slightly. No statistically significant

Table 1. Pre-/post-means and gain/loss values for each cohort and subscale

Cohort	Academic Self-confidence			Engineering Self-confidence		
	Mean Pre	Mean Post	Post-Pre	Mean Pre	Mean Post	Post-Pre
Control Females	4.13	3.90	-0.23	4.22	4.12	-0.10
Control Males	4.17 [d]	4.08	-0.09	4.24	4.24	0.00
ES110 Females	4.06	4.04	-0.02	4.17	4.27	0.10
ES110 Males	4.07	4.02	-0.05	4.18	4.21	0.03

Cohort	Satisfaction with Engineering/Sense of Fit			Understanding of Engineering		
	Mean Pre	Mean Post	Post-Pre	Mean Pre	Mean Post	Post-Pre
Control Females	4.28	4.17	-0.11	3.96	4.14	**0.18[b]**
Control Males	4.34	4.23	**-0.11[b, e]**	4.01	4.05	**0.04[a]**
ES110 Females	4.38	4.26	-0.12	4.03	4.40	**0.37[c]**
ES110 Males	4.37	4.29	-0.08	3.95	4.34	**0.39[c]**

Note: [a]Statistically significant at the $p \leq 0.05$ level
[b]Statistically significant at the $p \leq 0.01$ level
[c]Statistically significant at the $p \leq 0.001$ level
[d]Underlined values indicate the highest pre/post means across all four cohorts for each item.
[e]Bolded values indicate statistically significant changes

differences were determined between the four cohorts – only the two classes. Nevertheless, the drastic drop in academic self-confidence for control females in comparison to the other three cohorts is noteworthy. These results suggest that a sociotechnical course can impact students' academic self-confidence. It is important to note that ES110 students are not enrolled in a rigorous physics course during their first semester, which may have helped them maintain their academic self-confidence relative to students who were enrolled in a rigorous physics class.

There are also observable, yet not significant, differences among the mean pre- and post-mean scores across the four cohorts. Mean pre-scores for the control students, both male and female, were higher than for the ES110 students. This is not surprising given that students were placed into ES110 because of their lower performance on readiness exams. By the end of the semester, though, mean post-scores for the control males were still highest across all cohorts for this subscale, while the mean post-score for the control females was considerably lower than the other three cohorts. These combined findings – the greater decrease in academic self-confidence overall for students taking PH131, with the most substantial drop among PH131 females, and ES110 females' academic self-confidence remaining fairly stable – suggest that engineering students' academic self-confidence may benefit from taking a course that discusses engineering and its implications within a societal context, and that this may be more important for females than for males.

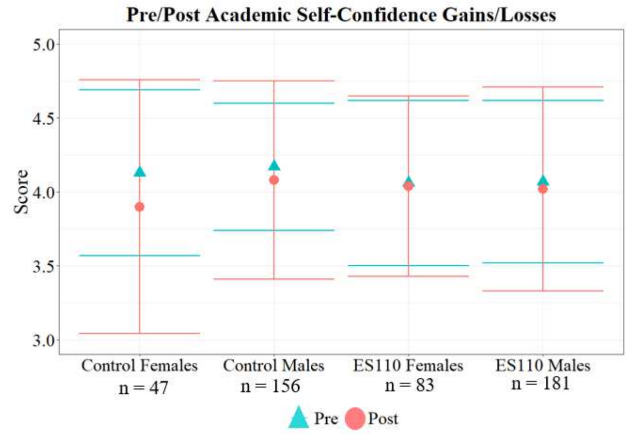

Figure 1. A plot depicting pre-/post-mean score differences with error bars for all cohorts for the academic self-confidence subscale.

Student responses to a few selected items in this subscale shed additional light on these findings (Table 2). For the item: "*On the whole, I am pleased with my performance as a student*," pre/post responses declined significantly for all students except for ES110 females. The largest drop was for control females (-0.55), followed by control males (-0.22), and then ES110 males (-0.14). Ironically, the highest pre-scores for this item were found among the control females, yet their post-scores were lowest across all four cohorts. Responses to *"I feel that I am at least as capable as other students in my classes"* yield different results. Control females' scores were the only ones to drop. Control males' scores increased significantly. Scores for both male and female ES110 students increased substantially but not significantly, with post-scores remaining below the control male score and higher than the control females.

Table 2. Pre-/post-student responses to selected items from the academic self-confidence subscale

Cohort	On the whole, I am pleased with my performance as a student.			I feel that I am at least as capable as other students in my classes.		
	Mean Pre	Mean Post	Post-Pre	Mean Pre	Mean Post	Post-Pre
Control Females	4.38[d]	3.83	**-0.55[b, e]**	4.19	4.03	-0.16
Control Males	4.23	4.01	**-0.22[c]**	4.18	4.36	**0.18[a]**
ES110 Females	4.08	4.00	-0.08	4.04	4.15	0.11
ES110 Males	4.06	3.92	**-0.14[a]**	4.02	4.12	0.1

Note: [a]Statistically significant at the $p \leq 0.05$ level
[b]Statistically significant at the $p \leq 0.01$ level
[c]Statistically significant at the $p \leq 0.001$ level
[d]Underlined values indicate the highest pre/post means across all four cohorts for each item.
[e]Bolded values indicate statistically significant changes.

The significant difference in pre/post changes to this subscale between ES110 and PH131 students support our own previous research, which found that ES110 students' self-confidence (academic and engineering-related) improved significantly compared to that of control students taking PH131 [34]. Gender differences were not explored in that study, but others have found an overall decline in first-year students' academic self-confidence, particularly among female students [32]. In fact, a recent study that examined gender differences among sophomore and junior level students enrolled in a sociotechnical energy course found that among these older students, females' self-confidence scores improved substantially compared to males' scores, which were unaffected [42]. The differences between these studies are likely reflective of an overall decline in first year students' academic self-confidence [43, 44].

B. Engineering Self-Confidence

Mean scores on the engineering self-confidence subscale decreased for control females, while ES110 females' scores increased (Table 1, Fig. 2). Engineering self-confidence scores for ES110 males also increased, although to a lesser extent than for ES110 females; scores did not change for the control male cohort (Table 1, Fig. 2). The pre-mean score was highest for the control male cohort across all cohorts, while the post-mean score was highest for ES110 females (Table 1). There were no significant differences between the mean scores, or between the pre/post changes, among any cohorts for this subscale. The most noteworthy changes are that the pre-scores were higher for control students relative to the ES110 students, but at the end of the semester, the post-score for the female control cohort was considerably lower in comparison to the other three cohorts, which were all quite similar.

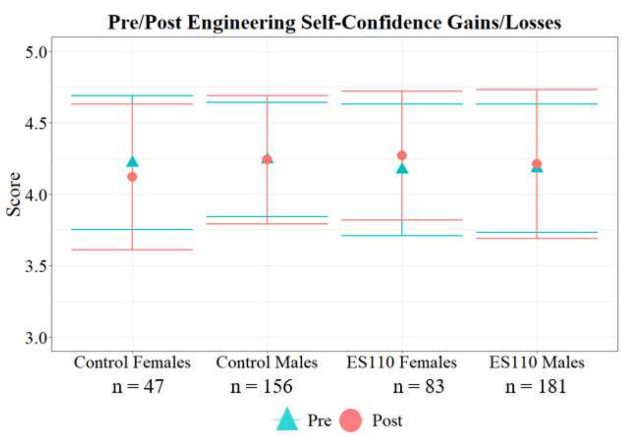

Figure 2. A plot illustrating pre-/post-mean scores differences with error bars for all cohorts for the engineering self-confidence subscale.

As with academic self-confidence, taking an engineering course that contextualizes engineering seems to positively impact female students' engineering self-confidence during their first semester, as exemplified by the rise in scores for female students taking ES110 and the drop in scores for female students taking PH131. Post-scores for ES110 females were highest across all four cohorts. The relative lack of change in both male student cohorts suggests that taking a contextualized engineering course during their first semester did not have a substantial effect on their engineering self-confidence.

Student responses to some of the items included in this subscale illuminate why the cohorts' mean scores changed the way they did (Table 3). For the item: *"I feel confident about applying a systematic process to solve an unfamiliar problem,"* control females' scores dropped substantially (-0.19), while ES110 females' scores improved significantly (+0.23; $p < 0.05$). Similar trends were found for the male cohorts, but to a much lesser extent. ES110 males' scores improved slightly (+0.05), whereas control males' scores decreased slightly (-0.02). At the end of the semester, control females' scores for this item were substantially lower than the other three cohorts, whose scores were all similar. Interestingly, responses to *"I feel confident working as a member of a team"* reveal a different story. Scores decreased for all cohorts except the ES110 females; control males decreased the most, followed by ES110 males, and then control females with a slight decline. ES110 females' scores did not change over the semester, and their post-scores were highest across all four cohorts, indicating that, relative to the other three cohorts, female ES110 students benefitted from participating in group projects during their first semester.

Although a statistically significant difference was not determined between ES110 and PH131 students for this subscale, these findings generally support our own previous research, which examined the combined group of male and female students and showed that ES110 students' self-confidence (academic and engineering-related) improved significantly compared to that of control students taking PH131 [34]. Besterfield-Sacre et al. [45] found that, in general, female engineering students start their engineering studies and end their first semester and first-year with lower engineering self-confidence than their male peers, which doesn't entirely coincide with our findings since control females had a higher pre-engineering self-confidence score than ES110 males and ES110 females had higher post-scores than both male cohorts. Students are enrolled in ES110 during their first semester because they scored lower on math and physics readiness exams before starting their studies compared to their peers in PH131; intuitively, it makes sense then that control females would have higher engineering self-confidence pre-scores than their male peers in ES110 since they scored higher on the math and physics readiness exams. The elevated scores for ES110 females relative to their male peers may have resulted from their exposure to engineering from a sociotechnical framework – which showed that being an engineer is not confined to math and science, but also involves collaborating with other professionals, working on teams, and problem-solving.

Table 3. Pre-/post-student responses to selected items from the engineering self-confidence subscale

	I know a lot about using different methods to solve a new problem or tackle a challenge			I feel confident working as a member of a team.			I feel confident about applying a systematic process to solve an unfamiliar problem.		
Cohort	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**
Control Females	3.96[b]	3.75	-0.21	4.26	4.21	-0.05	4.06	3.87	-0.19
Control Males	3.97	4.01	0.04	4.35	4.23	-0.12	4.10	4.08	-0.02
ES110 Females	3.87	4.10	**0.23**[a, c]	4.30	4.30	0	3.88	4.11	**0.23**[a]
ES110 Males	3.92	4.01	0.09	4.33	4.25	-0.08	4.06	4.11	0.05

Note: [a]Statistically significant at the $p \leq 0.05$ level

[b]Underlined values indicate the highest pre/post means across all four cohorts for each item.

[c]Bolded values indicate statistically significant changes.

C. Satisfaction with Engineering/Sense of Fit

Student mean scores decreased in the satisfaction with engineering/sense of fit subscale across all four cohorts, but the decrease was only significant for control males (Table 1, Fig. 3). Scores decreased the most for ES110 females (-0.12), although their pre-scores were highest across all cohorts and their post-scores were still higher than either of the control cohorts, and only slightly lower than ES110 males, whose scores dropped least over the semester (Table 1, Fig. 3). There were no statistically significant differences between the score changes, or between the pre- or post-scores, among the four cohorts. Control females scored considerably lower than the other three cohorts on both the pre- and post-surveys for this subscale.

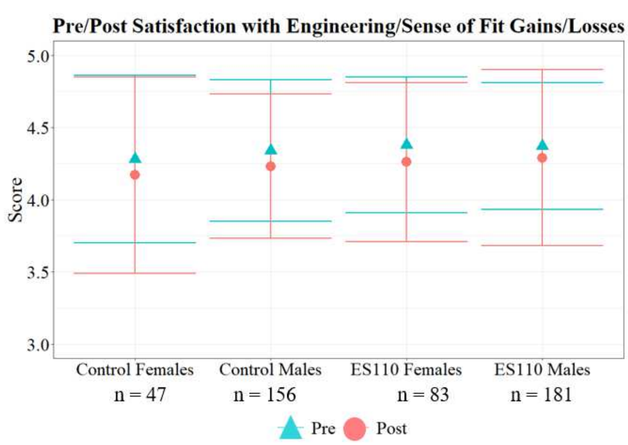

Figure 3. A plot showing pre-/post-mean scores differences with error bars for all cohorts for the satisfaction with engineering/sense of fit subscale.

The overall decline in students' satisfaction with engineering/sense of fit score among all four cohorts is surprising. There are six items in this subscale. In addition to the questions shown in Table 4, the other two questions ask students about their intention to persist in an engineering major, and whether they can "picture themselves" working as an engineer. Previous studies had separated this group of questions into two separate subscales (satisfaction with engineering, and fit within engineering profession) [34]. However, psychometric analysis of the survey recommended combining these items into one subscale [36]. As a result, the subscale mean scores tend to be dominated by the rather large number of items that relate more to "satisfaction" than to "belonging," and many of these received low student responses overall (Table 4). In the earlier study, student responses to the satisfaction with engineering subscale also decreased for ES110 students, and although they increased for the control group, scores for both groups were similar at the end of the fall semester [34]. In our case, post-scores for three of the four cohorts are similar, with the exception being the female control group, whose post-scores are considerably lower. Despite the widespread pre-post drop in average mean responses to items in this subscale (Table 4), in general both pre and post scores are quite high, with minimal discernable differences among the cohorts. Both pre- and post-scores for "*I look forward to a career in engineering*" are slightly higher for ES110 cohorts compared to the control cohorts. Across the six subscale items, ES110 females had highest post-scores on two questions, while the control females' post-scores were lowest on five questions.

Student responses to the one question included in this subscale that focuses directly on students' sense of belonging in engineering reveal an important finding that the overall subscale analysis failed to capture (Table 4). ES110 females' responses to *"I will feel 'part of the group' (i.e., I will fit in, or feel like I belong) if I get a job in engineering"* improved the most across all four cohorts, followed by ES110 males. Scores to this item for the control females slightly increased, while those for the control males slightly decreased. These findings align with the results from our earlier study which showed that ES110 students, as a whole, increased in their sense of belonging relative to the control group [34]. In the current study, both male cohorts started out with much higher scores on the pre-survey compared to either of the female cohorts, and although the male post-scores remained higher, the differences between the male and female cohorts were much less at the end of the semester than they were at the beginning. Moreover, the post-score for ES110 females was substantially higher than that of the female control cohort. These results support earlier findings from our own research that sociotechnical classes may help female students find a sense of belonging in engineering. For example, Bilow et al. [42] found that after taking a sociotechnical energy course, female engineering students' satisfaction with engineering/sense of fit increased significantly compared to their male peers, whose scores slightly decreased. Similarly, Bilow & DeWaters [46] found that compared to their male peers, higher percentages of female students in a sociotechnical biomedical engineering course reported that their sense of belonging in engineering had been positively impacted by the course. These findings also support the suggestions of various scholars, who have indicated that presenting engineering within a societal context or from a sociotechnical perspective may help women in engineering to find a sense of belonging [15, 27, 29-31].

Table 4. Pre-/post-student responses to selected items from the satisfaction with engineering/sense of fit subscale

	At the present time, I am satisfied with my decision to study engineering.			A degree in engineering will allow me to get a job where I can use my talents and creativity.			I look forward to a career in engineering.			I will feel "part of the group" if I get a job in engineering.		
Cohort	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**
Control Females	4.45	4.28	-0.17	4.51	4.30	-0.21	4.40	4.25	-0.15	3.85	3.87	0.02
Control Males	4.51	4.34[d]	**-0.17[b, e]**	4.51	4.37	**-0.14[b]**	4.48	4.28	**-0.20[a]**	4.10	4.06	-0.04
ES110 Females	4.58	4.34	**-0.24[b]**	4.58	4.46	-0.12	4.65	4.41	**-0.24[b]**	3.83	3.98	0.15
ES110 Males	4.52	4.28	**-0.24[c]**	4.58	4.39	-0.19[c]	4.56	4.44	**-0.12[a]**	4.03	4.10	0.07

Note: [a]Statistically significant at the $p \leq 0.05$ level
[b]Statistically significant at the $p \leq 0.01$ level
[c]Statistically significant at the $p \leq 0.001$ level
[d]Underlined values indicate the highest pre/post means across all four cohorts for each item.
[e]Bolded values indicate statistically significant changes.

D. Understanding of Engineering

All student cohorts significantly improved their understanding of engineering score over the course of the semester (Table 1, Fig. 4). Gains for both male and female ES110 cohorts were significantly greater than either of the control cohorts (ES110 males vs. PH131 males and females: $p < 0.001$; ES110 females vs. PH131 males: $p < 0.001$; ES110 females vs. PH131 females: $p = 0.003$; ES110 vs. PH131: $p < 0.001$). ES110 males' understanding of engineering increased the most (+0.39), followed closely by ES110 females (+0.37), then control females (+0.18) and finally control males (+0.04) (Table 1, Fig. 4). ES110 females' pre-and post-mean scores were the highest among all four cohorts in this subscale, and post-scores for both male and female control cohorts were significantly lower than both ES110 cohorts' scores ($p < 0.001$). There were no significant differences between any of the pre-scores, or between the male and female cohorts within each group (ES110 and PH131).

The significant improvement in this subscale for ES110 students is not surprising and confirms previous findings, which did not differentiate between genders [2, 34]. There was a slight gender difference among the ES110 students – males' scores increased slightly more than females' (0.02 difference); however, ES110 females started and finished with higher scores relative to their male counterparts. This finding supports other studies in the literature that have found female students are more apt to think about sociotechnical engineering and the role engineering plays in society. Kilgore et al. [29] found "that first-year women are more ready than men to do engineering in context" (p. 331). Swartz et al. [31] determined that female students place greater importance on the sociotechnical elements of engineering compared to their male peers. Bilow et al. [42] and Bilow & DeWaters [46] found that female students' understanding of engineering and the sociotechnical nature of engineering significantly improved after taking sociotechnical engineering science courses relative to their male classmates.

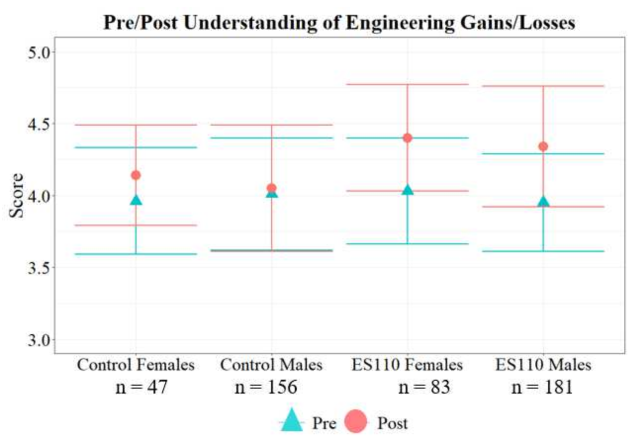

Figure 4. A plot illustrating pre-/post-average score differences with error bars for all cohorts for the understanding of engineering subscale.

Responses from the control students also increased for this subscale, although to a lesser extent, and their post scores were lower than their ES110 counterparts. Students in the control group were not enrolled in a course that discussed engineering work, so it is encouraging that being in an engineering program, working side-by-side with other engineering students, may contribute to their general understanding of the engineering discipline. Responses to selected items in this subscale reveal important differences between the cohorts, indicating that relative to the control group, students who enroll in ES110 develop a deeper understanding of engineering and the role it plays in society (Table 5), and those differences are even more pronounced for female students. For example, student responses to *"I understand the relationship between engineering and the society in which it is practiced"* were significantly higher on the post-survey for both ES110 cohorts compared to the control cohorts (ES110 females vs. PH131 males: p = 0.001; ES110 females vs. PH131 females: p = 0.01; ES110 males vs. PH131 females: p = 0.003; ES110 males vs. PH131 males: p = 0.000). For this item, both ES110 cohorts' scores increased significantly, control females' scores improved substantially, and control males' scores dropped significantly. ES110 females started out with considerably higher pre-scores across all four cohorts, and post-scores were considerably higher for both ES110 cohorts relative to their PH131 peers. In fact, ES110 students' post-scores were higher than those for the control cohorts on all items in this subscale, and post-scores for the female ES110 cohort were highest for 7 out of 9 items total (4 out of the 5 items in Table 5; remaining items available by request). These findings further confirm the benefits of a sociotechnical engineering course for developing students' understanding of engineering as sociotechnical.

Table 5. Pre-/post-student responses to selected items from the understanding of engineering subscale

	The role of engineers is limited to technical problem solving.[f]			I understand the relationship between engineering and the society in which it is practiced.			I understand how engineers work with other professionals and technicians to solve problems.			Ethical problem solving is an important part of engineering design.			I understand how engineering decisions are made.		
Cohort	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**	**Mean Pre**	**Mean Post**	**Post-Pre**
Control Females	3.81[d]	3.98	0.17	3.75	3.94	0.19	3.64	4.00	0.36	3.92	4.26	**0.34**[b]	3.51	3.55	0.04
Control Males	3.81	3.90	0.09	3.78	3.61	**-0.17**[a]	3.84	3.86	0.02	4.03	4.17	**0.14**[a]	3.68	3.72	0.04
ES110 Females	3.76	4.04	**0.28**[a, e]	3.90	4.45	**0.55**[c]	3.78	4.31	**0.53**[c]	4.17	4.64	**0.47**[c]	3.40	4.21	**0.81**[c]
ES110 Males	3.70	3.97	**0.27**[c]	3.71	4.34	**0.63**[c]	3.79	4.20	**0.41**[c]	3.99	4.59	**0.60**[c]	3.59	4.22	**0.63**[c]

Note: [a]Statistically significant at the $p \leq 0.05$ level
[b]Statistically significant at the $p \leq 0.01$ level
[c]Statistically significant at the $p \leq 0.001$ level
[d]Underlined values indicate the highest pre/post means across all four cohorts for each item.
[e]Bolded values indicate statistically significant changes.
[f]Negatively worded item reverse-scored for analysis

E. Summary

Overall, we found that ES110 students had a more positive experience than control students, especially in terms of their academic and engineering self-confidence, as well as their understanding of engineering. Regarding gender differences, ES110 females' experience was the most positive compared to the other three cohorts. Although the control students in PH131 began the semester with higher levels of academic self-confidence, their scores decreased over the course of the semester while the ES110 students' academic self-confidence remained relatively stable. PH131 females' academic self-confidence dropped substantially and was considerably lower than the other three cohorts' scores at the end of the semester. PH131 students' engineering self-confidence was also higher than ES110 students at the beginning of the semester. ES110 females' engineering self-confidence fared the best, with their scores increasing the most and having the highest post-score. In contrast, PH131 females' engineering self-confidence decreased considerably, and their post-scores were the lowest across all four cohorts. ES110 males' score increased slightly, while control males' engineering self-confidence was unchanged. Students' satisfaction with engineering/sense of fit decreased across all four cohorts over the course of the semester; however, this group of questions was dominated by a preponderance of items related to students' decision to study engineering and their perceptions of an engineering career, questions which students responded to more negatively over the course of the semester. There was one item that directly asked students about their sense of belonging in engineering, *"I will feel 'part of the group' if I get a job in engineering."* ES110 students' response to this item increased substantially compared to their PH131 peers, with ES110 females' scores increasing much more than ES110 males. All four cohorts' understanding of engineering significantly improved, but this improvement was much larger for ES110 students than PH131 students. In the control group, females' understanding increased more than males', and ES110 females' pre and post-scores were a bit higher than ES110 males.

It is important to note that the student responses to these surveys were influenced by a variety of factors, beyond the specific courses in which they were enrolled. This is especially true for the self-confidence and satisfaction with engineering/sense of fit items. First-year students, especially in their first semester, are adjusting to university life, as well as an engineering curriculum, which could play a role in their feelings of belonging at the university and in general, and would not be related to whether they took ES110 or PH131.

F. Limitations

The sample size had an impact on the analysis and was a limiting factor as the number of female students included in the study was much less than the number of male students. These numbers were representative of the engineering student population. Moreover, irregularities in the data required us to use nonparametric statistical procedures, which generally have less statistical power compared to parametric tests, such as Students' t-test and ANOVA. Collecting data over a longer period of time would help overcome these irregularities, and allow us to adjust our cohort numbers by randomly sampling within our populations. Another limitation is related to the type of data collected; Likert survey data limits student responses to distinct categories, which can lead to a loss of information [47-49]. Given the small number of females, this study would especially benefit from the addition of student interviews and open-ended survey questions to supplement the ordinal Likert data.

IV. CONCLUSION

A. Summary

This study has examined how female and male FYE students' attitudes toward and understanding of engineering were affected after taking a sociotechnical versus a more technical course during their first semester. Results from this study have shown that introducing students to the sociotechnical aspects and implications of engineering work can enhance FYE students' understanding of engineering, regardless of their gender, and that female students are particularly responsive to learning about engineering within a societal context. All students in this study experienced a decrease in their overall satisfaction with engineering/sense of fit over the course of the semester, although ES110 students showed a positive increase in the degree to which they would feel "part of the group" (i.e., fit in or belong) in an engineering job, with this increase being more pronounced for females than for males. Students' degree of satisfaction with engineering studies and careers declined over the course of the semester for all cohorts, although their post-scores were still generally high (ranging from 4.25 to 4.45 out of 5). These results point to the many complex factors that influence FYE students' first semester as college students.

Our results also show that students' academic and engineering self-confidence may benefit from taking a sociotechnical course, rather than an additional technical course like physics, during their first semester. Prior to the semester, FYE students who were placed into ES110 had lower academic and engineering self-confidence compared to the control group. Yet their academic self-confidence scores remained relatively constant, while the academic and engineering self-confidence of students in the control group declined over the course of the semester. The decline was particularly pronounced for females in PH131, whose post-scores were lowest across all three cohorts. In terms of their engineering self-confidence, female ES110 students' scores increased, both male cohorts remained relatively constant, and females in PH131 again experienced a severe decline. Post-scores were highest for female ES110 students and lowest for PH131 females. These findings suggest that taking an introductory engineering course instead of a rigorous, technical course during engineering students' first semester may be beneficial for all FYE students, but those benefits may be even more pronounced for females. This paper adds a case study to the growing body of literature that is investigating the most effective ways of enhancing engineering students' experiences in the classroom during their early years, as well as ways of developing students' abilities to understand and solve engineering problems through a sociotechnical lens, accounting for technical, social, environmental, economic, safety, and ethical implications during the design process.

B. Future Work

Future research includes tracking FYE students during their entire first-year rather than just the fall semester to examine how their attitudes toward and understanding of engineering might continue to change as they take either ES110 or PH131 during their spring semester. Additionally, this study will be broadened to include students from other engineering science courses that incorporate sociotechnical implications of engineering problems, to explore how their attitudes toward and understanding of engineering change after taking a sociotechnical course. These students will be recruited from all class years allowing an examination of class year differences along with gender differences.

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