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Work In Progress: Examining the Impacts of a Sociotechnical Approach to Energy Education on Engineering Students' Sense of Belonging and Attitudes Toward Engineering

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Introduction and Background

Engineering is sociotechnical – problems involve technical and non-technical (i.e. social, economic, cultural, political, etc.) factors that are simultaneously connected with one another [1]. In order for engineering students to be prepared to solve the challenges and problems in a constantly changing world, they must learn how to think in a sociotechnical way [2, 3]. However, current engineering curricula fail to prepare students to problem solve in this manner and instead mainly focus on the technical content [4-6].

One area that is suitable for a sociotechnical approach is energy education. Energy in engineering education is usually taught in foundational courses, such as *Thermodynamics* or *Circuits*, where problem solving is narrowly structured around the technical aspects [7, 8]. Each engineering and science discipline uses a different definition for energy; this can create confusion about energy for students as they continue through their studies [7, 8]. The lack of context in engineering curricula and confusion around a definition of energy can prevent students from seeing the importance of energy, the role it plays in sociotechnical problem solving, and the impact energy has on their own lives [7, 8].

It is well-known that women are underrepresented in engineering [e.g. 9]. Research suggests one factor that influences women to stay in engineering is finding a sense of belonging [10, 11]. Research also suggests that presenting engineering within a societal context can help attract and retain women in engineering because women tend to choose career fields that involve helping and working with people [11-13]. Courses that are designed to teach engineering concepts from a sociotechnical perspective may allow women to find social relevance to the profession [14] and find a sense of belonging in engineering. As a result, this may help increase the retention rate of women in engineering.

This work-in-progress paper examines how using a sociotechnical approach to teach energy influenced engineering students' sense of belonging/attitudes toward engineering, with a specific focus on the differences between male and female students. These differences were examined by using pre- and post-survey data from two sophomore-level introductory energy courses, *Introduction to Energy Systems* and *An Integrated Approach to Energy*, at two different universities, Clarkson University (CU) and the University of San Diego (USD).

Methods

Energy Courses

Both courses teach energy in a contextualized way with an emphasis on introducing students to fundamental energy principles and exposing them to a variety of energy topics. Students are required to critically analyze energy resources and energy systems within a social, economic, political, and environmental context, to gain a comprehensive understanding of the role of energy in our current and future society. *Introduction to Energy Systems*, taught at CU, takes a case study approach where students are in charge of leading discussion on particular issues. *An*

Integrated Approach to Energy, taught at USD, relies on structured active learning approaches within each class to help students discover knowledge for themselves [8].

Survey

Students in both classes were given a pre-/post-survey that was constructed using a selection of items from three existing surveys, in order to fully capture the breadth of topics we are interested in investigating. Students' technical knowledge was assessed with 19 energy-knowledge-based questions adapted from an energy knowledge survey developed by DeWaters [15, 16] to suit the needs of a parallel study investigating students' overall gains in content knowledge in these same courses [8]. Eight questions about the importance of professional engineering skills were adapted from [17] and will similarly be addressed in future work. This paper focuses on results from a set of 13 questions that ask students about their overall attitudes toward engineering and their confidence and sense of belonging as an engineer, which were extracted from an engineering attitudes survey developed and used to evaluate a first-year engineering course at CU [18, 19]. These questions are provided in the appendix.

Student Sample

The students who took the survey were enrolled in their respective course during the spring 2020 semester. A breakdown of the students who took the survey can be found below in Table 1.

Table 1. Student Sample

University	N	Female	Male
CU	33	4	29
USD	17	5	12

Analysis

Questions were split into three categories: self-confidence (4 questions), understanding of engineering (6 questions), and satisfaction with the decision to study engineering/sense of fit (3 questions) [18]. Sample questions from each category include: "I am capable of becoming an engineer" (self-confidence), "Engineering decisions are influenced by the societal context in which they take place" (understanding of engineering), and "I look forward to a career in engineering" (satisfaction with engineering/sense of fit). Survey responses were analyzed using the statistical software R. Responses were based on a 5-point Likert scale and were recoded to numerical values (strongly disagree = 1 to strongly agree = 5). Each student's overall score was calculated for each category as a percentage of the maximum attainable score. Students' overall scores for each category from the pre- and post-survey were compared using a paired t-test; female students' overall scores for each category from the pre- and post-survey were compared to the male students' overall scores for each category from the pre- and post-survey using an unpaired t-test [20, 21]. A statistically significant difference was justified with a p-value ≤ 0.05 (95% confidence interval). The student responses from both courses were combined when analyzing the differences to create a larger sample size (female: n = 9; male: n = 41).

Results and Discussion

The results indicate that, overall, female students' sense of belonging and attitudes toward engineering increased with measurable changes in all three categories of the survey. Male students' attitudes did not change appreciably between the pre- and the post-survey, yet their average responses were initially higher compared to the females in each category.

For the self-confidence category, the female students' average score increased after taking the energy course (Figure 1), though it was determined to not be statistically significant ($p = 0.15$). The male engineering students' average score remained unchanged ($p = 0.9$) for both the pre- and post-survey (Figure 1), but their responses on the pre-survey were already statistically higher than the females' ($p = 0.03$), indicating that even before the class male students had higher levels of self-confidence. There are many other studies that have found that male engineering students usually have more confidence in themselves and their abilities compared to female engineering students [22-24]. The change in the females' average score shows promising results that teaching an engineering concept contextually could have an impact on female students' self-confidence in becoming engineers, though a larger sample is needed to confirm this trend.

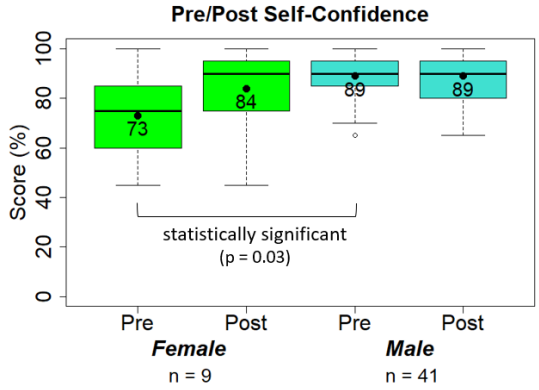

Figure 1. A box-and-whisker plot showing student responses to the pre- and post-survey for the self-confidence category. Black dots indicate average mean response, and the brackets indicate a statistically significant difference. Female students' average score increased from 73% (pre) to 84% (post). Male engineering students' average score remained at 89%.

As for the understanding of engineering category, female students' average score increased significantly ($p = 0.05$, Figure 2). Male students' average score was unaffected in this category ($p = 0.9$, Figure 2). The male students had a slightly greater understanding of engineering before starting the course compared to the females, but it the difference was not significant ($p = 0.40$). The female students' average post-score was significantly higher than the male students' average post-score for this category ($p = 0.04$). This difference reveals that female students were very receptive to this type of pedagogical approach and had a much better understanding of what engineers do and the context in which they solve problems after taking the course. Cohen and Sanford Bernhardt [1] similarly found that after contextualizing engineering and presenting engineering as sociotechnical in a course, first-year engineering students had gained a better understanding of the social implications of engineering, though gender differences were not reported in this study.

Female students' feelings of satisfaction with their decision to study engineering/sense of fit in engineering also increased significantly (p = 0.02, Figure 3). The male students' satisfaction with engineering/sense of fit slightly decreased after taking the energy course although the change was not significant (p = 0.2), and (Figure 3). The males initially had higher feelings of satisfaction with deciding to study engineering and feeling like they fit in compared to the female students (p = 0.004). This aligns with other studies in STEM education that have found male students have stronger feelings of belonging/sense of fit compared to female students [25, 26]. However, after taking the course, the females had the same feelings of satisfaction with engineering and sense of fit in engineering as the males. This finding suggests that the female students were able to find more of a sense of belonging in engineering after taking a course that taught energy in a contextualized way.

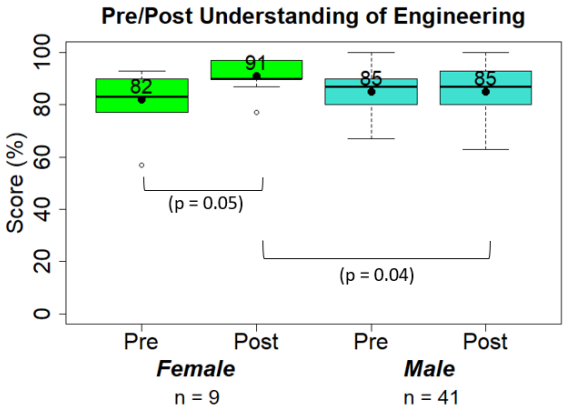

Figure 3. A box-and-whisker plot illustrating students' pre- and post- scores to the questions in the understanding of engineering category. Female students' average score increased from 82% (pre) to 91% (post). Male students' average score stayed at 85%.

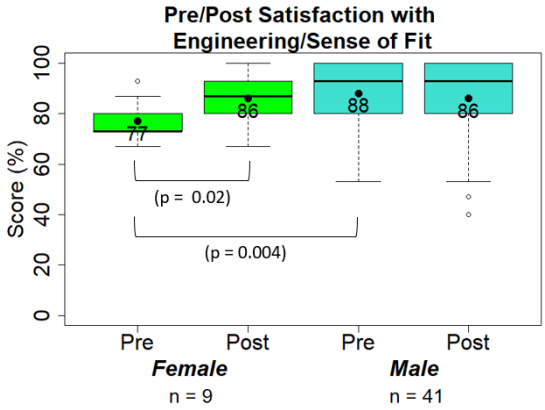

Figure 2. A box-and-whisker plot depicting students' pre- and post- scores to questions in the satisfaction with engineering/sense of fit category. The female students' average score increased from 77% (pre) to 86% (post). The male students' average score decreased from 88% (pre) to 86% (post).

The engineering attitudes survey has been used prior to this study on first-year engineering students at CU. DeWaters et al. [27] found that first-year engineering students who took a sociotechnical course their first semester improved significantly in their self-confidence, sense of fit within the engineering profession, and understanding of the broad nature of engineering and engineering problem solving compared to students who were enrolled in a physics course. However, gender differences were not analyzed in this study.

Future Research and Limitations

Likert survey data limits students in terms of how they can respond to each question, which can cause a loss of information [28-30]. Student interviews would provide a much better understanding of their feelings of belonging and why they feel that way. This study also had a small sample size, especially in the number of female students (n = 9), which does not allow for a complete, representative sample and may have created some bias in the study. Another limitation to this study is that students in both courses had to adapt to online instruction in the middle of the semester due to the COVID-19 pandemic; this adjustment may have affected how students responded to the post-questions and their feelings of belonging in the class, at their

university, and in engineering. It also may have affected how much they got out of the energy course.

Future research will further examine the full effects that using a sociotechnical approach can have on different genders. We are currently adding male/female differences to the analysis of first-year student experiences, previously described [27]. Future plans include using the survey in addition to semi-structured interviews with students to better understand their attitudes and sense of belonging. The study will be expanded to include students in other engineering science courses at both universities that discuss engineering problems and engineering within a sociotechnical context and comparing their feelings of belonging with students in similar courses where engineering problems are defined more narrowly. Another avenue for future research is investigating the learning environments of various courses and how those environments affect students, especially students from underrepresented groups.

Conclusion

Findings of this preliminary study suggest that using a sociotechnical approach to teach energy influenced female engineering students' sense of belonging/attitudes toward engineering, especially their understanding of engineering and feelings of satisfaction with engineering/sense of fit within engineering. However, the study indicated that there was not a large change in male engineering students' sense of belonging and attitudes toward engineering after using this approach to teach energy. Male students initially had higher feelings of belonging and attitudes toward engineering before taking their respective course versus the female students. Overall, this adds a case study to the existing literature that discusses how presenting engineering problems in a social context can enhance female engineering students' experiences and may retain women in engineering. It also presents new data to show that instead of just discussing the social or the technical factors of an engineering concept separately, but the two combined together, can affect students' sense of belonging and attitudes toward engineering, especially for female students. However, future research is still needed to get a more complete understanding of the effects that a sociotechnical approach can have on engineering students' sense of belonging/attitudes toward engineering.

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Appendix: Engineering attitudes portion of the survey

Self-confidence	
1	I feel that I am at least as capable as other students in my classes.
2	I have a positive attitude toward myself and my abilities.
3	I feel confident about applying a systematic process to solve an unfamiliar problem.
4	I am capable of becoming an engineer.
Understanding of Engineering	
5	The role of engineers is limited to technical problem solving.
6	Ethical problem solving is an important part of engineering design.
7	Engineering decisions are influenced by the societal context in which they take place.
8	I understand the relationship between engineering and the society in which it is practiced.
9	Engineers are responsible for solving technical problems with little to no collaboration with other professionals.
10	I understand how engineers work with other professionals and technicians to solve problems.
Satisfaction with Engineering/Sense of Fit	
11	At the present time, I am satisfied with my decision to study engineering.
12	I will feel a part of the group (i.e. I will fit in or feel like I belong) if I get a job in engineering.
13	I look forward to a career in engineering.