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Environmentally and Socially Responsible Engineering - Assessing Student Empowerment

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Introduction

Mechanical engineering in particular is known as the broadest engineering discipline and has particularly wide societal impacts (Sprouse III et al. 2021). Civil and environmental engineering are also known for their high and broad societal and environmental impact due to the design of long-lasting and large infrastructure systems. Engineering design that lacks social and environmental considerations likely leads to instances where social injustices are perpetuated. Thus, as engineering educators, it should be part of our profession to highlight and emphasize how these engineering professions impact society and the environment in which we live. This has been explored in many studies aiming to gauge the effectiveness of engineering programs at producing culturally and environmentally engaged professionals, and the consensus is clear: more efforts surrounding sustainability developments in mechanical and civil and environmental engineering are necessary.

While many higher education programs in these two disciplines are effective at producing students that can formulate, identify, and solve engineering problems, there is a need for broader understanding of engineering solutions in an environmental and social context. A study on infusing more socially conscious mechanical engineering coursework revealed that only 59% of students promised to engage in sustainable design post-course (Issa 2017). Another study showed that student interests in socially conscious topics and public welfare decline over the course of their engineering education (Cech 2014).

Corporations, government agencies, and other non-governmental organizations (NGOs) are increasingly recognizing the need for passionate employees who can understand and address environmental and societal challenges (Kumar et al. 2005). The increasing importance of all three aspects of sustainability makes it imperative that higher education programs prioritize the development of future engineers and decision makers who can effectively address sustainability topics; it is academia’s responsibility to infuse environmentally and socially responsible engineering into the curriculum.

With this responsibility in mind, our group of faculty members in the Mechanical Engineering and the Civil and Environmental Engineering departments at an R1 public institution took on the task of adding course modifications to required undergraduate courses in these departments. We will track how the student culture toward environmentally or socially responsible engineering changes over time. To track changes and, at this point in time, to collect baseline data, a survey instrument was created and has been distributed to 1st year, 3rd year, and 4th year students every semester since Fall 2020. Analyzing students' qualitative responses using a coding method has been found to be the best method for grouping similar statements and experiences (Lester et al. 2020). We will also discuss students' responses to an assignment asking them to identify the characteristics of successful professional engineers. We developed metrics to inform student attitudes towards economic, environmental, and social topics. After these metrics are decided, survey data including both closed and open-ended questions were quantitatively or qualitatively evaluated to form meaningful conclusions. Data was then thematically analyzed to assess any patterns. With these two initial pieces of program-wide assessment, the hope is to effectively gauge whether the curriculum changes being made are impacting student behaviors and attitudes surrounding sustainability topics, and to refine the engineering programs accordingly.

Data Collection

This WIP paper focuses on the survey that was distributed to engineering students in our school. The target population was 1st year engineering students from all majors and 3rd and 4th year students in the mechanical and the civil and environmental engineering majors. The survey was created in Qualtrics and was distributed in key courses to target the student population. The surveys were deployed near the end of each of the semesters online and according to IRB specifications and approval requirements. During the survey creation process, the team of instructors used current literature to get ideas for possible questions (K. Skamp et al. (2013), Bielefeldt et al. (2016), T. Shealy (2018), Shillaber et al. (2017), Strobel et al. (2009), Bielefeldt (2015)). The team decided on questions that would measure both students' perceptions and students' actions. The survey included quantitative and qualitative questions. Not all questions were asked in all years; instead, we focused on what would be more relevant according to the students' level of instruction in our institution. Among other questions, six quantitative questions were asked of students of all years and answers were categorized from strongly disagree to strongly agree. There were six questions that focused on students' perceptions.

A. I feel confident in using engineering knowledge or approaches for the advancement of human welfare and a sustainable future.
B. Nothing I can do as an engineer or private person will make things better on the planet.
C. In a future job, which of the following things would you like to be able to impact, directly or indirectly? - Poverty or lack of resources.
D. In a future job, which of the following things would you like to be able to impact, directly or indirectly? - Opportunities for women and/or minorities.
E. It is not the responsibility of engineers to assess the potential impacts on the economy, environment, or society; others who have different training should handle it. - What is your opinion?
F. To what extent is it a junior engineers' responsibility to reshape companies' goals to address environmental and social impacts of their technology/product? - What is your opinion?

Several qualitative questions focused on students' actions. Students in their 1st year were asked question 1 but not question 2 because the team assumed they would not have had time to accumulate enough experiences within the institution at that point.

1. Is there a time when you acted to improve some situation? Please explain.
2. Which projects with a social or environmental aspect have you participated in while at "our school" (in class, in projects)? Please list.

Question 1 will not be discussed in this paper because coding of the answers proved very challenging. In part, we think we should restructure the question since the answers are often too broad or vague to be usefully characterized. The team is still looking for ways to improve question 1 and gain more insight into how to gather data on students' actions rather than perceptions.

Aside from the survey, the team analyzed a different kind of assessment. Student teams in a 3rd year mechanical engineering lab course were asked to create a "list of characteristics or skills that [they] feel are critical to an engineering professional." Henceforth, this question will be referred to as the "characteristics of an engineer" question. The class includes no direct content related to environmentally or socially responsible engineering (although starting in the Spring 2021 semester, socially responsible design examples were introduced into lectures). Instead, the primary focus of the class is to highlight the value of non-technical aspects such as logistics and organization, team dynamics, and communication in successful engineering projects. These aspects, along with the traditional technical competency, dominate the student identified critical characteristics of engineering professionals.

Both the survey qualitative questions as well as the "characteristics of an engineer" question were coded by multiple researchers, both the team instructors as well as undergraduates with experience in qualitative coding. Question 2 coding eliminated answers that were absolutely outside the scope of this paper and categorized the answers in projects completed as part of a class or projects completed in an extracurricular activity. The "characteristics of an engineer" question was analyzed and categorized with three codes: environmental, social, and ethical.

Data Analysis and Discussion

Survey Quantitative Questions

A series of six questions were asked of 1st, 3rd, and 4th year students over 3 semesters, from Fall 2020 to Fall 2021, concerning their feelings and perceptions on topics related to social justice and environmental impact. Students were asked to report their extent of agreement with the statements A-F shown in the previous section. The results are shown in Figure 1. Responses to these questions were received from 285-370 1st year students, 317-368 3rd year students, and 191-235 1st year students, depending on the question, with the exception of questions C and D, which were not asked in Fall 2021 and therefore had 76 and 75, 237 and 234 and 237, and 134 and 127, respectively.

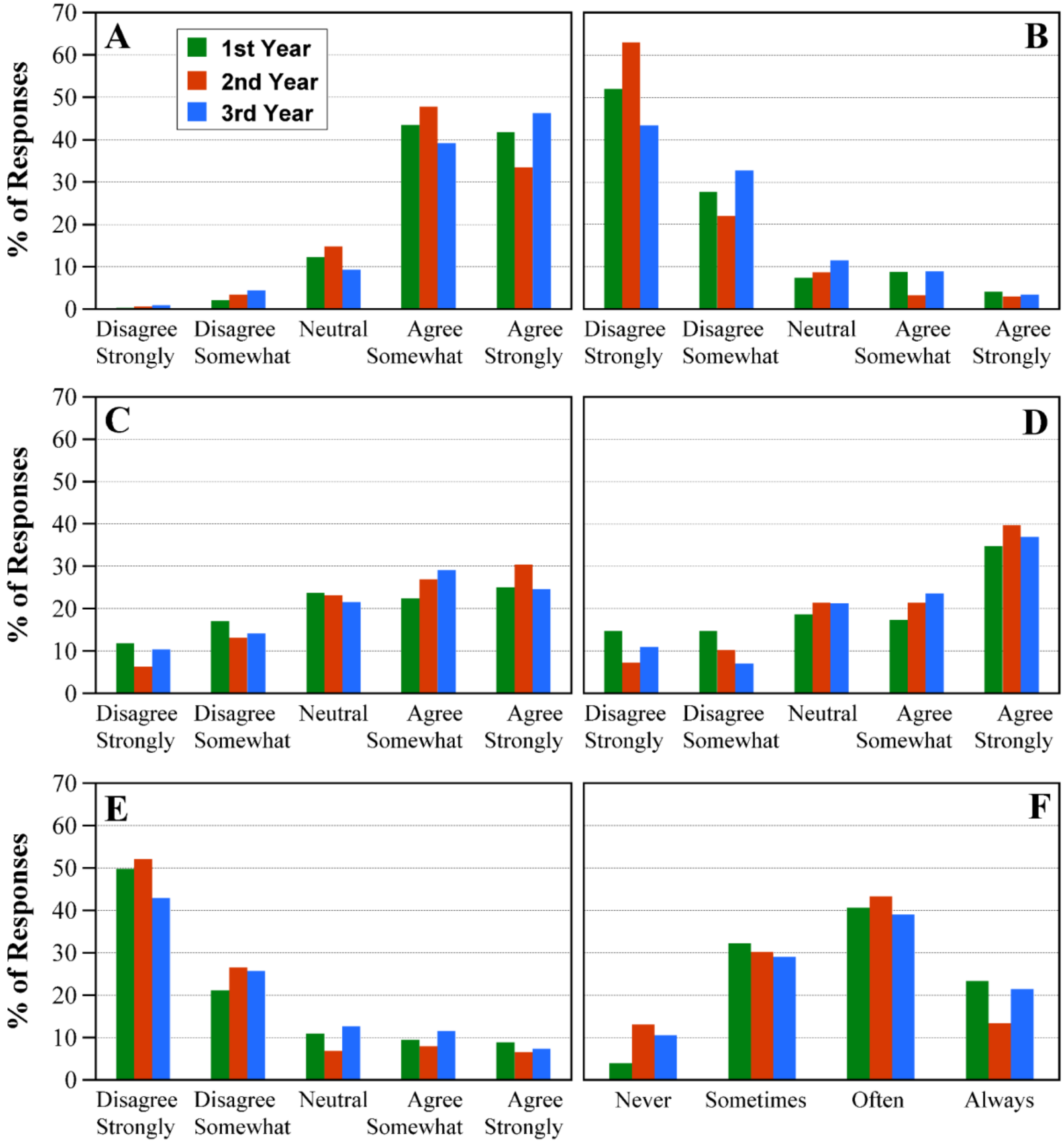

Figure 1. Responses to questions about student attitudes concerning skills, impact, and responsibilities. Letters A-F correspond to the question numbers in the text.

In general, these baseline data show no substantial and consistent differences among the different stages of the undergraduate education. To question A asking about students' confidence in using engineering skills to advance human welfare and sustainability, 84% of students responding to this question agreed or agreed strongly, whereas only 4% disagreed. To the negatively phrased question B aimed at feelings of empowerment, 81% disagreed and 10% agreed that nothing they could do would make things better. This shift may reflect the more global nature of B compared with A, but nevertheless shows considerable optimism.

Regarding one topic that students were asked about their desire to impact (C), poverty or lack of resources, feelings were more mixed, with 55% agreeing and 23% disagreeing. Likewise, regarding D, opportunities for women and minorities, 59% agreed and 20% agreed. The students, as a group, show a high degree of altruism. Though it is true that most students would like to impact, with their profession, poverty and opportunities for women and minorities, how and to what extent this will be true in the future is entirely another research project. However, it is important to know that this feeling is present in our students and this could be maximized and tapped into with the proper changes in the curriculum.

Question E asked whether engineers are responsible for assessing economic, social, and environmental impacts. This question was broadly similar to question B and was also phrased negatively. This question received 73% disagreement and 17% agreement; most students see the assessment of impacts as an aspect of engineering. The drop in disagreement with E compared to B may reflect either the engineering-specific phrasing of E, rather than the more general professional and personal phrasing of B, or the issue of specific responsibility versus general empowerment. This may suggest that some students believe that they have the ability to act as persons but not that such actions are inherent in engineering work.

Question F, regarding a junior engineer's responsibility to shape company goals, was divided into four categories, rather than the five of the previous questions. While 9% responded "never", the other 91% thought that it was at least sometimes their responsibility, with 19% going so far as "always". The inconsistency on the most negative responses between E and F is reflecting an as-yet not understood subtlety.

One question on the survey was asked only of 1st year students, probing the reasons they are pursuing an engineering degree, as shown in Figure 2A. The question asked students to rate agreement with these statements, separately: I am pursuing engineering … to help people, to earn a good living, because I enjoy it, and at the urging of my family. A large fraction, 84%, listed helping people as a reason, comparable to the 87% who agreed that they were doing it to earn a good living. Next came enjoyment, at 76%, although this had the highest fraction of "strongly agree". Far behind at 34% was family urging.

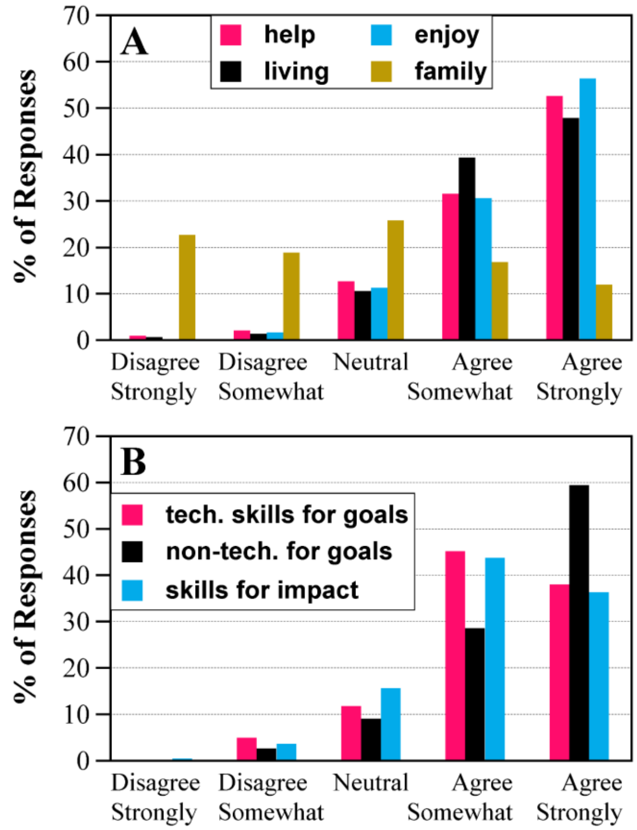

Figure 2. Responses to questions about student attitudes.

The seniors were asked, To what extent do you agree with the following statements?
- I have the technical skills I need as an engineer to accomplish my goals.
- I have the interpersonal/non-technical skills I need as an engineer to accomplish my goals.
- I have the skills I need as an engineer to positively impact society and the environment.

As shown in Figure 2B, students agreed most strongly that they had the necessary non-technical skills to accomplish their goals, which may be surprising in comparison with the lower level of agreement with the statement that they had the required technical skills. The skills needed for impact were rated to be the same as the technical skills.

Survey Qualitative Questions

As mentioned previously, some of the survey questions targeted students' actions, as opposed to feelings; they are listed in the data collection section of this paper. The quantitative results from the coding are presented in Tables 1 and 2. For the 3rd year students, around 30% (depending on the semester in which the survey was administered) answered the question. However, around 50% of the 4th year students answered the question. This is not surprising as the last year in an engineering program can make quite a difference in terms of lived experiences. Moreover, our school has a large number of transfer students that come from local colleges. It is possible that students had completed the social and environmental projects in previous institutions but did not find it appropriate to mention that here as the question specifically asked for projects completed in our school.

Given the students' responses, the team decided that splitting the answers between projects completed in classes and projects completed in extracurricular activities would provide an initial good analysis of the data. Projects completed in individual classes may be term papers, design projects, debates, and more in-depth capstone projects. Oftentimes in the engineering curriculum, these in-class projects do not really focus on the social and environmental aspects of technology or engineering design, however, this brief exposure may be enough to change students' perception of what engineering really is. Comparing the 3rd and 4th year students' responses, the numbers are not very surprising. Most of the 4th year students mentioned that their capstone had at least a small focus on social and environmental impact, and this explains the higher percentage of students answering in that way.

Projects that are completed in extracurricular activities include projects for Engineers Without Borders, for scholars' programs, for research projects, etc. Though students don't always give us enough information about the projects in the survey, it is likely that these projects provide a much deeper understanding of the real impact that technology and engineering designs have on society and the environment. These projects oftentimes focus on social justice issues and students seems to internalize a lot more of these aspects. In a future analysis, we would like to compare the data for this question to the quantitative questions to see if there is any relationship between students with one or multiple extracurricular activities that focus on social and environmental impacts and how they perceive their future professional impact.

Table 1 - Results of the coding of Question 2 for 3rd year students.

3rd year students - Which projects with a social or environmental aspect have you participated in while at "our school" (in class, in projects)? Please list.			
	Fall 2020	Spring 2021	Fall 2021
Total Respondents	74	183	115
Total Answers to this Question	21 (28.4%)	59 (32.2%)	36 (31.3%)
Answers that Mentioned Taking a Class	10 (13.5%)	30 (16.4%)	22 (19.1%)

Answers that Mentioned Extracurricular Activities	11 (14.9%)	29 (15.8%)	14 (12.2%)

Table 2 - Results of the coding of Question 2 for 4th year students.

4th year students - Which projects with a social or environmental aspect have you participated in while at "our school" (in class, in projects)? Please list.			
	Fall 2020	Spring 2021	Fall 2021
Total Respondents	56	90	100
Total Answers to this Question	28 (50%)	52 (57.8%)	54 (54%)
Answers that Mentioned Taking a Class	18 (32.1%)	35 (38.9%)	36 (36%)
Answers that Mentioned Extracurricular Activities	10 (17.8%)	17 (18.9%)	18 (18%)

"Characteristics of an engineer" Question

In a mechanical engineering lab course, students were asked to list the critical characteristics of engineering professionals. The data collected from Spring 2019 to Spring 2021 were coded to identify ethical, social, or environmental aspects, and the results are presented in Figure 3. Ethical items have some prevalence of reporting, but environmental and social aspects rarely appear within the self identification of professional characteristics. The course where this question was administered in, does not specifically cover content that addresses social justice issues, or more broad social impacts or environmental impacts. A higher prevalence of social and environmental professional responsibility would be expected within a course where these aspects are directly a part of the curriculum, as students are good at reflecting back the immediate content. This metric as it stands, provides an interesting un-influenced look at the engrained definition of professional engineering. Improving on this result may require an innate re-definition of an engineering professional, and this is a long term goal of the overall curriculum reform effort.

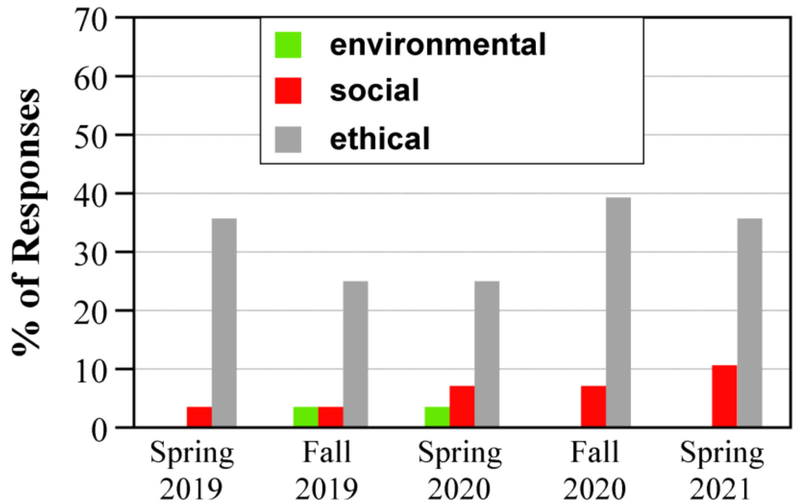

Figure 3. Characteristics of good engineers.

Conclusions

It has become increasingly clear that engineering education needs to more purposefully address social justice issues, as well as social and environmental aspects of sustainability. To make these an integral part of engineering design and the profession, these issues need to be embedded in the required curriculum as well as a strong presence in extracurricular activities that engineering students are interested in. Our study is starting to make curricular changes to address this. We have collected baseline data that shows that engineering students are already aware of some of the issues and present a strong interest in doing good as engineering professionals. The next step will be to refine our survey and other assessment methodologies with the input of the engineering education community and focus on content changes that can generate high impact.

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