Social responsibility views in science and engineering: An exploratory study among engineering undergraduate researchers

Kassandra Fernandez, University of Florida

Kassandra Fernandez is a Graduate Research Assistant at the University of Florida in Gainesville, Florida, where they are pursuing their PhD in Engineering Education (EED). They graduated from Miami Dade College with a B.S. in Biological Sciences and from the University of Florida with an M.S. in Microbiology and Cell Science. Before embarking on their PhD journey, they worked as a science teacher at a Title I school in Homestead, Florida and as an adjunct professor of Microbiology at a Hispanic-serving community college in Miami, Florida. As an educator, they utilized equitable teaching practices and encouraged student agency to ensure positive learning outcomes. Their doctoral research focuses on social responsibility in science and engineering, with special emphasis placed on the importance of science communication and policy advocacy. They are also interested in the intersection of institutional culture and transformational change towards cultivating more inclusive and equitable access for underrepresented minority students in STEM fields. Outside of their research, they are the President of the Policy Advocacy in Science and Engineering (PASE) student organization at the University of Florida.

Dr. Sindia M. Rivera-Jiménez, University of Florida

Dr. Rivera-Jiménez is an Assistant Professor at the Department of Engineering Education (EED) and an affiliate faculty to the Department of Chemical Engineering at the University of Florida. Her research focuses on understanding the role of engineering communities while enacting their agency in participatory and transformational change. She is particularly interested in broadening the participation of minoritized communities by studying the role of professional development in shaping organizational cultures. As an education practitioner, she also looks at evidence-based practices to incorporate social responsibility skills and collaborative and inclusive teams into the curriculum. Dr. Rivera-Jiménez graduated from the University of Puerto Rico at Mayagüez with a B.S. and Ph.D. in Chemical Engineering. She earned an NSF RIEF award recognizing her effort in transitioning from a meaningful ten-year teaching faculty career into engineering education research. Before her current role, she taught STEM courses at diverse institutions such as HSI, community college, and R1 public university.

Social Responsibility Views in Science and Engineering: An Exploratory Study Among Engineering Undergraduate Researchers

Abstract

This pilot study explores engineering students' views on social responsibility in undergraduate research experiences. Participants displayed high concern for human welfare and safety but needed more education and training to understand the importance of being socially responsible scientists and engineers. To address this, the authors recommend incorporating a formal curriculum to facilitate students' understanding and articulation of their views on social responsibility in science and engineering research. The authors provide suggested case studies for engineering educators to incorporate social responsibility topics into their curriculum, enabling students to learn and debate the ethical and social implications of their research, promoting critical thinking and reflection on their work's impact. This study emphasizes the need for comprehensive education and training tailored to scientists and engineers to address complex societal challenges effectively and responsibly in their professional roles.

Keywords: social responsibility, engineering ethics, engineering formation, undergraduate research, Research Experiences for Undergraduates (REU)

1. Introduction

Society is facing challenging problems that threaten both the present and future of justice, peace, sustainability, and the overall well-being of humanity. Given that the responsibility of scientists and engineers implies a duty to address those challenges for society [1], how could research-intensive universities prioritize transformative education for students to fulfill this call?

In 1981, Andrei Sakharov – recipient of the 1975 Nobel Peace Prize – published a thought-provoking piece in the journal *Nature*. He reflected on the worldwide community of scientists and engineers and how they possess a unique ability to comprehend the potential benefits and risks of scientific progress [2, p. 1]. Sakharov envisioned that, because of their education and training, scientists and engineers would be mindful of societal issues and ethical questions. Ideally, through their professional formation, they should develop an awareness of societal issues and ethical questions that lead them to ponder the positive and negative directions of progress and its possible consequences. Fast forward to today, and the world continues to be plagued by political strife and social injustices [3]. With these ongoing issues in mind, it is imperative that the Higher Education community evaluates whether institutions and faculty are adequately preparing future scientists and engineers to become socially responsible. Are we doing enough to ensure that our engineering students are aware of the larger implications of their work and are well-equipped to make ethical decisions that benefit society as a whole?

The Boyer Commission Report, published in 1998, urged research universities to reevaluate their dedication to significant changes in the education system. The report encouraged universities to explore how undergraduates could "benefit from the unique opportunities and resources available in research universities [4, p. 47]." The report acknowledged that research-intensive universities could prioritize transformative educational experiences for students by cultivating the professional formation of undergraduate researchers. Transformative experiences are defined as unique experiences that bring about an epistemic and personal shift in an individual's core personal preferences and the nature of their lived experiences [5]. These experiences can range from short-term to many years in duration. Transformative experiences in education can lead to the development of critical thinking skills and result in the replacement of conceptual frameworks. This replacement can enable students to discover new intellectual worldviews on "society, nature, and humankind [5, p. 570]." In essence, epistemic transformative experiences in education can create personal change that goes beyond simply acquiring new information.

Decades later, the 2017 Undergraduate Research Experiences for STEM Students Report from the National Academy of Science and Engineering and Medicine (NASEM) invited research programs to develop transformative experiences that extend from disciplinary knowledge and skills education to discoursing social issues such as justice and sustainability [6]. This report urges the inclusion of social responsibility learning goals in ethical development, cultural issues in research, and the promotion of inclusive learning environments. Furthermore, several organizations, including the Accreditation Board for Engineering and Technology (ABET), the National Academy of Engineering (NAE), and the National Science Foundation (NSF), all agree that social responsibility is a vital component of an engineer's professional formation. [7]–[9]. They emphasize that social responsibility must be a guiding and transformative experience in the education of engineers. Social responsibility refers to an activity or action within science and technology that is socially responsible if it satisfies certain ethical principles, and socially irresponsible if it does not satisfy those principles [10]." In a sense, social responsibility goes beyond the ethical obligation engineers have to society and the environment by including agency towards responsible conduct research (RCR), policy decision-making, human safety, sustainability, pro bono work, social justice, and diversity, equity, and inclusion work [11].

Many previous efforts in engineering education focused on structured research programs around skills such as research [12], research communication [13], and teamwork and leadership [14]. Zydney et al. surveyed engineering alumni to assess the impact of the undergraduate research experience [15]. In the study, participants reported perceived significant cognitive and personal skills benefits when exposed to undergraduate research experiences for a longer time. Because of the limitations of the survey used in the study, there was no report on how these research experiences created epistemic changes in the alumni's views on society. In another study, Bielefeldt et al. reported the benefits of undergraduate research experiences from 8-years of survey data from a ten-week summer NSF-funded REU site at a single institution focused on environmental engineering [16]. In this work, 50-60% of the students reported increased knowledge of responsible conduct of research, environmental justice, field sampling, the impact of engineering solutions in a global and societal context, the global need for environmental engineering, air pollution, and numerical simulation. Additionally, fewer students reported increased knowledge of environmental ethics, environmental policy, lab safety, and sustainability. A significant result from these studies is the critical role of structured scaffolding programs and mentors (i.e., faculty and graduate students) in improving student experiences in undergraduate research programs [15]–[17].

Even though transformational experiences may begin with increased knowledge about the world, it is through reflection and action that new conceptual framework can be shifted [5]. This paper explores the early stages of the integration of social responsibility in undergraduate research as a transformative experience of educating students about life, work, and citizenship while embracing science and technology solutions. Furthermore, the inclusion of socially and ethically relevant pedagogies in formal undergraduate research programs can help research intensive institutions improve enrollment, retention, and involvement of women and underrepresented minorities in engineering [18].

2. Study Aims

The current small-scale pilot study explores student views about social responsibility while participating in undergraduate research experiences to create an impactful professional development curriculum in policy advocacy in science and engineering. It investigates the following research question: *What views of social responsibility are important for engineering students participating in summer undergraduate research experiences?* The selected methodologies include the use of a validated instrument [11] and open-ended questions.

As the small sample size is a significant limitation, this study does not aim to obtain accurate and precise parameter estimates, but rather to identify the proposed methodology's feasibility and adequacy while laying the groundwork for a more extensive study [19], [20]. The researchers hope the results reported here will inspire critical reflection on undergraduate students' views of social responsibility and provide the opportunity to create formal and informal curricula that emphasizes the importance of social responsibility in science and engineering.

3. Methodology

3.1 Conceptual Framework of Social Responsibility of Scientists and Engineers

The Views of Social Responsibility of Scientists and Engineers (VSRoSE) instrument was used to guide our study design [11]. This validated instrument is based on a conceptual framework that considers the following major social responsibility dimensions for scientists and engineers:

1) HUMAN: Concern for human welfare and safety. Scientists and engineers conducting research are responsible for improving human welfare, health, and safety [21]. *Human welfare* is a broad term encompassing an individual's overall well-being, which includes happiness, health, material wealth, and feelings of security. *Protecting public health* is vital and involves ensuring individuals can function physically and mentally without pain. *Safety* is also important to safeguard individuals from physical harm or death.

2) ENVIR: Promotion of environmental sustainability. Promoting environmental sustainability requires scientists and engineers to be aware, committed, and capable of protecting the environment for sustainable development. Multiple ethical frameworks, such as anthropocentric [22], [23], biocentric [23], and ecological [23] perspectives, guide environmental protection. An anthropocentric framework acknowledges that preserving the environment is essential for human life and its preservation. In contrast,

the biocentric perspective recognizes the intrinsic right to life of all organisms on the planet. The ecological framework encompasses values that extend beyond maintaining human existence.

3) CONSEQ: Consideration of societal risks and consequences. Considering societal risks and consequences involves scientists and engineers understanding the potential impact of their work on society [2], including the equitable distribution of wealth and natural resources [21]. To minimize potential risks, scientists and engineers must be able to anticipate and take action to mitigate potential harm. This requires an awareness of uncertainty and the possibility of errors and a critical reflection on the research context, process, and attitude toward social demands [11]. Overall, scientists and engineers must be sensitive to equity and social justice issues as they work to minimize potential risks to society.

4) NEEDS: Consideration of societal needs and demands. Considering societal needs and demands requires scientists and engineers to be aware of the effective allocation of scarce human and financial resources. They must consider the needs of individuals and national, social, and economic goals [24]. The practice of care is essential in this dimension, as it requires engineering students to reflect on their motivations and how they might impact their interactions with others [25]. Caring for societal needs and demands also involves critical reflection on social justice issues, specifically opportunities, and conditions across demographic categories [26]. By critically reflecting on societal needs and demands, scientists and engineers can work to ensure that their research and work contribute to equitable and just outcomes for all.

5) COMMGOOD: Pursuit of the common good. Pursuing the common good refers to the responsibility that researchers have to prioritize the well-being of others [25]. This responsibility extends beyond the obligations outlined in disciplinary engineering codes of ethics. As mentioned in the fourth dimension, it also requires researchers to consider social justice issues integral to their research goals [26].

6) CIVIC: Service and community engagement. Service and community engagement refers to scientists and engineers who voluntarily use their technical expertise to assist individuals or organizations that cannot afford such services. This can take the form of providing services free of charge (pro-bono) or at a reduced rate [11]. Through service and community engagement, scientists and engineers can use their skills to make a positive impact in society and contribute to the common good.

7) COMMU: Communication with the public. Researchers are responsible for communicating with the public to disseminate their research findings and potential consequences to a diverse group of stakeholders, including underrepresented members of the general public [11]. Science communication aims to improve the public's understanding of science [27] by using "appropriate skills, media, activities, and dialogue to convey scientific research to the public" [28, p. 1]. Researchers communicate with the public for various reasons, such as raising awareness, demonstrating expertise, expressing interest or opinions, and increasing understanding of science [28], [29].

8) POLICY: Participation in policy decision-making. It is the responsibility of scientists and engineers to participate in governmental decision-making that influences policy formulation, implementation, evaluation, or change [30]. Scientists can play a role in policy decision-making by engaging in public communication and education, as discussed in dimension 7. Participation in policy, however, requires public engagement that goes beyond the dissemination a deeper level of public engagement that fosters dialogue and collaboration [30].

3.2 Description of Population, Sampling Method, and Study Participants

The current pilot study explores student views about social responsibility during the summer of 2022 at a college of engineering in a major, comprehensive, public land-grant research university located in the southeast United States. The study participants were selected on a voluntary basis from a combination of multiple summer research programs, such as a university-sponsored bridge program, four NSF Research Experiences for Undergraduates (REU) sites/supplements in disciplinary engineering, and a USDA Research and Extension Experiences for Undergraduates (REEU) site. There were 64 students in total participating in the aforementioned programs. Demographic information for the initial student population ($n = 64$) was unavailable. All programs and program sites provided formal professional development and networking opportunities for the undergraduate student researchers. No formal or informal social responsibility curriculum in science and engineering was provided by any of the programs.

3.3 Data Collection Methods

Data collection was conducted at the end of a 10-week-long research experience in Summer 2022 using a questionnaire built on Qualtrics. After IRB approval and notification to all involved principal investigators, the college of engineering provided access to the student participants. A call for participation was sent via email to all 64 students. After two weeks of reminders, 22 students responded to the questionnaire, resulting in a response rate of 34.4%. Of the 22 respondents, only 10 completed the entire questionnaire. This resulted in an attrition rate of 45.5%. For a feasibility pilot study, like the one presented in this paper, a sample size as small as 10-15 can be sufficient [3].

The IRB-approved questionnaire included 8 items of demographic data (Demographics), 31 items of Likert scale questions (Survey), and 3 items of open-ended questions (OEQs).

The Survey portion was comprised of two parts:

1) VSRoSE validated instrument [11], including 30 items where participants answered the statement "*I believe scientists and engineers should . . .*" using a 5-point Likert scale to the eight Dimensions of Social Responsibility discussed in Section 3.1. This part may be referred to as the Dimensions.
2) Awareness of Social Responsibility, including 1 item asking students to rate the importance of a professional engineer's skills in eight different areas using a 7-point Likert scale. This part may be referred to as the Skill Rating.

The OEQs were used to explore what experiences have influenced positive student views of social responsibility and provide rich information beyond the scope of the VSRoSE instrument.

- Describe in your experience what it means to be a socially responsible scientist and engineer. Can you provide an example?
- Describe any event or person that have influenced your views of social responsibility.
- Describe how the work you are doing this summer can help others.

3.4 Data Analysis Methods

Though 22 students started the questionnaire, only 10 completed it. To simplify quantitative data analysis, the Demographics and Survey data were analyzed in sections. A thematic analysis was done on the qualitative data (OEQs) using an inductive coding approach [31]. Thematic analysis is a method for analyzing qualitative data that entails searching across a data set to identify, analyze, and report repeated patterns [32]. Thematic analysis is a flexible approach that enables the research team to generate new insights and concepts derived from data, making it particularly useful for pilot study analysis [33]. The inductive coding process utilized here allowed the research team to derive codes emerging from the raw data itself [31].

4. Results and Discussion

4.1 Demographics

Participants (*n* = 10) self-reported demographic data in response to the following questions:

1. Which best describes your gender? Please select all that apply.
2. What is your race/ethnicity? Please select all that apply.
3. What is your intended major? Please select one.
4. What is your current GPA?
5. What is your current age in years?
6. Are you a transfer student?
7. What is your student classification?
8. How many times have you done research before this summer?

Each demographic question will be discussed, with the options shown as presented to the participants as well as the response selections that they made. All the data for this section has been visualized using pie charts (Figures 1 – 8). The authors observed many differences across intended major, student classification, transfer status, and previous research experience.

1. Gender. In response to the question, "Which best describes your gender? Please select all that apply.", participants could select any combination of the following options, shown here in the order in which they appeared: Man, Woman, Transgender, Nonbinary, Genderqueer, Gender Non-Conforming, Genderfluid, Agender, Polygender, Indigenous/Other Culturally Specific Gender Minority, Gender Not Listed Here (Please Specify), or Prefer Not to Answer.

One participant identified as a man, while the remaining 9 participants identified as women, as shown in Figure 1.

2. Race and Ethnicity. In response to the question, "What is your race/ethnicity? Please select all that apply.", participants could select any combination of the following options, shown here in the order in which they appeared: International Student of any Race/Ethnicity, Hispanic or Latino or Spanish Origin of any Race, American Indian or Alaskan Native, Asian, Native Hawaiian or other Pacific Islander, Black or African American, White, Two or More Races, Race/Ethnicity Not Listed Here (Please Specify), or Prefer Not to Answer.

To protect the identity of the participants, the data has been simplified to draw a comparison between the percent of participants who self-identified as White alone and the percent of participants who self-identified as any other race/ethnicity (Non-White). With this simplification, 4 participants identified as White alone, while the remaining 6 identified as Non-White, as shown in Figure 2.

3. Intended Major. In response to the question, "What is your intended major? Please select one.", participants could select from the following options, shown here in the order in which they appeared: Civil Engineering, Environmental Engineering, Mechanical Engineering, Chemical Engineering, Biomedical Engineering, Industrial and System Engineering, Computer Engineering & Computer Science, Electrical Engineering, Other Engineering Major NOT Listed Above, or Other Major that is Not Engineering. The last two options allowed participants to write-in responses.

One participant selected Electrical Engineering (labeled in Figure 3 as ElecE), 1 participant selected Biomedical Engineering (labeled in Figure 3 as BiomE), 1 participant selected Mechanical Engineering (labeled in Figure 3 as MechE), and 6 selected Chemical Engineering (labeled in Figure 3 as ChemE). Regarding the two write-in options, 1 participant selected the

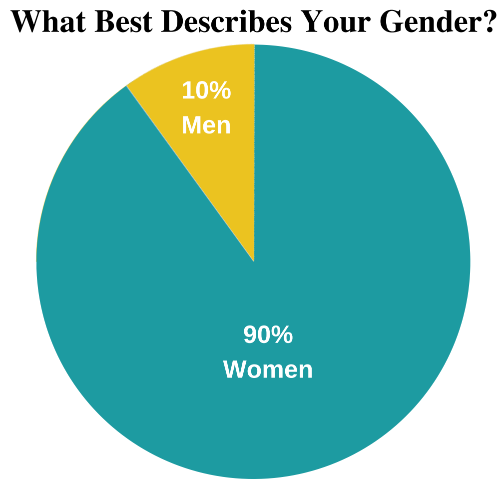

Figure 1: Gender.

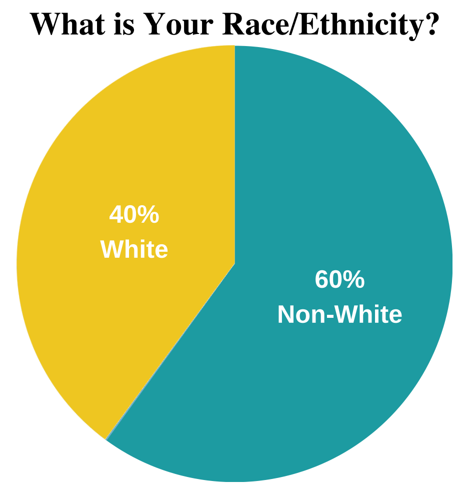

Figure 2: Race and Ethnicity.

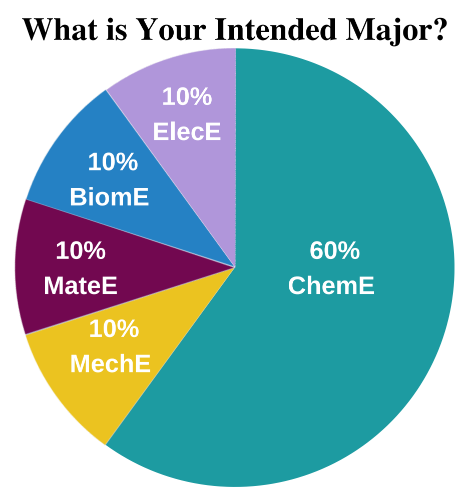

Figure 3: Intended Majors.

write-in option "Other Engineering Major NOT Listed Above" and added "Materials Science and Engineering". This is labeled in Figure 3 as MateE. The data for this question is visualized in Figure 3, which appears on the previous page.

4. Current Grade Point Average. In response to the question, "What is your current GPA?", the following options were available, shown here in the order in which they appeared: > 3.5, 3.0 – 3.5, 2.5 – 3.0, 2.0 – 2.5, or < 2.0.

Two participants selected 3.0 – 3.5, while the remaining 8 participants selected > 3.5, shown in Figure 4.

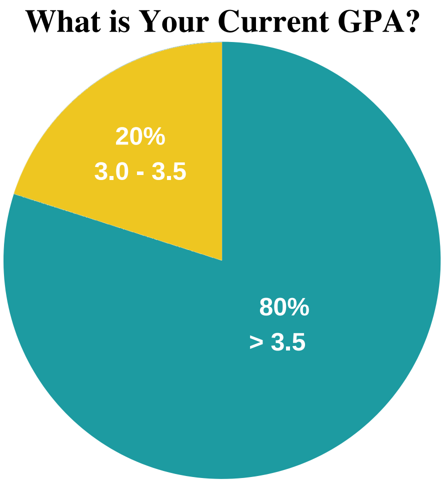

Figure 4: Current GPA.

5. Age in Years. In response to the question, "What is your age in years?", participants could select from the following options, shown here in the order in which they appeared: < 18, 18 – 20, 21 – 23, 24 – 28, or > 28.

Four participants selected 18 – 20, while the remaining 6 participants selected 21 – 23, shown in Figure 5. According to the Pew Research Center [34], "post-Millennials" or "Generation Z" consists of individuals born between the years 1997 and 2012. All the participants in this study, therefore, fall into that categorization, with the oldest participant being born in either 1998 or 1999 and the youngest participant being born in either 2003 or 2004. About 50% of the United States population of post-Millennials belong to racial or ethnic minority groups, and nearly 60% of them are pursuing college, making them both the most diverse and most well-educated generation of Americans [34].

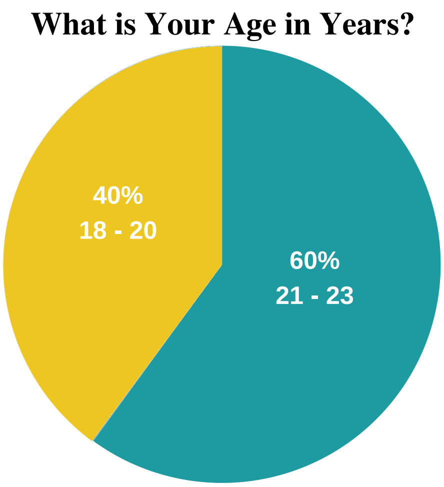

Figure 5: Age in Years.

6. Transfer Status. In response to the question, "Are you a transfer student?", participants could select either Yes or No. This question included supplemental text that read, "A transfer student is a student who comes to a university or school after having begun their course of study at a different university or school." This definition comes directly from the Cambridge Advanced

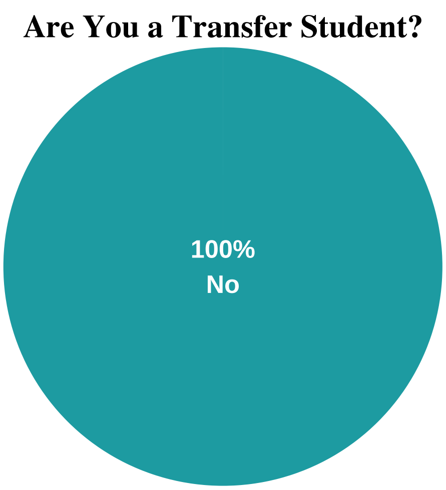

Figure 6: Transfer Status.

Learner's Dictionary & Thesaurus [35]. The research team recognizes the importance of transfer student participation in summer programs as they have the potential of increasing the number of underrepresented populations in the fields of Science and Engineering [36]–[38].

For this question, none of the participants selected Yes; in other words, all 10 participants selected No, as shown in Figure 6 on the previous page.

<u>7. Student Classification.</u> In response to the question, "What is your student classification?", participants could select from the following options, shown here in the order in which they appeared: First-year student (0 – 29 credit hours), Sophomore (30 – 59 credit hours), Junior (60 – 89 credit hours), or Senior (90 or more credit hours).

One participant selected Junior, 2 participants selected Sophomore, and the remaining 7 participants selected Senior. Figure 7 visualizes this data.

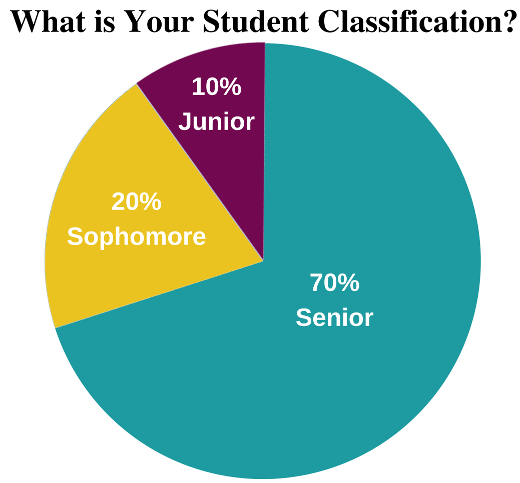

Figure 7: Student Classification.

<u>8. Previous Research Experience.</u> In response to the question, "How many times have you done research before this summer?", participants could select from the following options, shown here in the order in which they appeared: None, 1 time (semester or summer), 3 times (semester or summer), 4 times (semester or summer), More than 5 times (semester or summer).

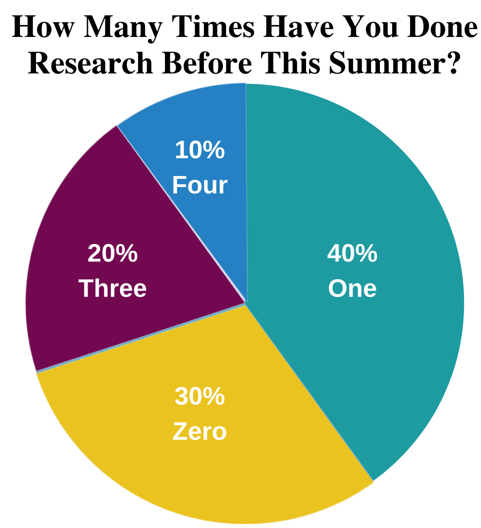

Figure 8: Previous Research Experience.

The responses selected here varied widely, as 1 participant selected 4 times, 2 selected 3 times, 3 selected None, and 4 selected 1 time. This is visualized in Figure 8.

4.2 VSRoSE Instrument Dimensions

The Dimensions data was visualized using 100% Stacked Bar Charts for the sake of clarity. Percentages were calculated by dividing the number of responses for a given option on the scale by the total number of participants, as shown below. As there were 10 participants, $n = 10$.

$$\text{Percentage} = \left(\frac{x}{n}\right) * 100, \text{ wherein } x = \text{number of responses for a given option and } n = \text{total number of participants}$$

<u>Dimension 1. HUMAN: Concern for human welfare and safety.</u> This section included five items asking participants, "How much do you agree with the following belief statements?" These were in the format "*I believe scientists and engineers should…*" followed by prompts 1 – 5 described below. The results are visualized in Figure 9.

1. *Not harm human health at the least*
2. *Place utmost importance on human health*
3. *Be vigilant whether his/her/their research risks human safety*
4. *Consider the possible adverse effects on human health*
5. *Prevent humans from the risks at the least*

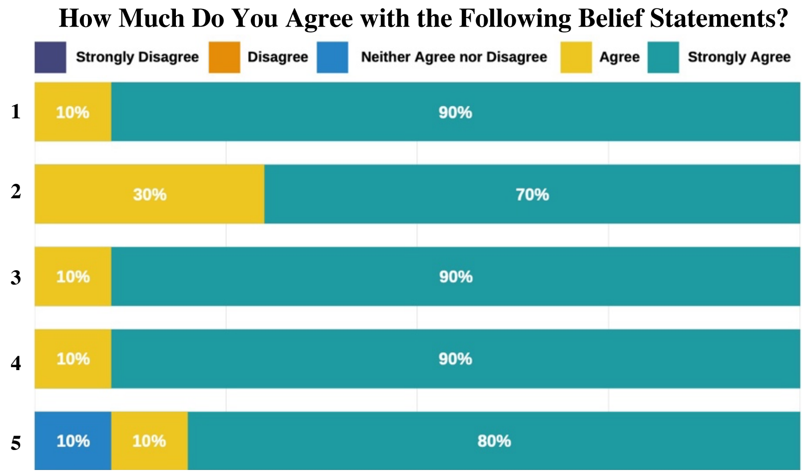

Figure 9: Concern for Human Welfare and Safety.

Overall, the results for HUMAN demonstrate high levels of concern for human welfare and safety among participants, with most selecting Strongly Agree and a few selecting Agree. The lowest level of agreement was for belief statement 5, "*I believe scientists and engineers should prevent humans from risk at the least*", wherein one participant was Neutral. This suggests that while the participants show general concern for human welfare and safety, they may need more or better education and training to fully understand the importance of HUMAN concepts.

<u>Dimension 2. ENVIR: Concern for environmental sustainability.</u> This section included three items asking participants, "How much do you agree with the following belief statements?" These were in the format "*I believe scientists and engineers should…*" followed by prompts 6 – 8 described below. The results are visualized in Figure 10.

6. *Protect the environment during the research process*
7. *Minimize the effects on ecosystem*
8. *Promote sustainable development in the environment*

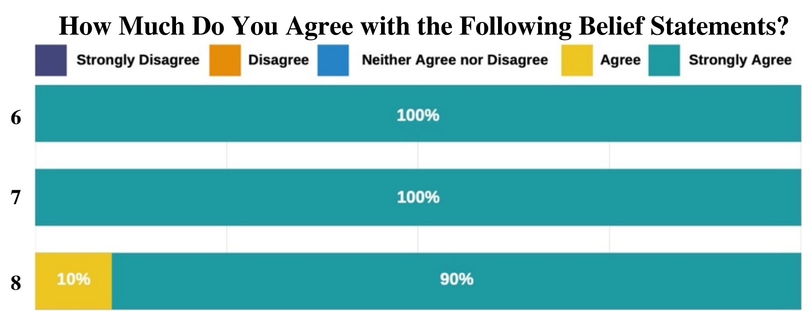

Figure 10: Concern for Environmental Sustainability.

In the ENVIR results, participants expressed high levels of concern for environmental protection and sustainable development, with nearly all participants selecting Strongly Agree for each item; the only exception was the one participant who selected Agree for belief statement 8, "*I believe scientists and engineers should promote sustainable development in the environment.*" This suggests that concepts related to ENVIR are sufficiently covered through the current curricula.

Dimension 3. CONSEQ: Consideration of societal risks and consequences. This section included five items asking participants, "How much do you agree with the following belief statements?" These were in the format "*I believe scientists and engineers should…*" followed by prompts 9 – 13 described below. The results are visualized in Figure 11.

9. *Recognize the potential social problems in one's area of expertise*
10. *Be able to identify social problems inherent in modern science and technology*
11. *Be cognizant of the contribution one's work can make to advancements in the field*
12. *Be able to identify pressing social problems in one's area*
13. *Carefully examine the conflicting values of multiple stakeholders*

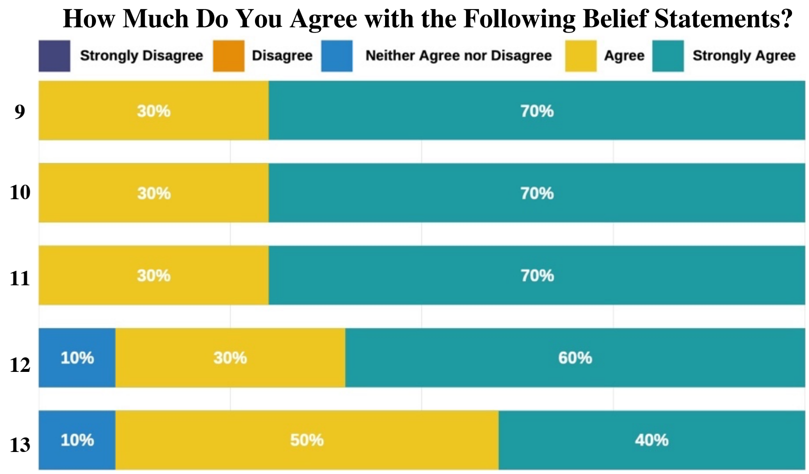

Figure 11: Consideration for Societal Risks and Consequences.

The results for CONSEQ showed that participants generally agreed that consideration should be given to societal risks and consequences, however, there were less Strongly Agree selections in the CONSEQ results than in the results for HUMAN or ENVIR. There were also two Neutral selections: one for belief statement 12, "*I believe scientists and engineers should be able to identify pressing social problems in one's area*", and one for belief statement 13, "*I believe scientists and engineers should carefully examine the conflicting values of multiple stakeholders*". Neutral participants may not feel that CONSEQ applies to their work or may not consider CONSEQ a priority. It may be beneficial to examine how responses correlate with exposure to industry or previous involvement in research activities as this may provide insight into how such experiences impact one's attitudes toward social responsibility in research.

Dimension 4. NEEDS: Consideration of societal needs and demands. This section included three items asking participants, "How much do you agree with the following belief statements?" These were in the format "*I believe scientists and engineers should…*" followed by prompts 14 – 16 described below. The results are visualized in Figure 12.

14. *Consider whether one's research generates knowledge needed by society*

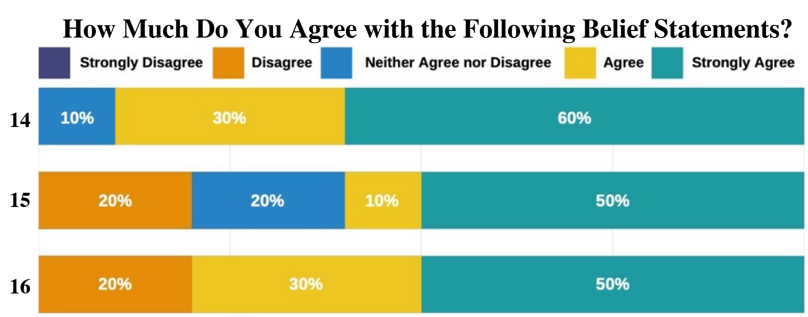

Figure 12: Consideration for Societal Needs and Demands.

15. *Conduct research consistent with the values and expectations of society*
16. *Identify the societal needs and expectations for scientific and engineering research*

In the NEEDS results, most participants Agreed or Strongly Agreed that social needs and demands should be considered, but there were more Neutral selections than in previous dimensions. Additionally, some participants Disagreed with belief statements for the first time in this Survey. There was one Neutral selection for belief statement 14, "*I believe scientists and engineers should consider whether one's research generates knowledge needed by society*", two Neutral selections and two Disagree selections for belief statement 15, "*I believe scientists and engineers should conduct research consistent with the values and expectations of society*", and two Disagree selections for belief statement 16, "*I believe scientists and engineers should identify the societal needs and expectations for scientific and engineering research*". It is possible that the disagreement stemmed from different definitions of the term "society".

Dimension 5. COMMGOOD: Pursuit of the common good. This section included three items asking participants, "How much do you agree with the following belief statements?" These were in the format "*I believe scientists and engineers should…*" followed by prompts 17 – 19 described below. The results are visualized in Figure 13.

17. *Conduct research that can enhance the quality of human life*
18. *View promotion of human welfare and safety as a primary goal of one's research*
19. *View reducing the challenge that people experience in their daily life as an important goal of one's research*

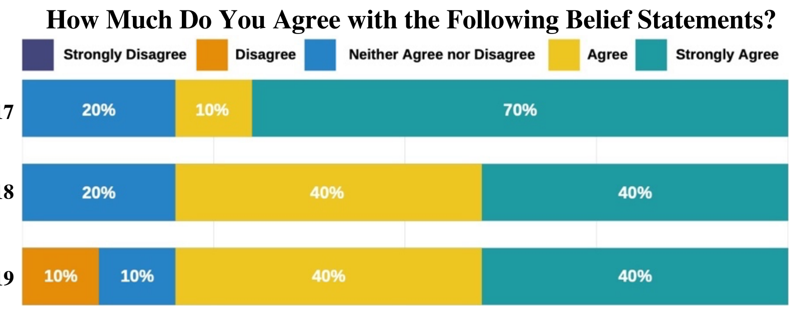

Figure 13: Views on the Pursuit of the Common Good.

The results for COMMGOOD indicate that 80% of participants Agreed or Strongly Agreed that one should pursue the common good. Two participants were Neutral regarding belief statement 17, "*I believe scientists and engineers should conduct research that can enhance the quality of human life*", and 18, "*I believe scientists and engineers should view promotion of human welfare and safety as a primary goal of one's research*". There was also one participant who was Neutral on and one participant who Disagreed with belief statement 19, "*I believe scientists and engineers should view reducing the challenge that people experience in their daily life as an important goal of one's research*". Participant neutrality or disagreement in response to COMMGOOD concepts may stem from a need to better recognize and articulate the broader impacts of one's work.

Dimension 6. CIVIC: Civic engagement and services. This section included five items asking participants, "How much do you agree with the following belief statements?" These were in the format "*I believe scientists and engineers should…*" followed by prompts 20 – 24 described below. The results are visualized in Figure 14 on the following page.

20. *Be willing to participate in civic affairs if the goal of the affair is to solve science and technology problems*
21. *Collaborate with the public and citizens to solve science and technology problems*
22. *Actively encourage others to participate in solving science and technology problems*
23. *Collaborate with knowledgeable and interested citizens to solve science and technology problems*
24. *Serve an advisory role for the public in their area of expertise*

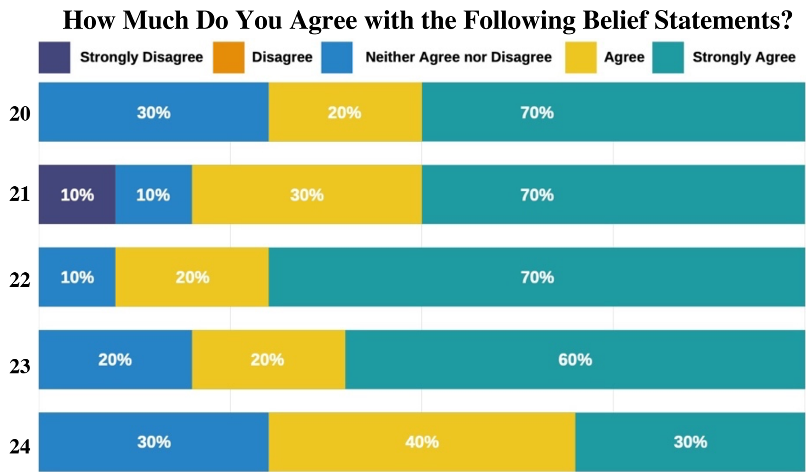

Figure 14: Views on Civic Engagement and Services.

The results for CIVIC had the widest variance in responses, which may indicate that the prompts were unclear to participants. The lack of concrete examples regarding the type of civic engagement and services being discussed could also have played a role. It is possible that participants may not see themselves as advisors or advocates in subjective matters, which is problematic as such roles are critical in ensuring that the public understands and values their work, and that the government continues funding research.

<u>Dimension 7. COMMU: Communication with the public.</u> This section included three items asking participants, “How much do you agree with the following belief statements?” These were in the format “*I believe scientists and engineers should…*” followed by prompts 25 – 27 described below. The results were visualized in Figure 15.

25. *Make the public familiar with science using media (books, articles, blogs, lectures)*
26. *Explain knowledge and research necessary for solving social problems to the public*
27. *Explain knowledge or research regarding science and technology in a way that is easy for the public to understand*

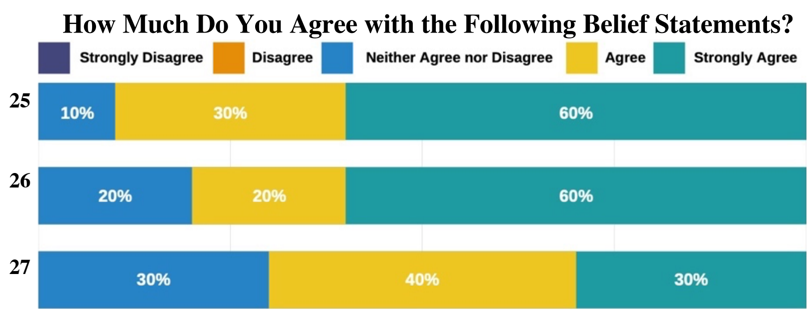

Figure 15: Views on Communication with the Public.

Most participants Agreed or Strongly Agreed that it is important to Communicate with the Public, according to the COMMU results, however, there were some participants that were Neutral (one for 25, two for 26, and three for 27). Belief statement 25, “*I believe scientists and engineers should make the public familiar with science using media (books, articles, blogs,* *lectures)*", is related to science communication, however, it may have been misunderstood as the term was not specifically mentioned. Belief statement 26, "*I believe scientists and engineers should explain knowledge and research necessary for solving social problems to the public*", may have caused confusion among participants who incorrectly assumed that science and engineering do not deal with societal issues. Belief statement 27, "*I believe scientists and engineers should explain knowledge and research regarding science and technology in a way that is easy for the public to understand*", suffers from the same issue as 25. Whether this was an issue of terminology or not can be determined by ascertaining the participant's reasoning when answering this question. Further analysis is needed to clarify these findings.

<u>Dimension 8. POLICY: Participation in policy decision-making.</u> This section included three items asking participants, "How much do you agree with the following belief statements?" These were in the format "*I believe scientists and engineers should…*" followed by prompts 28 – 30 described below. The results are visualized in Figure 16.

28. *As a member of a professional organization of scholars, must influence the policy-making process related to science and technology*
29. *Actively participate in policy-making processes related to science and technology*
30. *Emphasize its importance and must attract investment for science and technology*

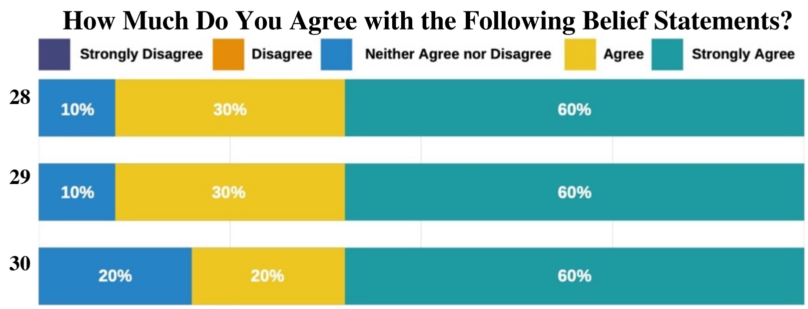

Figure 16: Views on Participation in Policy Decision-Making.

The results for POLICY indicated that most participants Agreed or Strongly Agreed, with only a small percentage of participants giving Neutral responses. This increase in Neutral responses suggests that some participants may need to familiarize themselves with the importance of participation in policy decision-making. Further analysis is needed to understand what may be influencing these views, such as concerns about objectivity or lack of training [39], [40].

4.3 Skill Rating

This section asked participants to rate the level of importance of eight skills a professional engineer should have by using a seven-item Likert Scale, wherein 1 = Very Unimportant, 2 = Unimportant, 3 = Slightly Unimportant, 4 = Neutral, 5 = Slightly Important, 6 = Important, 7 = Very Important. The question was as follows:

31. Please rate how important the following skills are for a professional engineer:
    1. Fundamental Skills (i.e. Engineering, Math, Science)
    2. Technical Skills (i.e. Conducting Experiments, Data Analysis, Design, Engineering Tools, & Problem Solving)
    3. Business Skills (i.e. Business Knowledge, Management Skills & Professionalism)

4. Professional Skills (i.e. Communication, Contemporary Issues, Creativity, Leadership, Life-Long Learning, & Teamwork)
5. Cultural Awareness/Understanding (i.e. of your culture, and those of others)
6. Professional Ethics (i.e. ensuring your work follows professional codes of conduct)
7. Societal Context (i.e. how your work connects to society and vice versa)
8. Volunteerism (for professional and personal reasons)

Percentages were calculated as done previously, by dividing the number of responses for a given option on the scale by the total number of participants (shown below). Again, $n = 10$.

$$\text{Percentage} = \left(\frac{x}{n}\right) * 100, \text{ wherein } x = \text{number of responses for a given option and } n = \text{total number of participants}$$

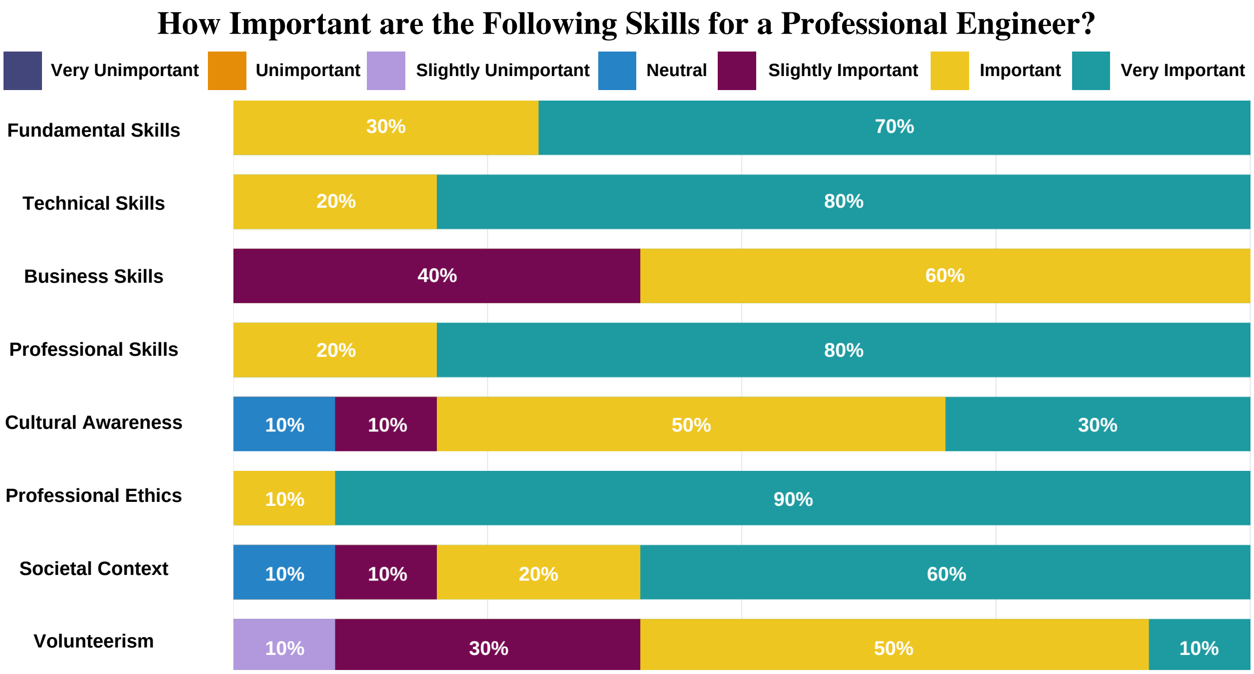

Figure 17: Perceived Importance of a Professional Engineer's Skills.

The results from the Skill Rating are summarized in Figure 17, as done previously for the Dimensions results. Most responses for the Skill Rating were in the Important range (Slightly Important, Important, or Very Important). Professional Ethics, Professional Skills, Technical Skills, and Fundamental Skills were the most highly rated skills while Volunteerism was rated the lowest. Further analysis is needed to fully understand these results.

4.4 Open-Ended Questions

In this section, three open-ended questions were posed to participants:

32. Describe in your experience what it means to be a socially responsible scientist and engineer. Can you provide an example?

33. Briefly describe any event or person that have influenced your views of social responsibility.
34. Briefly describe how the research work you are doing this summer can help others.

As previously stated, the authors chose to handle the resulting qualitative data using thematic analysis. Snippets of participant responses will also be shared to highlight certain points.

Question 32: Describe in your experience what it means to be a socially responsible scientist and engineer. Can you provide an example? In response to this question, participants identified several key themes, including individual behavior, awareness of broader impacts, and compassion. Participants emphasized the importance of integrity, respect, and responsibility in their individual behavior as a socially responsible scientist or engineer. When providing examples, they also highlighted the need to consider the broader impacts of their work, such as environmental, social, and economic impacts. Additionally, they stressed the importance of compassion and promoting accessibility, inclusivity, and harm reduction. One participant stated,

> "You should only want to make a positive impact and never brush off any negative effects that could arise."

Question 33: Briefly describe any event or person that have influenced your views of social responsibility. The participants recognized various factors that influenced their social responsibility views. These factors included both formal and informal experiences, as well as input from different sources such as faculty, family members, peers, and industry professionals. Formal experiences that shaped their views included classes and training programs. Informal experiences, on the other hand, included conversations, engineering disasters, and community outreach experiences. An example from one of the participants stated,

> "My mentor this summer was very influential in helping me think about social responsibility in engineering. One thing that she described was a hypothetical facial recognition software and making sure that the software can recognize people of all different skin tones. I had never thought about something like this before, and it really showed me how diversity and inclusion show up in technology made by engineers."

Question 34. Briefly describe how the research work you are doing this summer can help others. Most participants provided insightful and thoughtful responses, demonstrating a thorough understanding of the importance of their work in a broader societal context. There were a few participants, however, who evidently found it difficult to connect their work to a larger context, relying solely on factual descriptions of their work without establishing any linkages to external factors. A particularly reflective response stated,

> "My research is focused on developing new materials for solar cells. If implemented commercially, these materials would make solar energy cheaper and more accessible. This will reduce the need for burning fossil fuels and allow for better renewable energy."

4.5 Study Limitations

The authors want to acknowledge the limitations of the study by summarizing aspects of research design and methodology that could have influenced the interpretation of the findings [41].

Issue 1: Insufficient sample size for statistical measurements. The sample size in this exploratory study was ten, a number far too small to allow for the identification of significant relationships in the data. Statistical measurements require sample sizes large enough to ensure that the sample is considered representative of a population and that the statistical result can be generalized to a larger population. To run statistical analysis using SPSS software, for example, a minimum sample size of 100 is required before you can get meaningful results. In future studies, the authors expect to have a sample size greater than or equal to 100 so that SPSS can be utilized.

Issue 2: Methods/instruments/techniques used to collect the data. It is possible that the questions asked did not properly address the research question. For example, when prompted to answer questions relating to “society”, were participants all working with the same definition of “society”? This could be mitigated in the future by providing definitions for each term that may have differing meaning to better clarify what the questions are asking and ensure greater understanding of the questions by participants. These definitions may be provided as supplemental information after the question is posed, as was done for the term “transfer student” in the demographics section. Alternatively, definitions could be displayed at the beginning of each section of the questionnaire as needed. These changes will ensure that participants are able to consider and respond to the questions utilizing the same terminology.

Issue 3: Time constraints. This data was collected after a ten-week summer research experience. The time available to study a research problem and to measure change over time might be constrained by such practical issues, therefore necessitating a future study.

Issue 4: Non-representative sample composition. The sample in this study is non-representative of engineering students as it skews non-white and female in a heavily White male dominated field [42], [43]. Additionally, the two largest engineering disciplines, Mechanical and Electrical, are underrepresented in this sample [42]. It is possible that this sample – which is primarily composed of individuals from underrepresented groups – already had an interest in social responsibility topics prior to taking this questionnaire, which may have contributed to the results reported in this exploratory study. These potential confounding points necessitate further study.

5. Discussion

Engineering educators are constantly challenged with the need to adapt their pedagogical approaches to keep up with the rapidly evolving demands of industry, technological advancements, society, accreditation agencies, and higher education institutions [1], [4]. Research-intensive institutions, in particular, face the challenge of meeting international and national calls for undergraduate research programs that educate students not only on technical knowledge but also on the social responsibility of scientists and engineers [13], [18]. These programs are designed to provide students with lifelong learning skills that extend beyond the technical aspects of engineering and focus on their ethical and societal obligations. To prioritize the development of a curriculum for undergraduate research programs, the mean score for each VSRoSE Dimension was calculated. All mean scores were rounded up to the nearest tenth.

ENVIR had the highest mean score at 5.0, followed by HUMAN at 4.8. Next were COMMU and CONSEQ, which had mean scores of 4.6, while POLICY had a mean score of 4.5. CIVIC and COMMGOOD had mean scores of 4.3. NEEDS had the lowest mean score at 4.2. Priority levels were assigned to each Dimension based on these scores and whether they were already taught as part of the current engineering curriculum. The Dimension Scores Summary in Figure 18 displays this information.

Dimension	Score	Priority Level	Taught in Curriculum?
ENVIR	5.0	3	Yes
HUMAN	4.8	3	Yes
COMMU	4.6	2	Yes
CONSEQ	4.6	2	No
POLICY	4.5	2	No
CIVIC	4.3	1	No
COMMGOOD	4.3	1	No
NEEDS	4.2	1	No

Figure 18: Dimension Scores Summary

The mean score for each skill in the Skill Rating was also calculated and represented similarly in Figure 19. Professional Ethics received the highest mean rating (6.9), followed by Professional Skills and Technical Skills (both scored 6.8), and Fundamental Skills (6.7). As these skills received mean rating scores greater than 6.5, they are considered Very Important. These results are consistent with the emphasis traditionally placed on these skills in engineering education [14], [44], [45]. Societal Context (6.3), Business Skills (6.0), and Cultural Awareness (6.0), were rated as Important as they were greater than 5.5 but not higher than 6.5. Volunteerism received a 5.5, which is considered Slightly Important.

Skill Type	Score	Priority Level	Taught in Curriculum?
Professional Ethics	6.9	3	Yes
Professional	6.8	3	Yes
Technical	6.8	3	Yes
Fundamental	6.7	3	Yes
Societal Context	6.3	2	No
Business	6.0	2	No
Cultural Awareness	6.0	2	No
Volunteerism	5.5	1	No

Figure 19: Skill Rating Scores Summary

Upon initial analysis of the pilot data, it is evident that participants in this study share similar views on environmental sustainability, human welfare and safety, and communication with the public, as these themes are currently addressed in science and engineering curricula. However, further analysis suggests that more comprehensive education and training, with a focus on societal needs and demands, policy decision-making, service and community engagement, and pursuing the common good, may be necessary. Such training could facilitate the development of critical thinking skills needed to address complex societal issues effectively in the roles of scientists and engineers.

6. Further Implications for Engineering Educators: Challenging the Status Quo

Engineering educators can significantly impact student views of social responsibility by modeling ethical behavior [46], creating a positive classroom environment [47], [48], incorporating social responsibility into course content [49], [50], encouraging critical thinking

[51], [52], and providing opportunities for community engagement [53]. One way to meet these goals through pedagogical changes would be to add case study analysis to the curriculum.

Case studies present students with challenging and engaging real-world scenarios that illustrate ethical dilemmas and social responsibility issues [54]. Case study analysis, therefore, can be a powerful tool to help students recognize the importance of ethical behavior, utilize their critical thinking skills, and develop a deeper understanding of the complexities of social responsibility [55]. By fostering a positive classroom environment, students are empowered to critically analyze and evaluate complex situations, weigh different perspectives, and make informed decisions based on the available evidence [56].

The example case studies provided in Figure 20 were created using Bloom's Taxonomy, with a focus on higher level learning outcomes that encourage skill development in scientific and engineering research. Higher level learning outcomes allow engineering educators to integrate multiple skills into their pedagogical strategies and, as such, may cover multiple dimensions of social responsibility. Higher level learning outcomes related to ENVIR, for example, may also apply to COMMUN and POLICY. The goal in using these case studies is to challenge the status quo and move beyond just teaching professional ethics. These examples should spark engineering educators' creativity in bringing transformational experiences into both formal and informal learning environments.

Example Case Studies	Example Questions	HUMAN	ENVIR	CONSEQ	NEEDS	COMMGOOD	CIVIC	COMMU	POLICY
Plastic Pollution in Waterways and Oceans	How does plastic polluting the water affect animals (including humans) and the environment?	X	X	X				X	X
The Impact of Climate Change in Arid Regions	Who is most impacted by climate change in arid regions? Be sure to examine both positive and negative changes, and consider all possible stockholders.	X	X	X	X	X			
Bias in Facial Recognition Technology	What are the risks associated with facial recognition technology and what can be done to mitigate them?			X	X	X	X		X
Accessible Public Transportation Systems	Pick a current public transportation system and explain what changes can be made in order to increase the accessibility for all users.	X			X	X	X		X
Policy Advocacy for Renewable Energy	How would you communicate the importance of switching to renewable energy sources to different stakeholders, including the general public and policymakers?		X			X	X	X	X

Figure 20: Example Case Studies

7. Final Thoughts

Transformative experiences in education have been shown to be powerful catalysts for personal and epistemic shifts in individuals. This pilot study on social responsibility among engineering students during a summer undergraduate research experience highlights the need for a curriculum that emphasizes all the dimensions of social responsibility. The study used the VSRoSE validated instrument with open-ended questions to measure and explore the participants views on social responsibility in science and engineering. The results of this study revealed several new themes not covered in the VSRoSE dimensions, such as individual behavior and compassion. The study also showed that formal and informal experiences and input from different sources can influence one's social responsibility views.

While the participants shared similar views regarding environmental sustainability, human welfare and safety, and communication with the public, there is need for added emphasis on societal needs and demands, participation in policy decision-making, service and community engagement, and the pursuit of the common good. By incorporating a formal curriculum that encourages critical thinking and reflection on the impact of their work, scientists and engineers can broaden their skill sets and address complex societal challenges effectively and responsibly in their professional roles. Integrating transformative experiences into STEM education could be a valuable tool for developing impactful professional development curricula in social responsibility in science and engineering.

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