

Assessing Awareness and Competency of Engineering Freshmen on Ethical and Responsible Research and Practices

Abstract

This paper presents the initial work of a recently funded NSF project on ethical and responsible research and practices in science and engineering. The objective of this research is to improve instructor training, interventions, and student outcomes in high schools and universities to improve awareness and commitment to ethical practices in STEM coursework. The project will generate a robust snapshot of the ethical knowledge, reasoning skills, attitudes, and practices of several thousand undergraduate engineering students. This snapshot will inform the development of a three-week enrichment opportunity for high school STEM teachers. Working with university faculty and graduate students, these teachers will develop learning modules on ethical issues related to their courses. The snapshot will also identify gaps and guide the creation of targeted interventions that will be used in second-, third-, and fourth-year engineering courses.

This data-driven project uses a mixed-methods approach to generate a better understanding of the impact of ethics interventions at various points in a student's academic development by developing and using a set of instruments to measure cognitive, affective, and behavioral aspects of ethical competency and self-efficacy. To that end, a second snapshot will be taken by testing and surveying engineering students in their capstone courses to provide a broad overview of the competence and self-confidence that engineering students have in dealing with ethical STEM issues, to determine the efficacy of various interventions, and to improve future interventions. Utilizing repeated measures and possessing a longitudinal dimension, the project will generate extensive data about the development of ethical competency, ethical self-efficacy, and their relationship. The interventions designed for secondary and tertiary classrooms will build on best practices for micro-insertion of ethics content that are practical and help students understand how technical competencies fit within broader social, economic, and environmental contexts. The capstone snapshot will also provide some measure of the impact of other experiences (e.g., undergraduate research, internships, service learning) and courses (e.g., humanities, social science, and business courses) on development of ethical practices. This report marks the start of a five-year project; therefore, the results presented in this paper represent findings from the engineering ethics literature and baseline results from survey of engineering freshmen at Texas A&M University. The findings from the survey are being utilized in developing intervention modules that will be integrated in upper-level engineering courses and training materials for high school teachers.

Introduction

As engineering increasingly affects natural, social, and economic spheres, it becomes all the more important that engineers are responsible. Educating engineers for their career responsibilities has always been a priority of teaching institutions, but ethics education in engineering has not always been a significant part of the curriculum. The importance of ethics training for students in other fields such as medicine and psychology is more prevalent than that in the field of science and engineering. While the need for making ethical decisions for professionals in medicine and

psychology is apparent, it may not be so for engineers. Engineers make countless decisions that affect the welfare of their corporations, their communities, and their professions. For instance, a chemical engineer may have to choose between safety of those living near a plant and cost savings for their company; a civil engineer may face environmental ethics choices while designing a road that would cut through a forest. Moreover, there are certain business ethics issues that engineers regularly encounter, for example, dilemmas related to withdrawal of bids, bid peddling, cover pricing, and collusion [1]. Further, some other ethical issues identified and taught by US engineering schools are whistle-blowing issues, misrepresentation of data, plagiarism or giving due credit, accountability to clients, and quality control to name a few [1]. The NSPE Code of Ethics and state engineering practice acts have certain expectations for engineers who find themselves in conflicts of interest situations, and they prohibit deceptive acts such as misrepresenting qualifications and making paid public statements without appropriate disclosure. It is unlikely that engineers who have not been exposed to such concerns and have limited practice in moral reasoning would make as good of decisions as those that have. Thus, considering that the ethical issues in engineering can have an impact on society, environment, and health at large, combined with profession-specific responsibilities, it is important to train engineers to make sound ethical decisions.

Despite the growing need for and importance of ethics courses in engineering, these courses are rarely considered as a core requirement in engineering [2]. Ethical awareness of students is not an immediate priority of courses in engineering and as a result students are less inclined to think about the impact their job has on the society [2]. Engineers are trained to control and maintain complex socio-technical systems and develop products and services that transcend national borders [3]. Thus, the impact created by their work affects society at large and it becomes imperative for teaching institutions to help develop the ethical knowledge of their engineering students [4], [5]. Further, Zhu and Snieder argue that unlike other fields, engineering does not come with an embedded moral compass that helps guide engineers use their knowledge and power ethically [3]. In such cases, it becomes even more of a necessity for institutions to advance the ethical awareness level of the students.

When it comes to imparting knowledge about ethics in engineering, educators often find themselves in a dilemma [6]. Both delivery and content are to be considered when selecting what needs to be taught to the students [7]. Delivery approaches are often separated based on whether the information is disseminated through a technical course integrated with ethics content or delivered as part of a stand-alone course focused on either general or more field specific ethics [7]. Many engineering programs also incorporate workshops and seminars focused on ethics as part of the course curriculum [8]. LeClair & Ferrell state that although the teaching institutions use lectures as the most common method to deliver ethics training, it may not be the most effective way to train students [9]. The authors argue that lectures foster a passive learning environment which may not help the engineering students understand the complexities involved with ethical dilemmas in real world. To overcome this challenge, ethical dilemmas can be presented to the students and then require them to think about their feelings on the issue [7]. This approach has been widely used by using case studies [9]. This method has the “ability to introduce challenging, real-world situations and related decision complexity into the classroom” [10]. Case studies represent a well-defined problem, are ambiguous, and allow for numerous perspectives [11]. Especially when guided by those with adequate expertise in ethical principles and moral reasoning,

such cases give students the opportunity to think through ethical decisions that directly apply to engineering. Thus, helping students become ethical engineers requires a blend of instruction, guidance, feedback, and practice in moral reasoning. The multi-faceted nature of this development, and the differing abilities of faculty and students from different backgrounds, means that the limited empirical work on ethics education within engineering has not determine the “best” practices for integrating ethics into engineering [12], and likely, will not be able to do so.

Evaluation and assessment of the ethics interventions are also challenge a challenge. Not only does each intervention (such as having a stand-alone course, integrating micro-ethics to a technical course, seminar, or other modalities) have its own strengths and weaknesses, especially when considered as part of a four-year degree plan, there is also no single best method to evaluate a specific modality. Hess and Fore argue that in order to have an effective intervention, authors need to clearly describe the pedagogy, content, and evaluation of their intervention [12]. Having these factors clarified beforehand helps them understand the efficacy of the intervention and determine student learning outcomes. According to the study by Hess and Fore, some ethical interventions are inserted directly into the curriculum of a technical course, some take a semester long-approach, while other interventions are for a day or two [12]. Learning goals of these interventions vary from enhancing students’ awareness or sensitivity, helping them know how to act ethically, and build more confidence in their ethics knowledge.

The objective of this research is to improve instructor training, interventions, and student outcomes in high schools and universities to improve awareness and commitment to ethical practices in STEM coursework. Using the existing literature about ethics in engineering, this paper integrates key findings about the said topic to provide a more comprehensive idea about the importance of ethics in engineering education. The project aims at generating a robust snapshot of the ethical knowledge, reasoning skills, attitudes, and practices of several thousand undergraduate engineering students. This snapshot will form the basis for the development of a three-week enrichment opportunity for high school STEM teachers. Working with university faculty and graduate students, these teachers will develop learning modules on ethical issues related to their courses. The snapshot will also identify gaps and guide the creation of targeted interventions that will be used in second-, third-, and fourth-year engineering courses.

The remainder of the paper is organized as follows. The next section presents a brief background about the project, its objectives and goals, and key activities proposed in the course of the entire project. The project background is followed by a brief description on a baseline survey that was conducted during year 1 of the project. The survey description also includes preliminary results with respect to ethical and professional responsibility assessment of engineering students. The paper concludes with a discussion of survey findings and implications for future activities of the project.

Project Background

Ethical misconduct has been prevalent in all elements of science, technology, engineering, and mathematics (STEM), including laboratory-based research, engineering design, and data science and modeling. Unethical practices range from data fabrication and falsification, data tampering to plagiarism, intellectual theft, and misinformation. With the advent of social media and rapid

communication, these unethical practices can all occur simultaneously in real-time. With an increase in ethical concerns over data privacy and intellectual theft, the importance of ethical practices in the STEM field is now being recognized. That said, although all ABET accredited applied and natural science, computing, engineering, and technology programs require ethics in their curricula, the prior research (as described above) clearly shows a gap in the ethical research efficacy in the current workforce. There is a critical gap in the empirical work around the assessment of ethics in engineering higher education. To that end, this project proposes a standard research project to **Investigate, Intervene, and Instill Ethical Research Competency Self-efficacy (I³ERCS)** in future STEM researchers and practitioners by adopting evidence-based best practices in research and education. In addition to providing learning modules (the proposed intervention) on ethical STEM research and practices to current engineering students by integrating them into their undergraduate curricula, the proposed project also focuses on high school students to evaluate this early intervention and build a strong pipeline of future ethical researchers and practitioners in STEM fields.

The proposed I³ERCS project aims to achieve three distinct goals: **1)** Understand the impact of early ethically responsible research education in high school (9th -12th grade) on the ethical research practice of future scientist and engineers; **2)** Assess and improve the STEM ethical research competency (improved knowledge, moral reasoning skills, attitudes, and practices) and self-efficacy (*student's self-belief in being able to make ethical choices in research and practice*) of undergraduate students through targeted intervention; and **3)** Build a pipeline of future ethical STEM researchers by focusing on ethical norms imbued during their formative educational experiences by helping high school instructors in developing lesson plans that contribute to their understanding of ethical STEM research and practices.

In order to achieve the above listed goals, the specific objectives of this project are to: **1)** Conduct a survey of incoming freshmen college students to assess their ethical research competency and self-efficacy at the beginning of their tertiary education and during their senior-level capstone course; **2)** Evaluate the ethical research competency and self-efficacy of university students and identify any significantly contributing factors to develop an intervention plan to improve their ethical research competency (ERC) and ethical research self-efficacy (ERS) levels; **3)** Develop learning materials on topics related to ethical STEM research and practices (such as data ethics, research misconduct, human subjects, etc.) and integrate them into undergraduate curriculum in multiple engineering disciplines; **4)** Provide enrichment experience in ethical STEM research and practices to high school teachers who then can bring the knowledge back to their classrooms thereby helping to build a pipeline of future ethical STEM researchers and practitioners; and **5)** Use a rigorous assessment and tracking process and evaluate the impact of proposed intervention activities on student and teacher outcomes.

There are three key project activities to ensure the goals and activities listed above can be achieved: 1) Investigate: research design to evaluate ethical research competency and self-efficacy; 2) Intervene: develop targeted learning/ training modules and use cases for undergraduates and high school teachers; and 3) Instill: implement targeted intervention plan and learning modules on ethical STEM research and practices in undergraduate and high school curricula.

The first key activity will help in designing and developing a multidimensional approach to attain the stated goals. The incoming freshmen are assessed to measure their ethical research competency (ERC) and ethical research self-efficacy (ERS) levels. The next set of assessments of students' ERC and ERS levels would occur once intervention plans are implemented throughout the curriculum including select courses (at sophomore/junior levels) and senior capstone projects. Lastly, the project aims to evaluate the impact of E3 program on competency and self-efficacy of high school teachers and their students with respect to ethical STEM research and practices. The second key activity is centered around the goal to develop targeted learning materials that will be used in the undergraduate curriculum both in lower level (sophomore or junior years) and senior level capstone project courses. After having developed the learning materials, the third key activity of the project is to implement the intervention plans (or learning modules) in various undergraduate engineering courses at Texas A&M University and in appropriate STEM courses at participating high schools.

Assessing Ethical Self-efficacy and Competency: A Baseline Survey

Research design

To generate the baseline data on ethical self-efficacy and ethical competency of engineering freshmen, a comprehensive survey instrument was developed in fall 2021. The survey instrument consisted of five sections including: one of two cases previously developed in the engineering and science issues test (ESIT), items that measure constructs related to ethical, social, professional, and research integrity (ESPRI), a self-report of exposure to ethical and responsible research in high school, high school experience, and demographic attributes. The survey questions related to engineering and science issues test were adopted from a prior study by Borenstein, Drake Kirkman, and Swan [13]. These questions were already validated by the original authors of the paper. Questions on ethical and professional behavior were developed through consultation with a number of studies, including Canney & Bielefeldt's Ethical Professional Responsibility Assessment [14] and Howland et al. [15], as well as a number of other validated studies not specific to engineering. The items are intended to measure five constructs (motivation, honesty, collaboration, career-life alignment, and self-efficacy) to understand the ethical awareness and self-efficacy levels of the participants. In addition, the survey questions also included few check questions to ensure that the respondents were paying attention while filling out the survey. The survey design and questions received appropriate IRB approval. The survey questions for each section were organized in a tabular format so the students could navigate the survey easily. The estimated time to complete the survey was less than 15 minutes. Lastly, the survey population included two main groups: 1) all engineering freshmen (slightly over 3,000 students); 2) senior students taking a course in engineering ethics (approximately 1,000 students). The main objective of selecting the two very distinct groups for the baseline study was to investigate if there are any significant differences in average ethical self-efficacy and competency scores between the freshmen and senior students. This also gives an indirect measure as to what extent the students would have improved their ethical research self-efficacy and competency by being in the engineering programs at Texas A&M University. This is considered an indirect study because it is not a longitudinal study and involves two different set of student populations.

While the survey instrument included questions related to issues test and engineering and research ethics education in high school, this paper presents only a preliminary analysis of four of the

constructs (honesty, motivation, career-life alignment, and collaboration) in the section of the study measuring ESPRI. It may be noted that this project started in fall 2021, therefore, the scope of this paper is limited to only one section of the survey, and much of the analysis is work in progress. The PIs intend to share the full results and analyses of the survey in future publications.

Survey response rate and reliability

Although the survey instrument was developed by the project team, the actual survey was conducted by an independent project evaluation firm. The firm used an online survey platform to conduct this study. The external firm collected the data and removed all identifiable information and shared the deidentified raw data to the project team. The project team is currently analyzing that data which is expected to be completed by the end of Spring 2022. Thus, this paper presents only the preliminary analysis of one section of the survey. Specifically, this paper is focused on the ESPRI scores of two population groups: engineering freshmen and seniors. During the survey, questions from the four constructs were placed in a random order to avoid any biases in the study. Following the survey, the questions were organized by the constructs and their reliability were examined by calculating average Cronbach alpha for each construct. Table 1 depicts the Cronbach alpha value for each construct.

Table 1: Summary of Cronbach Alpha Value for each construct

Construct	Cronbach Alpha Value
Honesty	0.54
Motivation	0.68
Career-life alignment	0.74
Collaboration	0.32

While Cronbach alpha values for some constructs are below the desirable value of 0.7, it is important to note that the Cronbach alpha value for the overall data is 0.78. The potential survey pool consisted of 4000 students in the two engineering courses targeted. The survey was built on an online platform and distributed via a course learning management system. Overall, 1493 students (which is about 37% of the total population) responded to the survey. The data analysis was conducted in two phases: first a preprocessing of data was performed to remove all invalid data, and in the next stage, a comparative analysis of the survey responses obtained from engineering freshmen and seniors was conducted to identify any difference in findings between these two population groups.

In total, 243 responses were discarded from the analysis because of the following reasons:

- 142 responses were removed as they disagreed to “informed consent”, where they did not answer any questions.
- 101 responses were removed for missing responses.

Thus, after eliminating 243 non-responsive or flawed responses, the total number of 1250 valid responses was considered for the analysis.

Demographic attributes

As mentioned earlier, the potential survey pool consisted of 4,000 students of which 3,000 were engineering freshmen in their first semester of college and 1,000 seniors who were enrolled an

engineering ethics course during the fall 2021 semester. A total 1,493 students responded to the survey. After eliminating the 243 non-responsive responses, the ratio of female to male students was 266:961 (or, 31%), 14 participants chose not to reveal their identity, and 8 participants identified themselves as Other. The undergraduate engineering students participating in the study were majoring in- aerospace, biological and agricultural, chemical, civil and environmental, computer science, electrical and computer, engineering technology and industrial distribution, materials science, mechanical, nuclear, petroleum, ocean, and multidisciplinary engineering. The participants belong to a variety of ethnic groups- American Indian or Alaska native, Asian, African American or Black, Native Hawaiian or other Pacific Islander, and White. Further, many participants did not identify themselves as Hispanic, Latino, or of Spanish origin. Figure 1 a) & b) shows the demographic distribution based on ethnicity and Hispanic, Latino, or Spanish origin. Figure 1 c) depicts the demographic attribute based on gender. These figures depict that the survey respondents cover a very diverse group of students not only in terms of gender and ethnicity but also based on their fields of study, thus making this study a representative of the larger student body in the college of engineering.

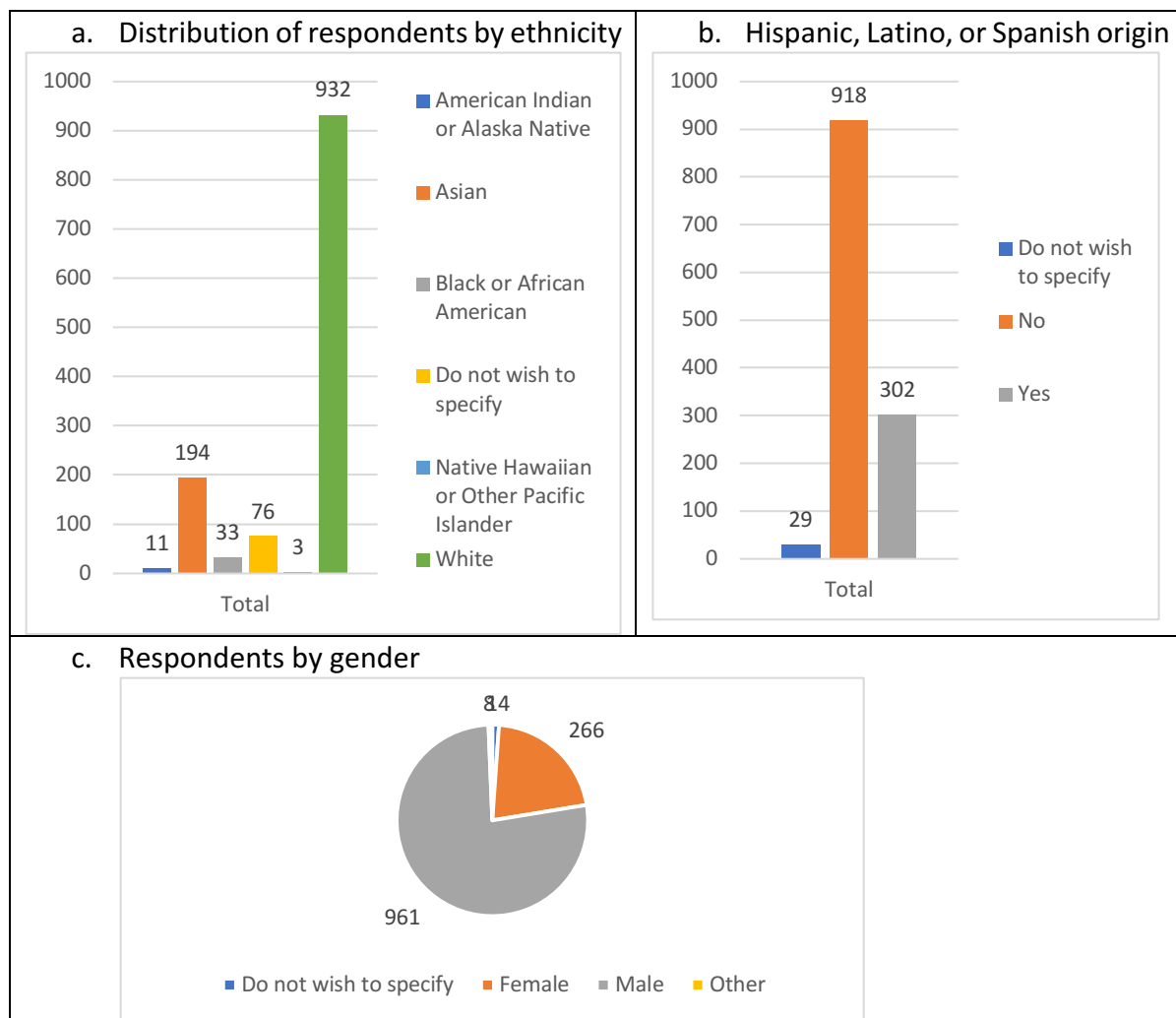


Figure 1: Demographic attributes of the survey respondents

Survey results and discussions

This section presents an early analysis of the survey results of ESPRI questions. It compares the average scores of freshmen and seniors with respect to four constructs and 24 questions. For example, Figure 2 shows the distribution of student ratings for the questions with respect to honesty construct. The ratings are on scale of 1 to 7, where 1 indicates “strongly disagree” and 7 indicates “strongly agree”. As illustrated in Figure 2, student ratings have almost an identical distribution for both student population groups (freshmen and seniors) with respect to all the six questions related to this construct.

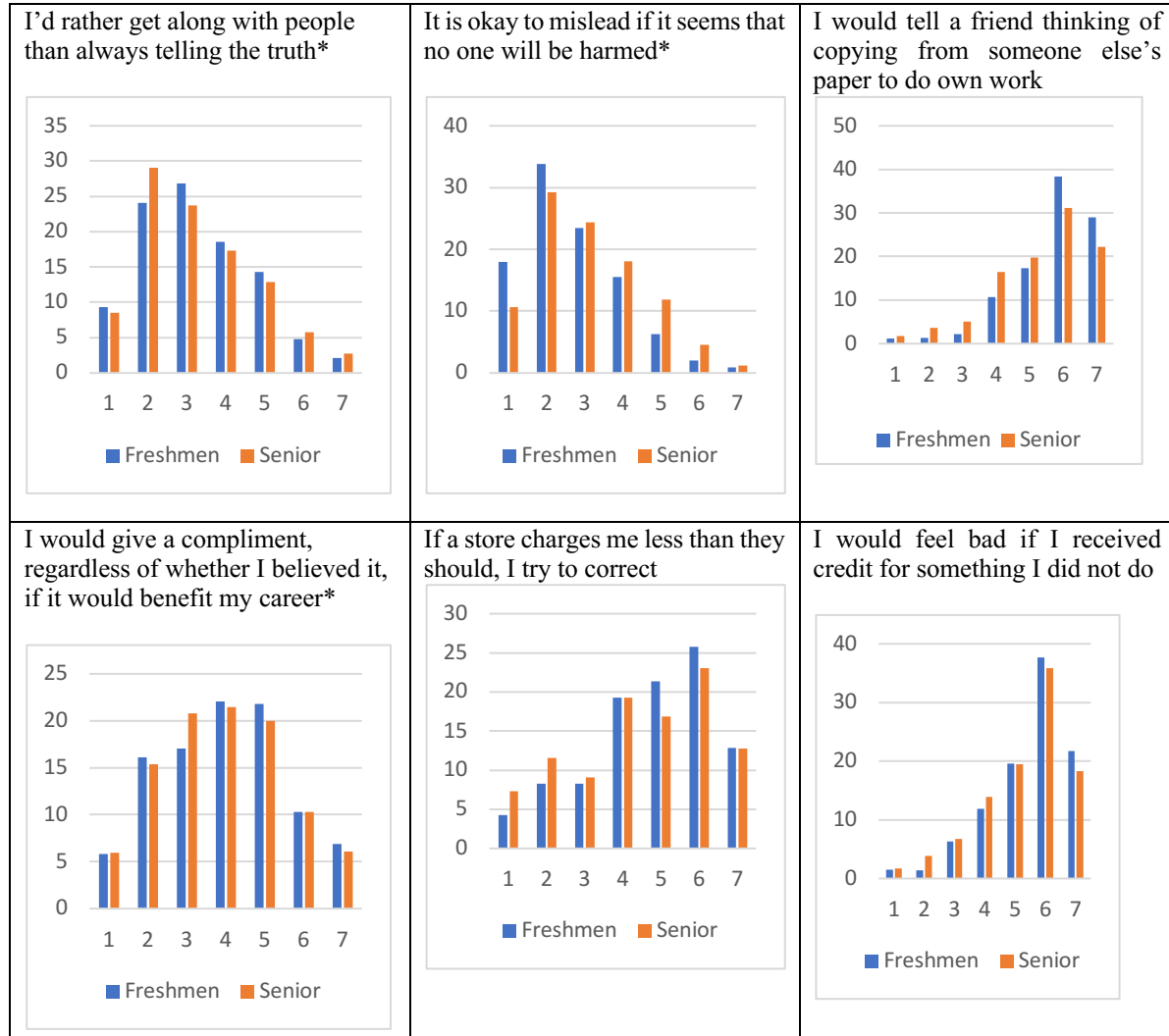


Figure 2: Distribution of survey ratings by freshmen and seniors for questions related to Honesty constructs (*Note: full description of questions are available in Table 2; asterisks denote items that will be reverse scored*).

Furthermore, Table 2 provides a numerical summary of the assessment scores with respect to all four constructs. Interestingly, our baseline survey results show that there were no significant difference in mean and standard deviation of the aggregated scores between the two population groups (freshmen and seniors) in all constructs. Although this paper does not include an in-depth

statistical analysis of the student responses, few observations were made during the preliminary analysis of each construct. First, the motivation construct had 7 questions and the responses from both freshmen and senior differ slightly. For instance, while 47% of freshmen strongly agreed with the idea that career success means a great deal to them, 42% of seniors strongly agreed with the same. Further, while 28% of freshmen strongly agreed that the quality of work that they do in their courses will have a major impact on their career success, only 13% of the senior strongly agreed with the same.

Table 2: Comparison of scores for the ESPRI questions

Construct	Question	Freshmen mean (standard deviation)	Senior mean (standard deviation)
Motivation	Career success means a great deal to me.	6.15 (1.20)	5.97 (1.22)
	The quality of the work I do in my courses will have a major impact on my career success	5.71 (1.24)	4.82 (1.49)
	I have a good understanding of the opportunities an engineering degree provides	5.36 (1.24)	5.45 (1.18)
	I have a good sense of how the engineering career I plan to have will contribute to society.	5.37 (1.39)	5.26 (1.37)
	I consider engineering to be a career that offers far more than just a paycheck	5.82 (1.21)	5.56 (1.28)
	I am pursuing a degree in engineering primarily because it is challenging or interesting work	5.40 (1.31)	5.19 (1.37)
	I am pursuing a degree in engineering primarily because it leads to a well-paid career or will be instrumental in some other career (e.g., intellectual law, medicine, or business)	4.87 (1.58)	4.92 (1.60)
Honesty	I'd rather get along with people than always tell them the truth	3.27 (1.43)	3.25 (1.48)
	It is okay to mislead someone if it seems that no one will be harmed.	2.68 (1.29)	3.09 (1.40)
	I would tell my friend to do his or her own work if he or she were thinking of copying some text from someone else's paper	5.72 (1.23)	5.31 (1.42)
	I would give someone a compliment if I thought it would help my career, regardless of whether I believed it.	3.96 (1.61)	3.89 (1.58)
	If a store charges me less than what they should have, I try to correct them	4.73 (1.62)	4.47 (1.81)
	I would feel bad if I received credit for something I did not do	5.46 (1.33)	5.26 (1.42)
Collaboration	In engineering work, being efficient is more important than considering a range of viewpoints	3.73 (1.43)	3.47 (1.48)
	Improving my ability to communicate is as important as improving my technical skills	6.05 (1.11)	6.13 (1.10)
	I feel confident expressing my opinions when people disagree with me	5.26 (1.31)	5.20 (1.32)

	I tend to become frustrated when there is ambiguity and uncertainty about what my group should do	4.93 (1.42)	4.82 (1.39)
	I find it interesting to learn why people think the way they do	5.85 (1.28)	5.71 (1.24)
	Almost all of my friends in college are studying engineering	4.31 (1.81)	4.29 (1.93)
	My success as an engineer depends in large part on what my colleagues do	3.77 (1.46)	3.80 (1.49)
Career-life alignment	I know what matters most to me.	5.49 (1.32)	5.61 (1.26)
	I can explain how what matters most to me aligns with my aims as an engineer	5.22 (1.34)	5.19 (1.24)
	I have a good understanding of the kinds of responsibilities engineers in industry have	5.15 (1.28)	5.38 (1.14)
	I know the characteristics and skills that make engineers in my industry successful	5.09 (1.25)	5.27 (1.16)

Moreover, 33% of the freshmen agreed with the idea that they have a good understanding of the opportunities an engineering degree provides, and 26% of the seniors agreed with the same. The collaboration construct also had 7 questions and the response of both freshmen and senior had many similarities. For example, an equal percentage of participants from both groups strongly agreed with the idea that their success as an engineer depends in large part on what their colleagues do. Further, both the groups agreed that they find it interesting to learn why people think the way they do. While 10% of freshmen somewhat disagreed with the idea of becoming frustrated when there is ambiguity and uncertainty about what their group needed to do, 8% of seniors disagreed with the same. Likewise, 52% of seniors strongly agreed that improving their ability to communicate is as important as improving their technical skills, while only 42% of the freshmen strongly agreed with the same. Lastly, the career-life alignment construct had 4 questions and the responses from both freshmen and senior were also similar. For instance, 13% of freshmen strongly agreed with the idea that they were aware of the skills that make engineers in their field successful, and 14% of the seniors agreed with the same. Moreover, 12% of freshmen strongly agreed with the idea that they have a good understanding of the kind of responsibilities engineers in industry have and 13% of seniors strongly agreed with the same.

Conclusions and Future Work

Previous research in the field of engineering indicates that ethical awareness is important for students. It is important for engineers to be aware of their contribution and impact on society at large. Ethical decisions are made by engineers on a daily basis and thus, it becomes imperative to impart ethical knowledge to engineering students before they begin their professional careers. To that end, the goal of this project is to investigate the current level of ethical research self-efficacy and competency among the engineering students during their formative years and offer them necessary training (intervention) so that their self-efficacy and competency levels are improved by the time they graduate.

This paper presented a preliminary analysis of survey results of engineering freshmen and seniors with respect to engineering professional responsibility assessment. Based on the responses of over

1,200 students, the survey results showed that there were no significant differences in how seniors and freshmen viewed the various ethical issues they currently face in their student lives and expect to meet in their professional career as an engineer. On the other hand, it is important to note few limitations of this study, which are: 1) this is a first baseline study using an unvalidated instrument; and 2) while overall reliability of the data was very good (Cronbach alpha = 0.78), the individual construct reliability values ranged from 0.38 to 0.74. Therefore, the authors would like to caution the readers not to generalize the findings of this study.

The project team plans to develop and validate a scale to assess the ESPRI items. More importantly, the future work of the project involves completing the in-depth analysis of the baseline survey data, identifying key gaps, working with high school teachers to introduce science and research ethics to their students, and developing curricular modules for junior and senior engineering courses for pilot intervention study.

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