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Board 217: Assessing Awareness and Competency of Engineering Freshmen on Ethical and Responsible Research and Practices

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

Abstract

This paper presents the progress made in the first year of a five-year National Science Foundation's Ethical and Responsible Research (ER2) program-funded project on ethical and responsible research and practices in science and engineering undertaken at a large public university in the southwestern United States. 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 paper will describe the progress made in several components of the grant: i) Preliminary analysis of measures of ethical knowledge, reasoning skills, attitudes, and practices of several hundred undergraduate freshmen and seniors, correlated with demographic data based on data captured in the first year of the grant; ii) Progress made in the development of the concept of "ethical self-efficacy" and an instrument to measure it for freshmen and senior engineering students and in assessing how it relates to ethical competency and student background; iii) Implications of these analyses in the construction of a three-week professional development program that guides high school STEM teachers through the development of learning modules on ethical issues related to their courses; iv) The assessment of the undergraduate engineering curriculum in two majors to determine appropriate courses for ethics interventions to help students understand how technical activities fit within broader social, economic, and environmental contexts; the construction of these interventions; and the development of measures to track their success; and v) Initial steps toward measuring impact of other experiences (e.g., undergraduate research, internships, service learning) and courses (e.g., humanities, social science, and business courses) on the development of ethical practices on assessments taken in senior engineering capstone courses.

Introduction

There are numerous documented instances of ethical misconduct across the fields of science and engineering [1, 2]. Authors have noted the importance of educating scientists and engineers in ethical behavior [3, 4]. Some accrediting bodies (e.g., [5]) include the teaching of ethics in their accreditation requirements. Even given these requirements and significant implications of ethical lapses that resulted in the loss of life [6, 7], some note that ethics is not a prominent topic in engineering education [8]. This work details results from a National Science Foundation project that uses evidence-based interventions to improve the education of ethical researchers and practitioners in STEM fields. To allow for a better understanding of views of ethics that students matriculate to the university with, this work details the results of a survey given to first year engineering students. This will not only identify the gaps that need to be filled during their college career but also inform the designing of the summer enrichment program for high school teachers to improve ethics content, which is also part of this project. This work also contributes to the lack of empirical work related to ethics at the tertiary level [1].

In this work, the definition of ethics used is that of [2]and refers to professional ethics related to engineering practice and the responsible conduct of research. Several instruments have been used to evaluate domains of students' ability to ethically reason [9, 10]. Like other competencies, moral reasoning ability (ethical competency) is different from one's self-efficacy related to moral reasoning (ethics self-efficacy). Self-efficacy is defined as "an individual's beliefs in their capabilities to plan and take the actions required to achieve a particular outcome" [11]. Self-efficacy is related to effort, resilience, and greater accomplishments [12, 13]. High levels of self-efficacy have been shown to be correlated with improved academic outcomes [14, 15]. In some cases, self-efficacy is seen as a significant predictor of academic outcomes [16-18]. However, just as in other areas, a universal measure of self-efficacy is not appropriate to determine ethics self-efficacy [19, 20]. Some domain specific self-efficacy scales include general engineering [21] and software engineering [22]. This work presents a survey instrument that attempts to measure ethical self-efficacy.

Whereas a general self-efficacy instrument would contain questions such as, "I can always manage to solve difficult problems if I try hard enough" or "I can solve most problems if I invest the necessary effort" [23], an instrument related to the design domain would include questions such as "I can identify a design need." These are usually answered on a Likert [24] scale ranging from strongly agree to disagree. The understanding of ethics competency and ethics self-efficacy will allow for the impact of interventions on these two metrics to be evaluated and isolated from the impact of the general education of college students.

Interventions have been shown to improve moral reasoning. In one case, an applied ethics course improved cognition and behavior outcomes [25]. Ethical judgment was improved among high school students as a result of incorporating ethics content into a high school course [26]. Just as moral reasoning (or ethics competency) can be improved through interventions, the broader study this work is part of proposed that moral self-efficacy can be as well. Sources of self-efficacy include: performance experiences, vicarious experiences, social persuasion, and one's physiological or emotional state [27, 28]. Those who experience success (or failure) in a particular task (performance experiences) can experience greater (or less) self-efficacy. Seeing other behavior (vicarious experiences) can also impact self-efficacy. The social persuasion of others (e.g., being part of a group that feels confident) as well as one's physical and mental state can also impact self-efficacy. For instance, positive emotions can improve self-efficacy [29]. Once a baseline for ethics self-efficacy has been established, these various sources will be used in interventions to improve ethics self-efficacy.

The remainder of this paper is organized as follows. The research design comprises of the research questions, the survey instrument details, and the data collection process which is discussed in Section 2. This is followed by an analysis of the data in Section 3 where we report some of the findings. In section 4, we summarize the progress of the project in the first year along with some of the challenges that were encountered. We conclude the paper with a few concluding remarks and some of the future work.

Research design

The objective of the survey (in year 1) was to create baseline metadata to inform future project activities such as summer research experience for high school teachers and curriculum development in undergraduate courses. In addition, the baseline data would also allow for evaluating the efficacy of the existing instruments in the literature. The first step in this process was to develop a set of appropriate instruments for assessing knowledge, moral reasoning skills, attitudes (moral reasoning aspects), and practices that would be of note at various levels but also could be tracked among all populations: secondary students and teachers, entering college students, and senior college students. To that end, a multidimensional approach was designed and developed by the project team to assess the ethical-self efficacy of engineering first-year students and seniors.

Research questions

The baseline survey was designed to investigate the following research questions:

RQ1. *What do high school students know about ethical and responsible research, and what affects their level of ethical commitment to it in educational practice? What has shaped their knowledge and attitudes to it? How is ethics introduced in high school, and specifically, in science and engineering courses? What is the effect of inserting an ethics component into high school science classes?*

RQ2. *Are there any underlying factors that may explain the variability in the Ethical Research competency (ERC) and Ethical Research Self-efficacy (ERS) levels across the different student populations such as student demographic and socioeconomic attributes, academic attributes (e.g., major), professional experience attributes (level of involvement in extracurricular activities, prior exposure to research, industry internship, nature of work experience)? Do certain factors correlate with shortcomings in science and engineering ethics formation of incoming freshmen?*

Survey instrument

The research questions cover broad perspectives of students' knowledge, moral reasoning skills, attitudes (moral reasoning aspects), and practices at all levels. The research questions also deal with students' educational backgrounds (e.g., high school education) and demographic variables. Therefore, to investigate these questions, the survey instrument consists of multi-scale multi-section questions that were partly adopted from the existing literature. That said, the project team developed the majority of the questions. For example, to investigate the ethical competency of students, this study uses Engineering and Science Issues Test developed by Borenstein, Drake [9]. Overall, the instrument consisted of five sections: Engineering and Science Issues Test (ESIT), Engineering Professional Responsibility Assessment (EPRA), exposure to ethical and responsible research in high school, ethical self-efficacy, and demographic attributes. Although the EPRA questions were framed along the lines of a similar prior study by Canney and Bielefeldt [30], the original questions were not adopted in this study because of differences in the scope and the objectives of the study. More specifically, Canny and Bielefeldt [14] focus on engineering students' views on social responsibility. In contrast, the present study aims to investigate the students' ethical awareness with respect to four constructs, namely, motivation, honesty, collaboration, and career-life alignment. The ESIT section includes two case studies instead of the original six cases used in Borenstein et al. [9]. More importantly, only one of the two cases is assigned (randomly) to each participant. The rationale behind keeping only two cases was primarily driven by the time it took to complete the survey.

Furthermore, two sets of self-efficacy questions are designed because freshmen and seniors are likely to have different levels of exposure and education on ethical research and practice. It is likely that the self-efficacy level of engineering freshmen largely depends on the type of education and exposure they had in high school. Therefore, the survey also includes questions related to the amount of ethics education a student may have had due to curricular and circumstantial exposures. To identify any unmotivated response that could impact the data quality, a few "attention check questions" are also added to the survey.

Data collection

An appropriate Institutional Review Board (IRB) approval was obtained before launching the survey. The survey was distributed electronically to students by an external project evaluator. The respondent pool included 4,000 students (about 3,000 first-year students and approximately 1,000 seniors). All first-year students are first-semester students fresh out of high school, and the seniors are the students who are currently enrolled in an engineering ethics class. Gathering data from two distinct population groups (freshmen and seniors) allows for a comparative study between the groups at two extreme points (one at the entry-level and the other about to graduate) of their engineering education at a major university. In other words, this is an indirect way of evaluating the extent to which students would have gained self-efficacy related to ethical research and practice while attending the university. However, in the future, the project team plans to conduct a direct assessment through longitudinal studies of students who go through different engineering programs at a major southwestern US University.

Data analysis

While the survey instrument included questions related to the engineering issues test, EPRA questions, level of ethics education/experience in high school, self-efficacy, and demographics attributes, this paper presents only the analysis of self-efficacy questions and their correlations with high school experience and demographic attributes. It may be noted that the project team has collected a new set of data at the end of the fall 2022 semester. However, due to the submission timeline of this conference, the new data and its analysis could not be included in this paper.

Survey response rate and reliability

The survey was distributed to freshmen in a first semester Engineering Computing class. The class had over 4,000 students. Although the project team developed the questions, an external evaluator converted those questions into an online survey and shared the link with students. After collecting the data, the external evaluator shared the deidentified data with the project team. The survey response rate was 17% (1,493 responses) of which 243 were excluded from the analysis due to missing or “inconsistent” response. By inconsistent, we mean if a student failed to choose a correct response in our “attention-check” questions or, in some cases, disagreed to the informed consent. At the end, 1,250 responses were considered for further analysis. The Cronbach alpha values for the data set varied across various sections of the survey. The overall Cronbach alpha for the survey was around 0.78.

Demographic attributes

Of the 1,250 responses included in the analysis, 650 of them were freshmen and the remaining 600 were seniors. About 20% of respondents were female which matches the overall split between male and female in the college of engineering at the university. With respect to racial diversity, about 75% of them were White, 14.5% Asian, 3% Black or African American, and about 7% others or did not specify. Likewise, 23% the respondents said they were Hispanic or Latino, whereas 74% said "no" and 3% did not specify. Ethnicity split is also approximately the same as the overall student populations in the college of engineering at the university. In that context, the survey response is representative of the student populations. The demographic attributes of the first-year students are depicted using plots in Figure 1.

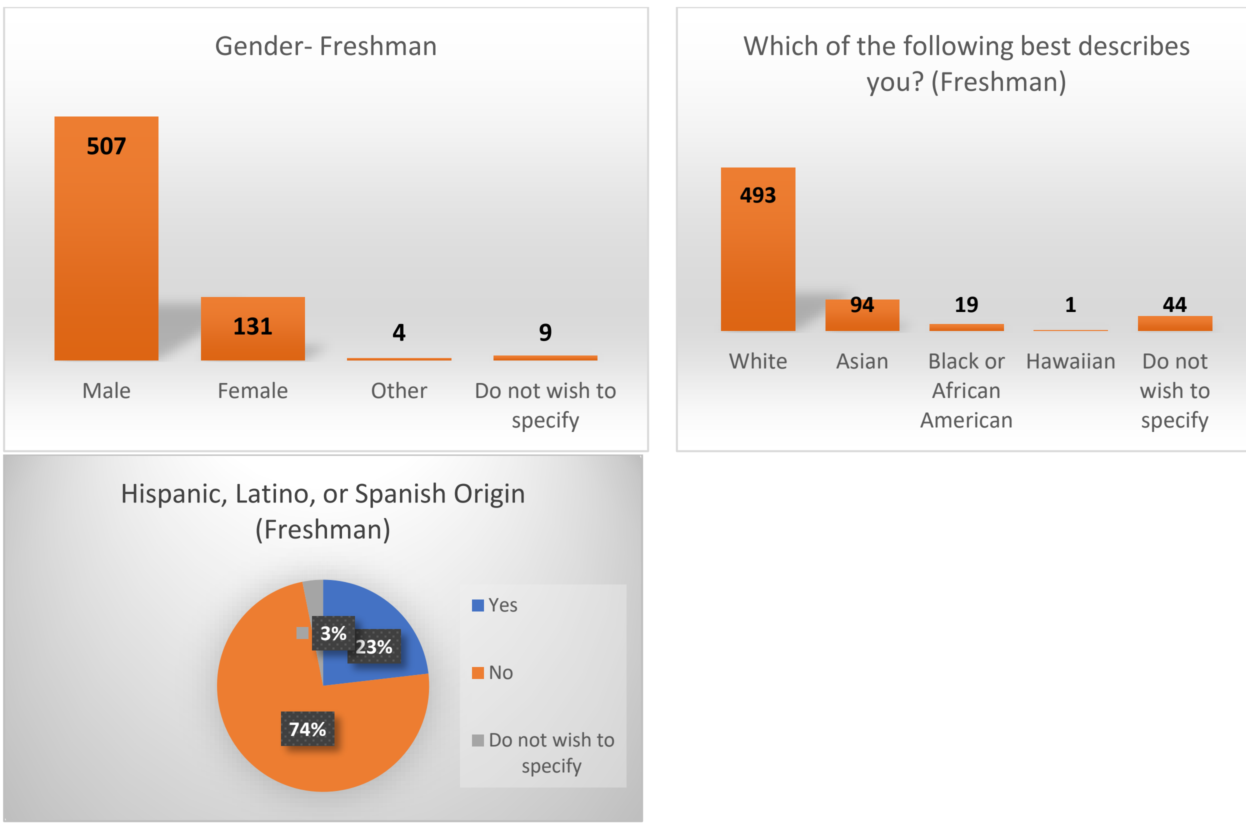

Figure 1: Demographic attributes of the first-year students

Survey results and discussions

This section presents the survey results of self-efficacy questions. Table 1 shows the list of self-efficacy questions for freshmen and seniors.

Table 1: Self-efficacy survey questions

Q. #	Population Group	Self-efficacy Questions
D1	Freshmen	I am confident that I know what is required to avoid academic integrity issues (e.g., acknowledging the contributions of others, avoiding plagiarism, and accurately reporting data).
D2		I feel certain that my experiences have prepared me to work effectively with students regardless of their major, culture, and how much money they have.
D3		I feel that I will be able to withstand the temptation to take shortcuts on assignments by using other people's work when I feel like I have too much to.
D4	Seniors	I am certain that I would respond correctly if I were choosing a vendor or making another professional decision that could make my family, my friends, or me better off financially.
D5		I am concerned that I will be unable to respond effectively if my client pressures me to accept a flawed engineering solution.
D6		I feel that I am prepared to work effectively with co-workers from different racial, ethnic, and disciplinary backgrounds.
D7		I am sure that if my boss asked me to complete a task that I did not feel like I had the education or experience to do, I would respond appropriately.
D8		I feel prepared to address interpersonal tensions that arise between my coworkers
D9		I know how to balance the interests of my employer, myself, and the public, and how to explain my decisions.

As shown in Table 1, there were separate set of self-efficacy questions for freshmen and seniors because their levels of exposure to research and education in engineering ethics are likely to be different. In other words, seniors would have more education and experience in ethics compared to freshmen due to additional coursework and industry internships. Seniors will soon have to face the real-world where they may be presented with ethically challenging decisions whereas the freshmen have just entered college without any real exposure to engineering ethics education. However, the high school experience and demographic questions were the same for all students.

The following sections present the analysis results related to the two broad research questions stated in section 2.1.

Analysis based on demographic attributes: Table 2 illustrates results of t-tests on the difference in mean self-efficacy scores for different population groups. The results are organized separately for freshmen and seniors as each had a separate set of self-efficacy questions.

There were no significant differences in mean self-efficacy scores concerning all three questions (D1-D3) for freshmen. In summary, the demographic attributes did not have any influence on the student's ethical self-efficacy level across the freshmen class regardless of the population groups included in this study. On the other hand, there were some interesting findings in the seniors' data. Specifically, male students scored significantly higher than the female students for question D8 which states, "*I feel prepared to address interpersonal tensions that arise between my coworkers.*" For question D5 (that is, "*I am concerned that I will be unable to respond effectively if my client pressures me to accept a flawed engineering solution*"), the first-generation students scored less than their non-first-generation peers. Lastly, students who took multiple AP courses in high school scored better in question D6 ("*I feel that I am prepared to work effectively with co-workers from different racial, ethnic, and disciplinary backgrounds*") than the other students who didn't take multiple AP courses.

Table 2: Self-efficacy scores compared to demographic attributes (T-test results)

Demographic Attributes	Gender (Male/Female)	Firstgen_Student (Yes/No)	Career_choice (Industry Vs. Academia)	Multiple_AP_courses (Yes/No)
Freshmen				
D1	Fail to reject H0	Fail to reject H0	Fail to reject H0	Fail to reject H0
D2	Fail to reject H0	Fail to reject H0	Fail to reject H0	Fail to reject H0
D3	Fail to reject H0	Fail to reject H0	Fail to reject H0	Fail to reject H0
Seniors				
D4	Fail to reject H0	Fail to reject H0	Fail to reject H0	Fail to reject H0
D5	Fail to reject H0	**Yes>No**	Fail to reject H0	Fail to reject H0
D6	Fail to reject H0	Fail to reject H0	Fail to reject H0	**Yes>No**
D7	Fail to reject H0	Fail to reject H0	Fail to reject H0	Fail to reject H0
D8	**Male>Female**	Fail to reject H0	Fail to reject H0	Fail to reject H0
D9	Fail to reject H0	Fail to reject H0	Fail to reject H0	Fail to reject H0

Analysis based on high school educational experience: As shown in Table 3, there were 10 questions related to students' high school education experience involving ethical decision making. The survey questions asked to what extent (in a scale of 1 to 4 where 1= Never, 2= Once, 3= Occasionally, and 4= Frequently) students were taught to embrace ethical practices in decision making in their academic and personal lives. The objective of this study was to investigate if the level of ethics education or exposure in high school had any impact on the freshmen's self-efficacy scores. For analysis purpose, the data was divided into two groups based on the types of students' responses. For example, all the "Never" or "Once" responses were combined into one group, and "Occasionally" and "Frequently" responses were combined into another group. Next, mean and variance of self-efficacy scores for each group were calculated and compared by conducting series of t-tests (with unequal sample sizes and variances). The p-values of the t-tests with respect to all three self-efficacy questions (D1-D3) for all ten high school questions are reported in Table 3. The p-values showed that majority of hypotheses were significant. In other words, amount of ethics education in high school had direct impact on student's self-efficacy scores. It may be noted that the high school question #10 (education related to environmental ethics) did not have significant impact on the self-efficacy questions (D1-D3). It was expected as the given self-efficacy questions were not directly related to the environmental issues.

While the t-test results in Table 3 illustrates a direct impact of high school education on freshmen's ethical self-efficacy scores, there are some limitations to this analysis. Specifically, the sample sizes for the "Never/Once" group for High School Questions 1, 2, 3, and 7 were significantly smaller compared to those for the "Occasionally/Frequently" group. Similarly, the number of "Never/Once" responses in questions 4, 5, and 7 were unusually high thereby demonstrating a need for ethics education/ exposure at the high school level.

Table 3: Comparison of self-efficacy scores with high school experience

HS Education Experience	Occurrence	Self-Efficacy Scores								
		D1: Academic Integrity (N)	D1 Mean score	D1 Variance	D2: Working with Others (N)	D2 Mean score	D2 Variance	D3: Withstand Temptation (N)	D2 Mean score	D3 Variance
Q1. Emphasized to follow accepted procedures in science experiments	**Never or Once**	29	5.0	**3.21**	26	5.0	**2.56**	28	5.6	**2.04**
	Occasional or Frequently	625	6.2	**0.92**	625	6.0	**1.31**	624	6.0	**1.30**
	p-values		**0.00**			**0.00**			**0.04**	
Q2. Encouraged to accurately report results regardless of outcome	**Never or Once**	35	5.5	**2.31**	32.0	5.5	**2.29**	33.0	5.2	**2.93**
	Occasional or Frequently	608	6.2	**0.94**	581	6.2	**1.20**	587	6.2	**1.08**
	p-values		**0.00**			**0.00**			**0.00**	
Q3. Importance of doing own work and recognitizing the contribution of others	**Never or Once**	21	5.4	**1.99**	18	4.8	**3.43**	19	4.7	**3.99**
	Occasional or Frequently	622	6.2	**0.99**	595	6.2	**1.16**	601	6.2	**1.07**
	p-values		**0.00**			**0.00**			**0.00**	
Q4. Grades for group work based on the individual contribution	**Never or Once**	100	5.8	**1.63**	**94**	5.6	**2.32**	94	5.8	**1.90**
	Occasional or Frequently	543	6.3	**0.89**	**519**	6.2	**1.03**	526	6.2	**1.08**
	p-values		**0.00**			**0.00**			**0.00**	
Q5. Taught to welcome and work with people from different backgrounds	**Never or Once**	132	6.0	**1.52**	**123**	**5.7**	**1.86**	134	6.0	**1.65**
	Occasional or Frequently	525	6.1	**3.30**	**521**	**6.1**	**1.25**	524	6.1	**1.17**
	p-values		**0.00**			**0.00**			**1.68**	
Q6. Teachers interested in student's development and growth	**Never or Once**	80	6.1	**1.21**	**76**	**5.6**	**2.36**	82	6.0	**1.65**
	Occasional or Frequently	563	6.2	**1.37**	**537**	**6.2**	**1.06**	546	6.2	**1.17**
	p-values		**1.00**			**0.00**			**0.15**	
Q7. Teachers treated me and my classmates with respect	**Never or Once**	24	5.6	**3.12**	**24**	**5.5**	**2.60**	22	5.3	**3.12**
	Occasional or Frequently	619	6.2	**0.94**	**589**	**6.1**	**1.20**	598	6.1	**1.13**
	p-values		**0.00**			**0.01**			**0.00**	
Q8. Taught to think about my role requiring to make decision that was not in my (or family) interest	**Never or Once**	223	6.1	**1.22**	**208**	**5.8**	**1.70**	211	5.9	**1.57**
	Occasional or Frequently	420	6.3	**0.93**	**405**	**6.3**	**0.95**	409	6.2	**1.03**
	p-values		**0.02**			**0.00**			**0.00**	
Q9. Taught to think how individual actions affect community	**Never or Once**	92	5.8	**1.82**	**89**	**5.5**	**2.74**	87	5.9	**1.78**
	Occasional or Frequently	551	6.3	**0.88**	**524**	**6.2**	**0.94**	533	6.2	**1.13**
	p-values		**0.00**			**0.00**			**0.02**	
Q10. Taught to consider choices that can affect environment	**Never or Once**	93	6.1	**1.18**	**83**	**6.0**	**1.39**	85	6.0	**1.3**
	Occasional or Frequently	548	6.2	**0.92**	**527**	**6.2**	**1.12**	531	6.2	**1.0**
	p-values		**0.14**			**0.15**			**0.23**	

D1=Confident to avoid academic integrity issues

D2=Prepared to work with students from different background (major, culture, income level, etc.)

D3=Able to withstand temptation to shortcuts on assigments by using other's work

Project progress and challenges: year 1

Progress was made in all aspects of the project. As noted above, data on the ethical attitudes, moral reasoning performance, and high school experiences of 650 freshmen and 600 seniors was collected. A provisional analysis was carried out on the data, and some of the scales were changed to provide finer measures. The team assembled profiles that capture the socioeconomic status, teacher education, and teacher experience of Texas public high schools, and ran initial analysis to determine correlations between these profiles and the student data that had been collected. The project team also determined the parameters for a thematic literature review of engineering ethics interventions and assessments that have been published over the last decade and began its analysis. Finally, three courses in the Engineering Technology & Industrial Distribution and in Industrial and Systems Engineering programs were identified as appropriate candidates to introduce ethical content.

The project team worked with the university's *Spark!* PK-12 Engineering Education Outreach to identify the relevant sections of the Texas Education Agency's Texas Essential Knowledge and Skills (TEKS) curriculum standards to determine four courses (biology, chemistry, integrated physics and chemistry, and physics) that were suited to integrated research ethics and discussions of the roles, importance, and limitations of science and engineering in society. An initial review of undergraduate student responses showed that research integrity has been stressed occasionally or frequently to most, but not all, students.

Over the first year, a number of challenges have been identified. "Ethical and professional responsibility" covers a wide range of concerns, knowledge, attitudes, and skills, many of which are difficult to measure. Of the four elements identified by moral psychologists as necessary for moral action, two (moral awareness and moral commitment) are difficult to measure accurately, and one (ethical knowledge) is difficult to measure sufficiently because that includes a variety of elements that depend on an engineer's industry and role, as well as codes of ethics that vary by discipline, and knowledge of technical standards and cultural norms. Even an instrument designed specifically to measure moral reasoning for engineers, Borenstein et al.'s Engineering and Science Issues Test [9], has not been widely adopted. The project team realized that most measures will likely be more useful for longitudinal and year-over-year comparisons.

Another considerable challenge encountered in the design of the survey instrument is the change in perspective that students experience as they move through the degree program from freshmen to seniors. Items for first-year students are primarily backward-looking, formed by high school experiences, interested in whether they know the ethical behavior expected of students, whereas fourth-year students are asked whether they have known what ethical behavior is required of them as students and what it will require of them in their careers. This challenge is especially problematic for self-efficacy measures. Yet another challenge arises from an initial analysis of undergraduate engineering courses that are candidates for adding ethics modules, which revealed that instruction focuses primarily on scientific, engineering, and mathematical techniques, taught in an abstract manner, which does not allow for easy extension to ethical and societal concerns, which are often taught through cases and for which context often matters.

Conclusions and future work

This project is providing a solid platform for the project team to test some of the hypotheses related to ethics and ethics training in high school and engineering curriculum in a diverse and representative sample of students that are being trained as engineers of today and tomorrow. The first year data from a sample of 1,250 students (650 freshmen and 600 seniors) provided valuable insights on self-efficacy across different demographic attributes and high school educational experience.

One of the inferences that can be drawn from the survey data is that the demographic attributes did not have any statistically significant influence on the student's ethical self-efficacy level across the freshmen class regardless of the population groups (gender, first generation student, career choice option, taken multiple AP courses). There are three statistically significant findings that were observed from the data from the seniors. Male students scored significantly higher than female students on the question related to preparedness to address interpersonal tensions between coworkers. The first-generation seniors scored significantly less than their non-first-generation peers on the question regarding ability to handle client pressures to accept flawed engineering solutions. Seniors who had taken multiple AP courses in high school scored statistically significantly better on the question related to preparedness to work effectively with co-workers from diverse backgrounds.

The analysis of the data on high school educational experience revealed a couple of insights. The amount of ethics education in high school had a direct impact on the students' self-efficacy scores. Some of the collected data revealed a need for ethics education and exposure at the high school level.

As the project continues, the project team plans to conduct a direct assessment through longitudinal studies of students who go through different engineering programs to assess the impact of ethics training in the engineering curriculum. Given the size of the engineering program at the institution, the sample is likely to be large and representative of the population of the engineering professionals that are likely to be joining the workforce in the future.

The project team is developing plans to work with high school teachers through the Research Experience for Teachers (RET) to provide training and education in ethics during the summer months and help prepare ethics curriculum that can be integrated in the high school curriculum. The team is going to work with teachers from high schools that have significantly larger population of prospective first-generation students to provide adequate exposure to ethical issues to that segment of the population to help improve their ethics self-efficacy.

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