Implementation Strategy for Infusing Engineering-Specific Ethics Into the Mechanical Engineering Curriculum

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Abstract—

According to ABET, one major student outcome is "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts." Although some departments in the nation try to implement this through a standalone course, others cannot find the space in their curriculum to do so. Even when presented as a standalone course, it is typically introduced at the higher (junior or senior) levels. We aim to develop a detailed template for a department-wide plan for disseminating engineering ethics topics throughout the Mechanical Engineering curriculum in sophomore, junior, and senior year courses. This includes guidance on the frequency and quantity of time and effort devoted to engineering ethics topics in the identified discipline-specific courses. Some of these may require the development of example case studies used in lecture material, quizzes, and discipline-specific projects. A course instructor can use the appropriate rubrics for ABET assessments. This paper introduces the department ethics assessment plan that was used in the ABET self-study report for the last cycle. There is a periodical review of the implementation plan for continuous improvement. This plan is based on Bloom's taxonomy where each course is designed to equip the students at the appropriate learning level. At the sophomore level, we focus on students understanding the basic ethics theories and the ASME code of ethics through a case study and writing assignment. The junior-level course addresses the next higher learning level, namely analysis. Teams of students are asked to analyze and resolve developed course-specific problems that involve ethical considerations in the ASME code of ethics. The senior-level course examines and revisits some broad moral theories (Utilitarianism, Kantianism, Virtue-based) and the ASME/NSPE Code of Ethics. In this last stage, students evaluate various case studies, providing a much deeper learning experience. The current approach does have some challenges and requires alignment between the courses involved and periodical changes and updates. The proposed model could be expanded to other engineering disciplines. (*Abstract*)

Keywords—Ethics; ABET; Mechanical Engineering; Curriculum.

Accredited engineering programs are expected to demonstrate the fulfillment of student outcomes put forth by the ABET Engineering Accreditation Commission (EAC). The student outcomes "describe what students are expected to know and be able to do by the time of graduation." Furthermore, the student outcomes demonstrate "knowledge, skills, and behaviors the students acquire as they progress through the program" [1]. Programs being considered for accreditation or re-accreditation must provide evidence to the extent the student outcomes are being attained, and under Criterion 4, the assessment process demonstrates continuous improvement of the program. The integration of ethics within the classroom has no comprehensive framework for how to do so [2-4]. Within the authors Mechanical Engineering (MEEN) program, the assessment of all outcomes spread across the required curriculum. Due to the number of course-sections offered each semester and the number of faculty involved in the process, the program relies on both an ABET committee and course coordinators to facilitate regular assessment of the student outcomes. Figure 1 provides an overview of the assessment process adopted.

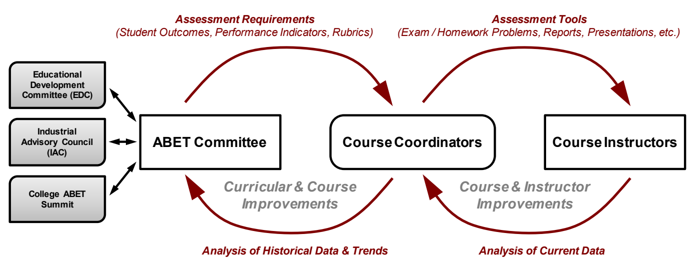

Fig. 1. Overview of Assessment Process

I. Assessment Methodology

An evaluation rubric was created to facilitate equitable evaluation across multiple courses, sections, and instructors. The targeted level of attainment for each performance indicator is 75% of students meeting or exceeding a threshold of 3.5 / 5.

The broad topic of "Engineering Ethics" is represented in Student Outcome 4 (SO4):

"An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental and societal contexts."

To assess the attainment of SO4 within the Mechanical Engineering Program, the outcome was divided into individual performance indicators. By evaluating each performance indicator individually, the attainment of the complete student outcome can be assessed. Within the program the following four performance indicators were used to evaluate SO4:

i. Recognize when ethical issues or dilemmas are encountered in global, economic, environmental, and societal contexts

ii. Identify ethical standards relevant to an issue or dilemma

iii. Analyze ethical concerns within the context of the relevant ethical standards

iv. Apply ethical perspectives / concepts

An evaluation rubric was created with each indicator having a 5 – 1 scale, with (5) being exemplary and (1) being unacceptable. The targeted level of attainment for each performance indicator was 75% of students meeting or exceeding a threshold of 3.5 / 5. Figure 2 shows the rubric that was used for assessment of SO4.

Performance Indicator	5 = Exemplary	4 = Good	3 = Adequate	2 = Marginal	1 = Unacceptable
(i) Recognition of ethical issues	Clearly identifies the ethical dilemma; clear understanding of the dilemma; identification of the affected stakeholders and the broader societal implications.	Clearly identifies the ethical dilemma; clear understanding of the dilemma and the affected stakeholders.	Clearly identifies the ethical dilemma and understands the implications of the issue.	Identifies the ethical dilemma.	Unable to recognize an ethical problem.
(ii) Identify ethical standards	Identifies and applies relevant case studies to a recognized dilemma; knows the value of professional codes.	Familiar with the value and importance of professional codes.	Demonstrates the ability to locate professional codes of ethics.	Aware that conduct standards exist, but cannot utilize them.	Cannot identify basic components of professional codes.
(iii) Analyze ethical concerns within context of relevant standards	Locates case studies and conduct codes to address the ethical dilemma; understands personal, professional, and wider social consequences of violations of codes.	Understands personal, professional, and wider social consequences of violations of codes.	Knows the professional consequences of violating codes of ethics.	Recognizes the violation of a professional code of conduct, but unable to identify consequences.	Unaware of consequences of violating codes of ethics.
(iv) Apply ethical concepts	Provides clear arguments; considers multiple points of view in their analysis; addresses the dilemma in light of relevant stakeholders.	Provides clear arguments; considers multiple points of view in their analysis.	Multiple points of view are considered to resolve the issue, but the plan is not clear or clearly articulated.	Takes only one point of view when analyzing a dilemma.	Unable to identify an ethical issue or formulate a plan to resolve the issue.

Fig. 2. Evaluation Rubric for Individual Performance Indicators Comprising SO4.

II. Implementation Plan

Due to curriculum limitations the College of Engineering (COE) moved away from a standalone ethics course. A detailed template was developed for a department wide plan for incorporating engineering ethics topics through the MEEN curriculum in sophomore, junior and senior selected courses. To the extent possible, guidance was included on frequency and quantity of time and effort devoted to engineering ethics topics in each of the identified discipline specific courses. Example case studies were identified. Delivery models ranged from lecture material, quizzes, discipline-specific exams with appropriate rubrics for ABET assessments as presented in Figure 2.

In addition to the COE first-year courses that include some ethical cases studies; three major specific courses were identified as follows:

i. Engineering Measurements (MEEN 260): This course has designated as a writing component.

ii. Materials and Manufacturing (MEEN 360): Ethical case studies were developed as part of the required design problems of the course.

iii. Intermediate Design (MEEN 402): The course is the second semester course of a two-semester senior capstone requirement culminating their undergraduate engineering education.

The presented implementation was designed with the least impact on the course involved. For example, the MEEN 260 is designated as a writing course in our school. This was altered by changing one of the major writing assignments to be ethics related. As part of this we did not need to redesign the course but rather realign it with ethical parts related to the ABET accreditation. In preparation for this assignment students were introduced to ethical theory and case studies during the first three weeks of the course.

The plan was based on Bloom's taxonomy where each course is designed to equip the students with the appropriate learning level. MEEN 260 focused on students understanding the basic ethics theories and the ASME code of ethics through a case study and writing assignment. MEEN 360 addressed the analysis learning level. Teams of students were asked to analyze and resolve ethical issues based on the ASME code of ethics. MEEN 402 provided a much deeper learning experience focused on ethical evaluations. Figure 3 presents the courses and their Bloom's Taxonomy focus levels.

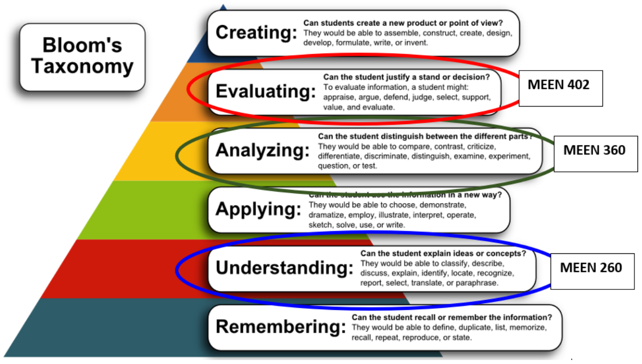

Fig. 3. Selected Courses Bloom's Taxonomy Focus Levels.

The following section presents more details of the implementation plan for these selected courses.

A. MEEN 260

Ethics was taught the first three weeks of the semester. A textbook was recommended as an engineering ethics reference: Ethics for Engineers by Martin Peterson (ISBN-13: 978-0190609191). The course started with a review of personal ethics, specifically cheating in college. Cheating and the consequences of it were defined. This was followed by an anonymous survey where students state whether they have cheated in college, known someone who does cheat, if they think cheating in college leads to ethical violations in the workplace, if they agree with the University Honor Code, and if it bothered them when instructors did not enforce the Honor Code. Sample results of the anonymous survey are presented in Figure 4.

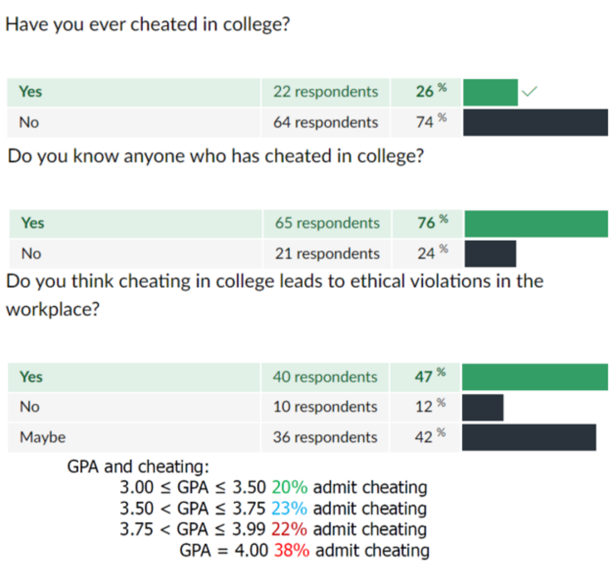

Fig. 4. Sample Results of MEEN 260 Survey.

ASME code of ethics and a case study of the Citicorp building in New York City was introduced. Students read about the case study prior to class and took a short quiz at the beginning of class before our discussion. "Muddy" cases of ethics when some codes are violated were introduced. There was homework assigned on similar cases where students drafted a short paper discussing the ethics in the cases.

Writing ethics were discussed such as plagiarism, using imprecise language, manipulating statistics, using misleading visuals, promoting prejudice, distributing misinformation and ways to avoid research misconduct. There was class discussion and individual exercises on identifying these ethical issues. There was homework assigned on the "3 cardinal sins" of research misconduct: Falsification, Fabrication, and Plagiarism. This was a very appropriate topic for MEEN 260 which has a lab component of class where students take data and draft reports about it. This was expanded on the ethics of Falsification and Fabrication of data. Volkswagen Emissions scandal was discussed and analyzed. Students were asked to read about the case prior to class and took a short quiz over it before discussion. This was related to the ASME code of ethics. Whistleblowing ethics were discussed to identify when it was appropriate and what the consequences could be.

B. MEEN 360

In this course students work in team projects that were developed with an ethical issue that would require the ability to analyze the ethical issues and propose a solution that is in alignment with the ASME code of ethics. In these projects the students were asked to select a material for a high-risk design/application such as:

- High pressure
- High or low temperature
- Susceptible to stress corrosion cracking/aggressive environment
- Fatigue loading
- Cost sensitive
- Under high pressure from upper management to build and operate the equipment
- They must identify and apply the ASME Code of ethics in their decision-making to select the material and communicate with upper management.

Where applicable homework problems were incorporated where students apply material science fundamentals/principles covered in the class to resolve problems that involve ethical considerations in the ASME code of ethics. Some examples suitable scenarios to formulate this type of problems were:

- Application of failure mechanisms/concepts to resolve dispute between user and manufacturer of a failed piece of equipment.
- Present a reasonable failure scenario based on information provided to the students and supported by material science concepts in a situation that is not favorable to the party/company work is being done for. Dispute between manufacturer and end-user of equipment.
- Recommend a material replacement in a critical application where a timely resolution and cost is considered.
- Handling of dangerous materials in a materials manufacturing facility

C. MEEN 402

In the lectures, the seriousness and gravity of ethical considerations were emphasized, weaving them into various lectures in the second semester of the senior capstone program. For instance, as part of the modules on Risk, Reliability, and Failure Avoidance, the program delves into some well-known textbook failures, such as the Space Shuttle disasters, the Deepwater Horizon accident, the Union Carbide plant tragedy, and the Kansas City Hyatt debacle. These case studies not only highlighted the technical aspects of the failures but also delved into the ethical decision-making involved, fostering a deeper understanding of the importance of ethics in engineering. It was explained how miscommunication or the perception that communication has happened lead to corporate neglect and irresponsibility and, thereby, ill-conceived designs. Students learned from these discussions that it is critical that risk assessments not be confined to only technical issues but must also consider human and organizational factors. For example, employees often succumb to pressure from their leadership to "get the job done" as quickly as possible. In addition to the material sprinkled over the various lectures, the second semester also includes two dedicated 1-hour lectures on Ethics for the Engineer.

Two modules were introduced; the first module, with a discussed how the students defined Ethics in their own words before some universally accepted definitions were revealed, such as the branch of knowledge that deals with moral principles or the moral correctness of specified conduct. They were asked to recall their recollection of moral theories from earlier classes and describe/discuss a few of them in detail: Utilitarian, Kantian, Virtue and Aspirational Ethics. Alternate definitions of these theories were provided, such as Kantianism, also known as Duty-based (what people need to do), or non-consequentialist (actions are absolute and not dependent on consequences of actions). Students considered why we would want a moral theory and how moral theories are not mutually exclusive. Students were asked to reflect on their multitude and diversity, which raises the question of whether one moral theory could or should ever be accepted as the "only" right one, and like models, they also have limits [2]. They realized that not everything in Life fits the classic textbook Trolley dilemma of "What would you do? Why?" (Figure 5)

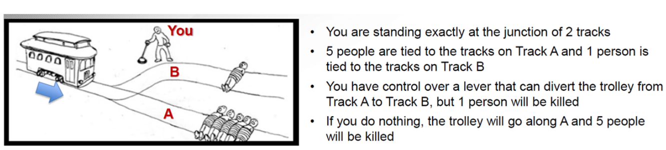

Fig. 5. What would you do? Classic Ethical Dilemma.

The rest of the first module introduced ethical standards for engineers as codified by the American Society of Mechanical Engineers (ASME) and the National Society of Professional Engineers (NSPE). The ASME Code of Ethics has three fundamental principles followed by ten fundamental canons that provide mechanical engineers with some basic guidance on ethical behavior [5]. The importance of safety in design is clear from the first canon, namely, Engineers shall hold paramount the safety, health, and welfare of the public in performing their professional duties. For its part, the NSPE Code of Ethics starts with its own six canons (almost identical to ASME), followed by five rules of practice and nine professional obligations [6]. The students then analyzed a case study (Gift to Public Official [7]) in small teams based on their interpretation of the class material thus far. The first module ended with a 10-question individual quiz on moral theories and these codes. These questions were either multiple-choice or True/False and intended to gauge the knowledge that the students take away from the first class.

For the second module, the students were assigned to watch an 80-minute video called "The Dropout" before coming to class [8]. It is the episode on ABC's 20/20 program of Silicon Valley entrepreneur Elizabeth Holmes and the fall of her start-up, Theranos, in an unbelievable tale of ambition and fame gone terribly wrong. After watching the video, the students were told to come prepared to class for discussions in small teams about the various ethical aspects (considerations, as well as actions, good/bad/indifferent) of the main protagonists in the case study. They were reminded to do this considering what they learned in the first module on Moral theories and the ASME/NSPE Code of Ethics and Canons. They were told that each team will be assigned one of six roles: Villains, Enablers, Dissenters, Investors, Whistleblowers, and Press. The exact role is not revealed to them until they come to the classroom (Figure 6) to ensure the students look at the big picture and analyze all the characters.

Fig. 6. Assignment of Roles to the Different Student Teams.

The most interesting parts of the class were not when the roles of the villains or whistleblowers were being discussed, since their actions were quite obviously dastardly or heroic. Rather, it was in the gray areas of ethical expectations and understanding that some of the most debated arguments happen. Usually, the class was evenly divided between those who felt one way or the other in terms of these grey ethical areas. Such discussions were useful as reminders that not everything in real world ethics is black and white, and it is up to the individual or company to figure out the best way forward. After each role had been discussed by the class, the faculty person went through an earlier-curated list, making sure that all the points were covered, and added bullets on added information that surfaced in the class. An example of this is shown in Figure 7.

Fig. 7. Example Curated List of Ethics Discussion Points for One Role.

Students at were expected to be at the evaluate level of their ethics learning journey. They were also expected to describe ethical considerations and aspects in the semester-end Final Report, specifically regarding their capstone project and prototype. To help with this task, they were provided with resources [9-12] as well as with some thought starters such as:

- What are some potential ethical challenges with your design? Recall some of the ethics cases you might have seen in the past.
- Safety Considerations for Man and Machine; Is intuitive use of your design safe?
- Failure of the system
  - Pressure to not operate it right, could it have been designed better?
- Usage of the system
  - Learnability, Efficiency, Error-proofing, Satisfaction
  - Can it be used in a "bad" way? Other misuses?
  - Exploitation of the weak, young, poor, old or other disadvantaged groups?
- Environmental impact
  - What is the environmental impact of your design? Is it sustainable?
- Privacy and Cybersecurity
- What potential Conflicts of Interest (CoI) of your design could users have?

III. Discussion and Conclusions

Direct assessment data was collected each semester for courses at the sophomore, junior, and senior levels. Figure 8 shows a sample of how this data was summarized to evaluate the attainment of SO4. In addition, to evaluate each element of the student outcome, all performance indicators were evaluated individually.

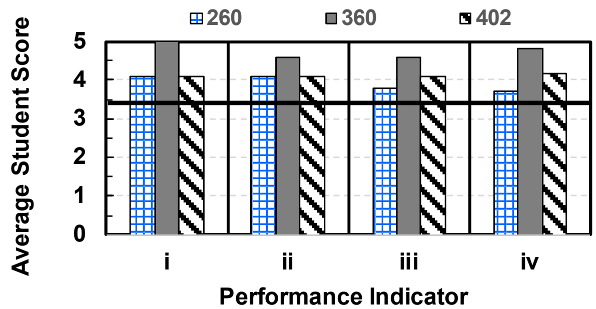

Fig. 8. Sample Summary Evaluation Data of SO4.

As indicated in Figure. 9, the percentages of students attaining the average were reviewed by the instructors and coordinators.

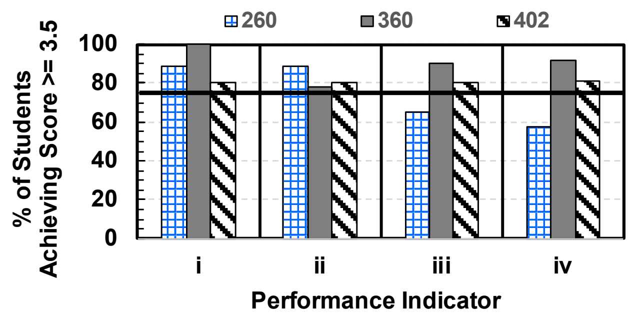

Fig. 9. Percentage of Students Attaining Performance Indicatores of SO4.

The 2023 - 24 ABET Self-Study Report prepared by the Current program MEEN department was selected for display of well-prepared Self-Study Reports at the 2024 ABET Symposium in Tampa, FL.

This paper presented a framework for including major specific ethics components as required from ABET. The changes to the curriculum were minimal and were tailored to the department's needs. The implemented method has been used for the last 4 academic years. The proposed methodology was proven to be effective in the latest ABET accreditation cycle.

This paper represents an answer to the question on how to effectively incorporate ethics in the engineering curriculum without a major disruption of courses involved. This by no means is a unique and only solution but a working solution. Other departments can utilize this framework to help tailor their own solutions based on their own needs and circumstances.

The current solution did have some challenges and requires alignment between the courses involved and periodical changes and updates. Currently we revisit this model once a year to check on how to make it more effective by analyzing students' responses and instructors' feedback to update the work. We believe this framework could be expanded to other engineering disciplines by identifying potential courses and having a plan based on Bloom's taxonomy to equip the students with the appropriate learning level.

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