An Exploration and Review of Ethics Instruction Methods for Undergraduate Engineering Students and an Examination of the MIT Mechanical Engineering Department's Current Practices in Teaching Ethics

by

Kiera Gavin

Submitted to the
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All accredited undergraduate engineering programs are required to teach ethics based on the ABET mandated Student Outcomes. How programs choose to do this is highly variable, but curriculum typically falls into one of three categories: the case method, theory-based method, and professional codes method; despite their prevalence in contemporary teaching, each of these methods has its flaws [1]. One school of thought argues that teaching the ethical thought process as a parallel to the engineering design process is the most effective way to communicate ethics to engineering students [2–5]. In order to understand what mechanical engineering students at MIT take away from their ethics education, a survey was sent to all students who had completed the most recent semester of one of the MIT Mechanical Engineering capstone courses. 52% of students responded, revealing a large variation in understanding of ethics and engagement with the ethics components of the course. Recommendations are made for changes to the ethics components of the course curriculum, aiming to improve the deficiencies highlighted in the survey and approach ethics instruction through the design process lens.

Thesis Supervisor: Maria Yang
Tile: Professor of Mechanical Engineering

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Chapter 1: Introduction

As technology continues to give humans more and more power to control the world around us, the role of engineers developing that technology becomes increasingly impactful. As this impact grows, so does the influence of each decision made by engineers, thus, a basic understanding of ethics is essential for the success of professional engineers. As Michael Davis from the Center for the Study of Ethics in the Professions, put it, “Insofar as engineering is a profession, knowing how to calculate stress or design a circuit is in part knowing what the profession allows, forbids, or requires” [6]. In 2000, developing a basic knowledge of ethics in engineering students became an official responsibility of accredited engineering programs when the Accreditation Board for Engineering and Technology (ABET) introduced ethical competency as a required student outcome [7]. Despite two decades spent teaching ethics based on this requirement, the way in which engineering programs teach ethics still varies greatly across universities [4]. This thesis aims to explore the different methods for teaching ethics to engineers and to gain a sense of the most effective techniques that have been utilized at universities around the world.

In the Mechanical Engineering Department at the Massachusetts Institute of Technology (MIT MechE), ethics instruction is most heavily concentrated in a capstone engineering design course (Course A). This research sets out to evaluate whether the ethics instruction within the course is on par with successful ethics instruction happening in other engineering programs and the recommended ethics instruction found in research. The teaching approach in Course A closely aligns with the most common methods in ethics instruction; however, the efficacy of these methods is called into question by a range research, leading to an assumption that the ethics instruction in the course may not be as effective as it could be [1–5]. To gain a better understanding of student takeaways, a student survey was developed and distributed to every student in the most recent term of Course A. The literature review and survey analysis are combined in an attempt to understand how MIT MechE should be incorporating ethics into its curriculum in order to produce engineers who are well equipped to think and act ethically in their professional lives.

Chapter 2: Background

ABET Requirements

ABET's criteria for accreditation includes a set of seven expectations called Student Outcomes. These outcomes encompass many of the skills and abilities required for engineers to practice—the abilities to analyze, experiment, solve problems—but they also incorporate ethical considerations as a key takeaway for students in their undergraduate education in engineering. The main ABET Student Outcome that addresses ethics states that students should gain,

> *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.*

In addition to this explicit call to ethics, another one of the seven outcomes states that students should attain,

> *an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors* [8].

Together, these outcomes encourage engineering programs to teach students how to think ethically and enable students to think through the impact of a design or a problem beyond the scope of a classroom.

Contemporary Methods for Teaching Ethics to Engineers

Engineering programs typically approach meeting these requirements in one of three ways, the case method, the theory-based method, or the professional codes method [1]. Perlman and Varma explain the case method as an approach that "picks a number of cases (real and hypothetical) which engineers face or are likely to face such as conflicts of interest, trade secrets, confidentiality, professional responsibility, and public health and safety. It then highlights the ways engineers should conduct themselves in their professional capacity" [9]. With the case method, teachers often choose engineering dilemmas or disasters to analyze and review. The method allows students to see the different factors that led the engineers to made certain decisions, and encourages students to consider whether an action is right or wrong as well as how they might have acted in that same situation.

The theory-based method focuses on the philosophical questions of ethics where students and instructors set out to explore the common facets moral theories and discuss the basics of ethical thought. "There are three dominant theories: deontology, utilitarianism and virtue ethics" that classes typically engage in and digest when studying the theory-based method [1]. This method is often prefaced with defining of ethical terminology since "philosophers depend upon definition for both substance and common ground" and a baseline understanding of verbiage can lay the foundation for students to engage in conversations about theory [10].

Many businesses and professional engineering organizations rely on codes of ethics to guide their ethical and moral directives. Some professors focus on these professional codes as a method of teaching ethics. The idea being that "code work can help students understand the necessity of common norms for behavior" in a workplace [10]. This can take many forms but often involves teaching what a code is, discussing the different principles within the code, and can include asking students to determine whether certain actions in a given scenario abide by, or break, a code [10,11].

Problems with the Current Methods

Despite the prevalence of ethics education in engineering curriculums, it is difficult to teach ethics effectively because "the inability of the student to visualize how the ethical question will impact them in a real sense may lead to an apathetic response" [12]. The challenge in teaching is not just to convey *what* ethics is, but also *why* students should care about it and *how* an understanding of ethics will be relevant to them in the future. But professors teaching ethics, "seldom focus on how engineers actually understand and do engineering," leaving students without the necessary context to apply their learning [9]. Since students are learning ethics concepts before their professional careers have begun, it is difficult or abstract for them to imagine how the ethics they learn in the classroom will be applied in their day to day work as professional engineers. Beyond this general challenge in conveying ethics to engineering students, each of the three commonly employed teaching methods has its own flaws and detractions, encouraging calls for different ways of teaching.

The case method is primarily criticized for the distance it places between the student and the ethical dilemmas they could face. When thinking through cases, students are presented with real or imaginary stories or engineering experiences, and are asked to answer hypothetical questions like "what would you have done or said in this scenario?" "how should this person have reacted to when they received information?" or "was this decision ethical?" When students hear these types of questions, they switch into a different frame of thinking. Rather than truly considering how one might answer the question, students employ "a thinking mode that attempts to search for a right answer" or the answer your professors or classmates might want to hear [12].

Beyond how students approach case exploration, cases are also criticized for how they portray the scenario in question. "Cases are generally presented in idealized forms, with little reference to contextual details of available resources, work practices, existing rules and regulations, workplace culture, and the history of ethical decision making" [9]. Without the full picture, it is hard to garner exactly how one might approach a situation. The partial details of a scenario cannot convey to students the many interconnected influences and factors that would weigh on a decision in the real workplace.

The theory-based method is similarly criticized in that it separates students' mindsets from engineering in practice. The approach is difficult to explore within a technical class because "the theory-based approaches [requires] the burden of philosophical expertise" [4]. Digesting and understanding theory requires a mindset and thought process vastly different than the analytical and logical methods used in engineering, so teaching ethics to engineers through the theory-based approach divorces the concepts of ethics and engineering. This forces students to think about the two topics separately, rather than seeing ethics as something that should be incorporated into their every thought and act as an engineer.

The theory-based method also poses challenges in getting through to students because the goal of examining a problem through a theoretical lens is drastically different than the goal of solving an engineering problem. Peter Bowden explains how the nature of ethical theory can sometimes provide conflicting solutions or no clear solution at all, and engineers may disengage from the material due to the "the unsatisfactory and incomplete nature of the underlying theory" [1].

Professional codes of ethics pose some benefits of combining moral theory and cases—theory of what is right and wrong serves to drive what content is in a code, while case-like analysis can review how actions that take place agree or disagree with a code. But still, codes of ethics are not a perfect method. When relying on professional codes as a teaching method, Gonzalo Génova and M. Rosario González warn, "one of the biggest dangers [in an engineering ethics course]...would be to reduce ethics to a set of behavioral rules (an ethical code) that could be followed in a mechanical or quasi-algorithmic way" [11]. When codes are shared only as examples of ethical guides or as something to be accepted, rather than understood, the professional code method falls short of teaching engineering students how to rely on, or challenge, codes in their professional lives.

Teaching via the theory-based approach and the professional code-based approach leaves a gap in engineers' ability to apply ethical thought in the workplace. Lynch and Kline argue that "mitigating potential threats to public safety requires engineers to reflect on the way workplace practices shape routine decisions that may lead to undesirable outcomes. Knowing what to do—whether by practicing autonomous moral reasoning or by following professional codes of conduct—may be insufficient to prevent harm if the engineer is not skilled in recognizing potential problems" [13]. This concept can go beyond just considerations of public safety, because every decision made in engineering has an ethical impact, and every decision made in engineering is the product of many factors and many agents in the workplace. Without the ability to recognize these factors, engineers may succumb to their influence and unknowingly perpetuate harmful or unethical practices.

How MIT MechE Teaches Engineering Ethics

In MIT MechE, the ethics teaching incorporates versions of each of these three methods. Daniel Frey, a Professor of Mechanical Engineering and MIT MechE's ABET Faculty Lead explained, "The principal course in which [mechanical engineering] students demonstrate their attainments in professional ethics and teamwork is [Course A].'" The class is a capstone and integrates many of the technical aspects that students have learned throughout their MIT MechE education, while incorporating learning and practice in communication, teamwork, and ethics. Students spend the semester working in teams of 15 to 18 to ideate, design, and develop an alpha prototype for a new product. In the final days of the course, each team presents their product to an audience of peers, industry professionals, and course staff.

Course A offers ethics instruction with multiple approaches throughout the term. The first component of formal ethics teaching follows the case method with two different approaches. In one approach, students are presented with the cases of three different ethical dilemmas in the workplace and asked to guess which scenario actually happened. After thinking through the three scenarios and submitting a guess for which is real, students are told that each case is, in fact, true. This outcome elicits strong reactions in the students—triumph for the few who guessed correctly but, more commonly, awe at the fact that such preposterous stories were actually true. In the second approach, a series of quotes, shown in Figure 1, that clearly imply unethical conduct are shared and it is subsequently revealed that these quotes are actual excepts of messages exchanged between Lockheed Martin employees. The reveal that these quotes are real surprises students since the messages seem unbelievable, but this serves as a lesson that these types of conversations do happen in the workplace, and students should be prepared to react and respond to them ethically.

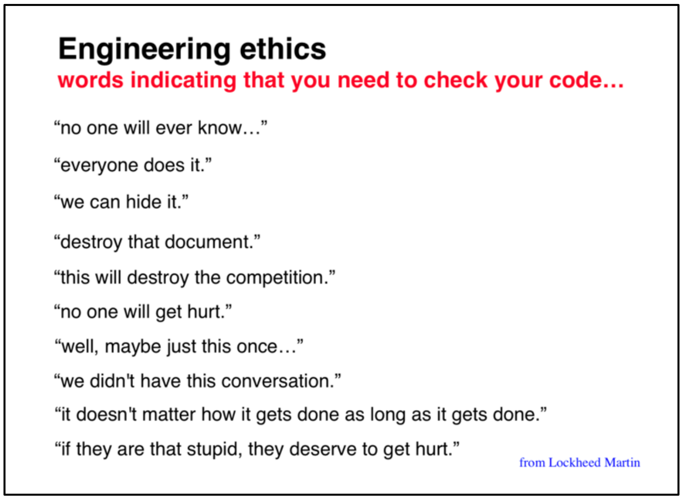

Figure 1: A slide from lecture in Course A showcasing real quote from Lockheed Martin to reveal how ethical dilemmas might begin in the workplace [14].

The theoretical focus of ethics instruction in the course stops short of philosophical conversation or debate, and instead includes definitions of some of the groundwork terminology required to discuss ethics. During lecture, the concepts defined include ethic, value system, values vs. preferences, principles, canons, and codes of ethics. The latter is then further dissected as the final stage of ethics instruction in the course. [15].

The primary method for students to engage in ethics involves a focus on professional codes of ethics. Professional codes are defined and their purpose explained in lecture, followed by a brief review of the American Society of Mechanical Engineers (ASME) professional code. With this foundation in place, each team of students is tasked with creating a code of ethics for themselves as a "code of values that defines guiding principles for how they will work with each other" [16]. For every team, the code is signed by each member and is printed onto a poster that is then placed in the team meeting space for the remainder of the term.

These three approaches to teach ethics span the most common methods of teaching ethics and offer a variety of avenues for students to absorb and engage with the topic. This combination of mediums and method is a great start to successfully conveying ethics, but may not be the most effective way to approach the topic.

Chapter 3: Review of Teaching Methods in Course A

The course includes a great variety of methods to teach ethics, but do these methods stand up against the criticism of contemporary ethics teaching? The first case method of sharing three ethical mishaps and asking students which was true, is engaging and offers the benefit of interactivity, but the approach does little to place the students in the shoes of engineers who experienced these dilemmas or made these choices in the workplace. "Instead of fixating on dramatic cases of whistle- blowing or idealized cases of moral conflict...ethicists need to pay attention to the complexities of engineering practice that shape decisions on a daily basis" [13].

These cases may be a good ice breaker and a way to get students thinking about ethics, but they also separate students from the reality that they may face similar ethical dilemmas in the future. Students may find it easy to feel that the scenario is extreme or implausible if the case appears dramatic or obvious—this is especially possible since the cases in class were given with the prompt "which of these actually happened?". When a case is dissected briefly, and in retrospect, it can seem to students that the ethical missteps could have been easily avoided, even if in practice the problems were much less obvious and much more inherent components of the workplace. This approach doesn't convey to students that they themselves could become part of systems and organizations where these same issues are encountered, and it ignores the reality the ethical dilemma will likely not be glaringly obvious or appear as a simple yes or no question.

The second part of the case method, sharing unethical messages passed between Lockheed Martin employees, is a unique approach and has the benefit of showing students what the steps to an ethical wrongdoing sound like, and that these are things that actually happen in real workplaces. While it is true that real practices that encourage ethical wrongdoing might be less obvious than the phrases shared, this approach still gives students the sense that these issues are real and are something they might encounter.

Within the definition-focused portion of teaching, the course is efficient in broaching only a few topics that might be effectively conveyed via a lecture. One could argue that teaching these definitions and terminology is a necessary baseline for developing a further understanding of ethics [10]. However, it is unlikely that students gain a grasp of the material from this single exposure, and the course offers little follow-up for many of the concepts conveyed, so the value of this component of the teaching is ambiguous.

The teaching around code of ethics is the most engaging component of the ethics curriculum, as the content goes beyond material in just one lecture and asks students to help create and subsequently abide by a code of ethics. This approach is unique and encourages students to engage with the process of defining their own team's sense of right and wrong. In this way, the course surpasses the baseline concern with teaching codes—that students will just be tasked with memorizing or learning the principles of a code for the sake of applying them as black and white criteria to different hypothetical scenarios—but it falls short of a holistic teaching tool. Perlman and Varma advocate for some combination of the case method and code method, but caution that even the combination of methods cannot encompass, "the ambiguity faced in the application to cases of norms, rules, and standards - ambiguities that cannot always be clarified" [9]. So even if students become well-versed in processing codes of ethics, they are not necessarily learning how to apply them to the complex situations they will face in practice.

Chapter 4: Review of Student Survey Responses

In order to further understand the efficacy of the ethics teaching methods, a survey was shared with all of the students who took the course in the Fall 2019 term. This includes 136 students, the majority of whom are in their fourth year at MIT and are mechanical engineering majors. Every student was sent the survey via the class mailing list and the class messaging system. 71 students completed the survey. Respondents included several members of each of the eight project teams in the class, giving a wide and representative range of perspectives. In the survey, students were asked about ethics terminology, their engagement with the course's team code of ethics, how often they considered ethics during the term, and what other courses they have taken at MIT that taught ethics.

Student Understanding

One of the takeaways from the survey is understanding what students knew about ethics before taking the class. Question 8 on the survey reads:

> *Which of the following could have you answered—with reasonable degree of confidence—before taking [Course A]?*

Students could answer the question by selecting any of the following options, each of which was a concept covered during the course,

> *What is the purpose of professional codes of ethics?*
> *What is an ethic?*
> *What is a values system?*
> *How do personal, professional, and societal value systems differ?*
> *How do values and preferences differ?*
> *What is a principle?*
> *What is a canon?*
> *What do ethical dilemmas in engineering look like in professional practice?*

Student responses, shown in Table 1 reveal that understanding prior to the course differed widely in these topics. Students' understanding was lowest for the questions about ethics terminology like "What is a canon?", "What is a principle?" and never exceeds 70% for a given topic.

Table 1: Student selections for Question 8: "Which of the following could you have answered—with a reasonable degree of confidence—before taking [Course A]?"

Question	**Number of Students**	**Percent of Students**
What is the purpose of professional codes of ethics?	50	69%
What is an ethic?	43	60%
What is a values system?	48	67%
How do personal, professional, and societal value systems differ?	44	61%
How do values and preferences differ?	41	57%
What is a principle?	30	42%
What is a canon?	9	13%
What do ethical dilemmas in engineering look like in professional practice?	42	58%

Given this baseline of knowledge, we are able to look at what students took away from the course by comparing their answers above to their answers to the subsequent question, which reads,

> *"For which of the following did you gain* ***an enhanced or improved understanding*** *after their presentation in [Course A] Lecture?"*

Survey respondents select from the same set of questions above, with the additional two response options:

> *"I do not remember seeing this material in lecture"*
> *"I likely did not attend this lecture"*

For each of the eight topics, responses for the gain or enhancement of knowledge was analyzed for the subset of students who did not claim to have a good grasp of the topic at the beginning of the term. These responses reveal that few students who did not initially know the material left the class with new knowledge about the topic. Notably, three topics that the highest number of students did not understand coming into the term were also the topics where the lowest percentage of those students gained an enhanced or improved understanding after seeing the material in lecture. The responses for these three topics, outlined in Table 2, show that, respectively, only 27%, 32%, and 14% of students who could not have answered the question before the course left the course with enhanced knowledge of the topic.

Table 2: Student answers to Question 9: "For which of the following did you *gain an enhanced or improved understanding* after their presentation in [Course A] Lecture?" for the three topics with the lowest rate of improved understanding.

How do values and preferences differ?	**Number of Students**	**Percent of Students (in this subset)**
Could not answer the question before the course	30	
Gained an enhanced or improved understanding after seeing the material in lecture	8	27%
Did not gain an enhanced or improved understanding after seeing the material in lecture	15	50%
Did not attend the lecture or do not remember seeing the material in lecture	7	23%

What is a principle?	**Number of Students**	**Percent of Students (in this subset)**
Could not answer the question before the course	41	
Gained an enhanced or improved understanding after seeing the material in lecture	13	32%
Did not gain an enhanced or improved understanding after seeing the material in lecture	22	54%
Did not attend the lecture or do not remember seeing the material in lecture	6	15%

What is a cannon?	**Number of Students**	**Percent of Students (in this subset)**
Could not answer the question before the course	56	
Gained an enhanced or improved understanding after seeing the material in lecture	8	14%
Did not gain an enhanced or improved understanding after seeing the material in lecture	38	68%
Did not attend the lecture or do not remember seeing the material in lecture	10	18%

By contrast, students reported the highest rate of understanding growth on the topic regarding their ability to recognize ethical dilemmas. Students who initially could not answer this question reported to have gained understanding at a much higher rate than the above topics, where 66% of students showed an improved understanding after the course. This large difference is likely due to the presentation of the material; while the three topics above were presented as definitions read to students, the topic of ethical dilemmas was presented in a more engaging formats, as case studies, and was covered more than once.

Table 3: Student answers to Question 9: "For which of the following did you *gain an enhanced or improved understanding* after their presentation in [Course A] Lecture?" for the topic with the highest rate of improved understanding.

What do ethical dilemmas in engineering look like in professional practice?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	29	
Gained an enhanced or improved understanding after seeing the material in lecture	19	66%
Did not gain an enhanced or improved understanding after seeing the material in lecture	5	17%
Did not attend the lecture or do not remember seeing the material in lecture	5	17%

Engagement with Professional Codes

Given that a key learning point in the course surrounded professional codes of ethics, specifically through teams making their own codes, students were asked how actively they participated in the process of making their team's code in survey Question 2,

> *How did your team develop your Code of Ethics? For reference, you can find your Code of Ethics here: [course link to codes from Fall 2019].*

Students could select from a set of options that ranged from very involved to minimally involved and included responses for both in person and remote contributions to the code. The options in response to the question were:

> *In person through team discussion where everyone could participate*
>
> *Over messaging (such as slack) where everyone could participate*
>
> *A small group or an individual—including you—created the code then shared with the whole team to get feedback before submitting*
>
> *A small group or an individual—excluding you—created the code before sharing with the whole team to get feedback*
>
> *A small group or an individual—excluding you—created the code and submitted without sharing with the whole team*
>
> *I do not remember this process*
>
> Or students could select *"Other"* and explain how they developed their code.

Students could choose as many of the options as they felt applied to their own experience creating their team's code. Upon reviewing responses, options were divided into two categories, "involved" and "uninvolved." An involved student is one who selected *only* answers within the first three options. An uninvolved student is one who selected or more of the latter three options. Some students selected options one or two—that their team incorporated a group discussion or group message during their code development—but also answered that their team had a subgroup, that they were not a part of, who mainly created the code before showing the team. These students were categorized as uninvolved because the bulk of the thought that went into creating the code was likely taken on by the subgroup and not the student.

After the categorization, 31 students were categorized as involved in the process of creating their code and 37 students were uninvolved. 3 students selected responses that were contradictory or spanned across the two categories and were therefore discarded from this portion of the analysis. These results reveal that less than half of the students in the course take an active role in creating their team code of ethics; therefore, it is likely that less than half of the students in the course gain the skills and lessons imparted from participating in the code-making process.

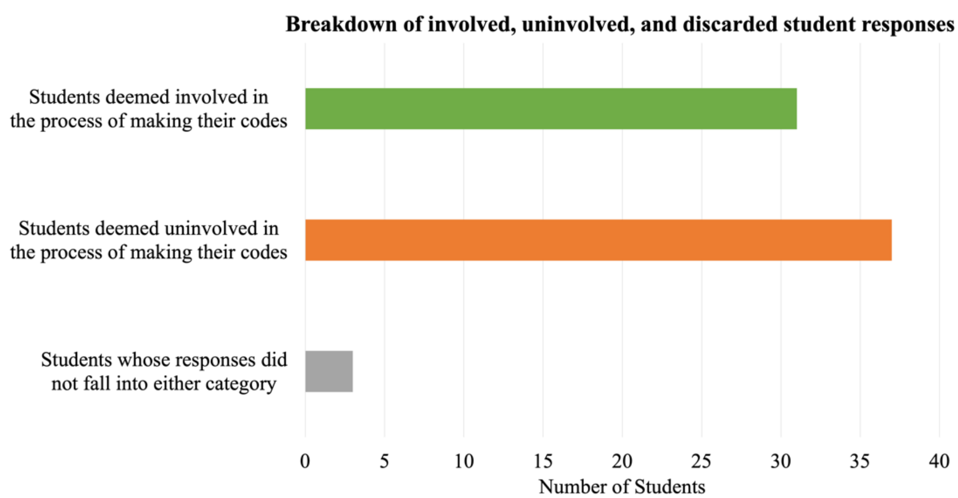

Figure 2: A distribution of student involvement in the creation of their team codes of ethics.

To understand the range of involvement within the involved and uninvolved groups, these two subsets were broken down back to the level of their student responses. Responses in Figure 3a reveal that involved students participated in their code creation mainly through one of two ways: either they were a part of a subgroup who developed the code, or they engaged in team conversation to create the code. The former is arguably the "most" involved a student could be, since in a small group they likely needed to be an active participant in the conversation to develop their code, but this group only represents 15 students, 21% of the respondents, leaving the majority of students in a less participatory role.

Within the subgroup of uninvolved students—shown in Figure 3b—the majority noted that, while they did not personally help create their team's codes, they did have the opportunity to review the code and share feedback before the code was finalized and some students noted that they had the opportunity to discuss their codes as a team in person or through messaging. The remaining two response options are the least involved a student could be in the code-making process, and this applies to 9 students, 13% of respondents. These students show very little engagement in the code-creation process.

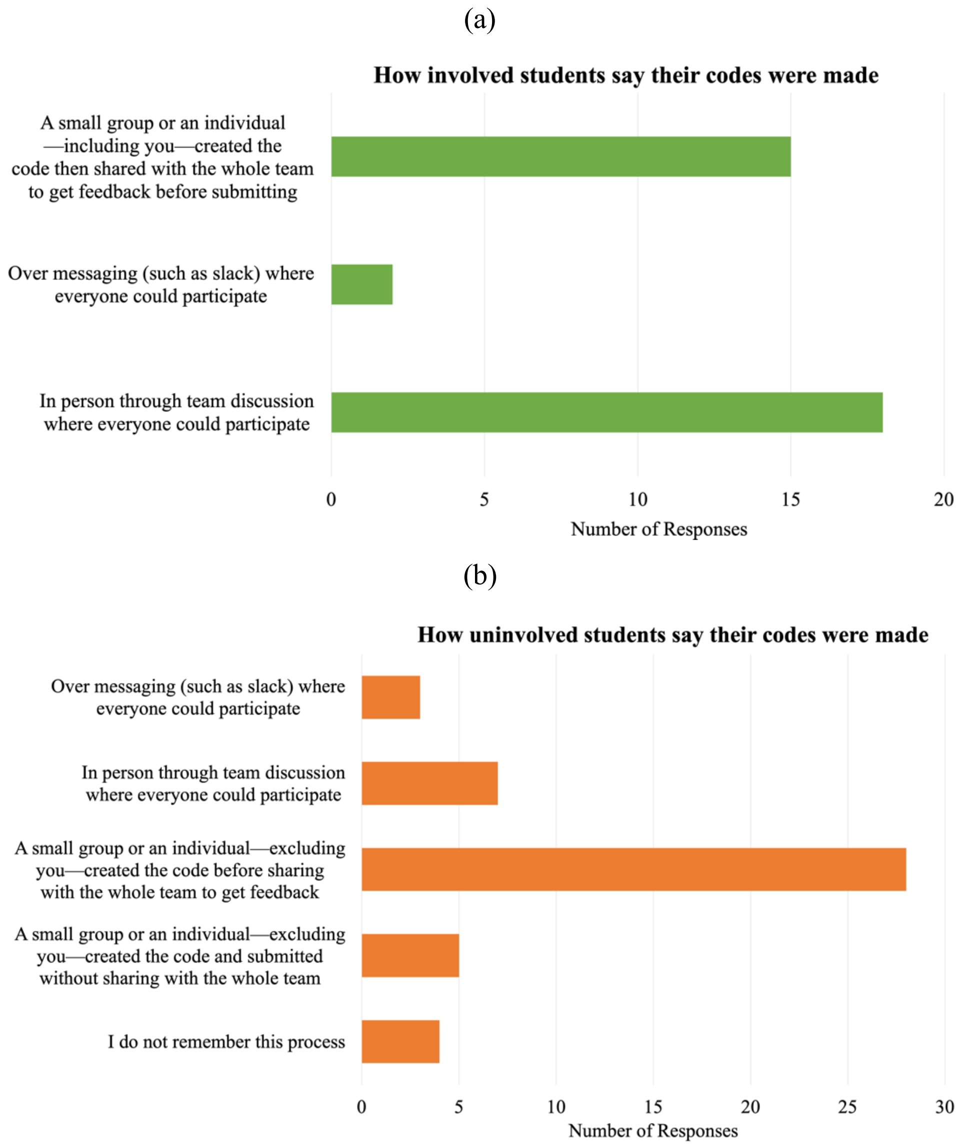

Figure 3: A distribution of responses from students who were (a) involved and (b) uninvolved in the creation of their team codes of ethics of what process(es) their team used to make their code.

Students were also asked what resources they referenced in order to make their codes. Question 3 on the survey reads,

> *While developing your team's Code of Ethics, what resources do you remember referencing?*

Students could select one or more response from the following options,

> *[Course A] lecture presentation on codes of ethics*
>
> *Team's codes of ethics from past terms*

Professional Codes of Ethics such as the ASME code of ethics
Ethics instruction from another course at MIT
I was not involved in developing my team's code
I do not remember this process
Or students could select *"Other"* and describe the resource(s) they used.

Responses reveal that students widely relied on the first two resources, while many did not review any resources at all. This, in combination with the rates of involvement in creating codes, means many students are not gaining experience reviewing or thinking about professional ethical codes.

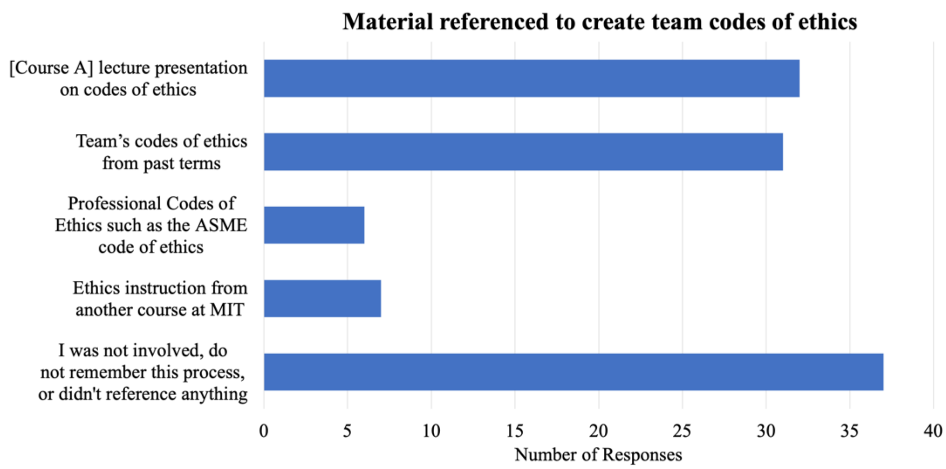

Figure 4: A distribution resources students utilized to create their team's code of ethics. Many students report referencing the course lecture presentation as well as past term's codes of ethics, but an even larger number of students did not reference any material at all.

To gain a better sense of what resources students relied on, the subset of responses from students who were deemed involved with the process of making their team's code were explored—this time excluding the students who were uninvolved with the code creation process and therefore likely did not reference any materials. The results are largely similar to what resources that the entire population found helpful, while the proportion of responses sharing that a student did not reference any materials dropped drastically, confirming that those responses were mostly from the uninvolved or uncategorized students.

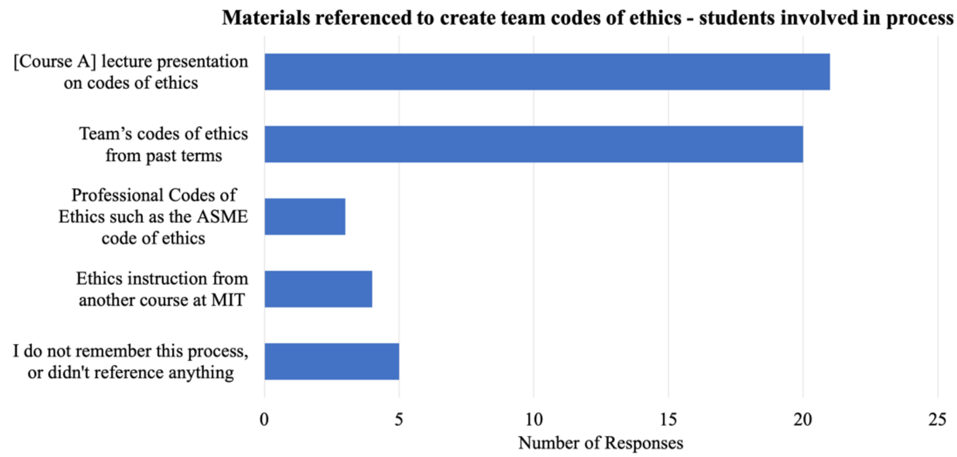

Figure 5: A distribution of responses to what resources were utilized by students who were involved in the process of making their codes. The trend of usage is similar to that of the full set of students except for the drastic decrease in reports of not referencing any materials.

Interestingly, few students referenced professional codes when creating their own team's code, even though professional codes are discussed and displayed briefly in lecture and the ASME code is linked in the assignment description for creating team codes. It is worthwhile to consider whether or not students *should* be relying on and referencing professional codes during this process and, if so, what about the current set up of the course leads them to avoid this material.

Consistent Engagement with Ethics

Beyond just creating a code, students could put ethical thinking into practice by engaging with ethics during the term. This is the component of the course that is most similar to how a student might engage with ethics once working as a professional engineer. Thus, survey questions were developed to gain an understanding of how often students considered the ethicality of their designs, in reference to their code of ethics and independent of their code. Questions 4 and 5 on the survey respectively asked students,

> *How often, if ever, did you or your teammates reference your code as it pertained to team dynamics?*
>
> *How often, if ever, did you or your teammates reference your code as it pertained to design decisions?*

Students could select from the timeframes of:

> *At least weekly*
>
> *At least monthly*
>
> *Once or twice during the term*
>
> *Never*
>
> Or could select "*Other*" and explain

Table 4: Student answers to Question 4 (left) and 5 (right) for all students. Students referenced their codes very infrequently throughout the term.

	How often, if ever, did you or your teammates reference your code as it pertained to:			
	team dynamics		**design decisions**	
At least weekly	6	8%	5	7%
At least monthly	11	15%	12	17%
Once or twice during the term	30	42%	23	32%
Never	22	31%	30	42%
Other responses	2	3%	1	1%

After creating their codes, less than a quarter of students claim to reference their codes more than once or twice in the term as it pertains to team dynamics, and the same for design decisions. Notably, the student's response in "Other responses" for Question 5 was, "I don't remember exactly. I don't think Code of Ethics had much to do with design in general." This response highlights the gap in comprehension from some students as to how engineering can have a social, environmental, or economic impact, and emphasizes the need to further highlight the value of professional codes as drivers, or guides, of decision making.

Even if students do not focus much of their attention on their codes specifically, they may still be engaging in ethical thought during the course. Thinking through the impact of decisions is a valuable skill for students to take away, and it may not matter whether their considerations are in reference to a code or to ethicality in general. Questions 6 and 7 on the survey asked students,

> *How often, if ever, did you or your teammates have conversations about the ethical or moral implications of your design decisions?*
>
> *How often, if ever, did you or your teammates have conversations about the safety implications of your design decisions?*

These two questions more broadly attempt to understand if students are thinking about engineering and design within the larger context of ethics. Students could answer with the same options as in Questions 4 and 5.

Table 5: Student answers to Question 6 (left) and 7 (right) for all students. Students discussed safety of their design decisions much more frequently than they discussed ethical or moral implications.

	How often, if ever, did you or your teammates have conversations about the:			
	ethical or moral implications of your design decisions		**safety implications of your design decisions**	
At least weekly	7	10%	47	66%
At least monthly	21	30%	6	8%
Once or twice during the term	19	27%	6	8%
Never	23	32%	12	17%
Other responses	1	1%	0	0%

Promisingly, students claim to have had conversations about safety of their designs much more frequently, with 3/4 of respondents discussing safety implications at least once a month or at least once a week. Less than half of the students in the course had the same frequency of conversations with respect to the ethical or moral implications of their design decisions. This might mean that students have a good grasp of the direct impact their design might have—a strong focus of the course is on user experience and user interaction with the product, so it makes sense that students thought often about how safe a user might be when using their design—but unfortunately students' thinking does not often go beyond the user experience to consider broader implications and ethical impact.

Survey Conclusions and Sources of Bias

It is valuable to note that this survey has the potential for self-selection bias. Questions within the survey ask about students' involvement in creating deliverables for the team, participation in the product development process, and engagement with the lecture material. Students who were more willing to fill out the survey may also be students who were more engaged and involved in the course, therefore the responses here may misrepresent the average student in the class, who might have participated less in the course than the average student in the survey. This bias is further corroborated by the fact that at most 10% of respondents reported to have not been in attendance when ethics material was discussed in class, a number which is likely much lower than the absence rate of a typical class lecture when all 136 students are considered.

An additional source of bias comes from the timeline of the survey. Course A concluded in December of 2019 but students were asked to complete the survey in April 2020, so some answers—especially those that ask students to reflect on something they did during the term—may be skewed by students forgetting what they did or learned a few months before.

These survey results tell us a lot about the impact that different components of ethics teaching have on students. Before taking the course, students have a lot to learn when it comes to ethics but a limited number of students—typically less than half of students who originally did not know the material—actually gain enhanced understanding from its presentation in lecture. The survey also reveals that just over half of the students played an active part in creating their team code of ethics, while even fewer frequently referenced their code later in the term. Finally, with respect to design decisions, students most often discussed the safety of their designs, with three quarters of respondents saying they discussed safety at least monthly or weekly, but this frequency of discussion was much lower for ethical or moral implications of design decisions. Despite the multiple opportunities for students to learn ethics in [Course A], it appears that most students do not take away an enhanced knowledge of ethics and do not consider ethics frequently during the term.

Chapter 5: An Alternative Approach

Teaching Ethics through Design

The downfalls of contemporary methods of teaching ethics to engineers in conjunction with the outcomes of the student survey in MIT MechE impact motivate the search for another approach to train engineering students in ethics. Some engineering professors and ethicists have already paved the way for this change. A common theme in these alternative approaches to teaching ethics is to focus on how engineers think or, as Génova and González put it, teach "ethics explained to the mentality of the engineer." [11]

Creating an engineering-style framework for ethical thinking may be a valuable approach because it gives students a process to apply to a variety of decision-making opportunities they might encounter. Relying on teaching codes of ethics is akin to giving students a memorized set of rules that are not flexible and that make it difficult to consider the many factors that influence a situation. Instead, this route proposes that teaching students "the similarities of ethical decisions to design decisions gives them a familiar frame of reference for action" [3]. This approach translates ethics into a language engineers can understand and apply.

This opens doors to thinking about ethics teaching in new ways, particularly through relating ethics to the engineering design process [2–5]. Caroline Whitbeck explains this relationship through four main similarities:

> *[T]here is rarely, if ever, a uniquely correct solution or response…*
>
> *Some possible responses are unacceptable…and some are better than others.*
>
> *Solutions may have advantages of different sorts, such that where there are two candidate solutions, neither may be clearly better than the other.*
>
> *A proposed solution must do all the following (in addition to being reasonably secure against accidents and miscarriages):*
>
> > *Achieve the desired performance or end…*
> >
> > *Conform to given specifications or desired criteria…*
> >
> > *Be consistent with (usually unstated) background constraints* [5].

These commonalities offer a helpful baseline for comparison, Jonathan Beever and Andrew O. Brightman consider these similarities but describe them with the terminology of design and the terminology of ethics, saying "the principles can be understood as constraints, and the specification, prioritization, and justification as processes similar to generation of design specifications through the building and testing of prototypes in an attempt to produce an optimized design solution." [4]. This comparison begins to form a concrete way to mirror the design and ethical decision-making processes, and Bridget Bero and Alana Kuhlman digest these parallels further. They break each component into the specific steps of the design process, as shown in Table 6. After teaching this approach, they give their students the chance to practice applying it with a few examples [3].

Table 6: Bero and Kuhlman's parallel process steps for the engineering design process and ethical decision-making process [3].

Step	Engineering design process	Ethical decision making process
1	Identify the problem	Identify relevant moral factors (normative, conceptual and factual)
2	Identify the constraints	Identify conflicting moral responsibilities and dilemmas
3	Brainstorm options to solve the problem	Consider moral theories and rank
4	Develop design alternatives (preliminary design of several alternatives)	Consider alternate courses of action (full implication of each)
		Obtain alternative perspectives
5	Selection of final design and completion of design	Make decision
6	Implement the design	(Implement the decision.)

Note. Reprinted from Bero, B., and Kuhlman, A., 2010, "Teaching Ethics to Engineers: Ethical Decision Making Parallels the Engineering Design Process," Science And Engineering Ethics, **17**(3), pp. 601.

Application to Course A

In a course like Course A, students begin the engineering design process immediately when the term, starts, iterating over early steps in the process often until finally reaching the point of selecting and implementing a design. This offers the opportunity to incorporate the ethical decision-making process into teaching early in the term and to help students walk through the different ethical steps at the same time as they are participating in the steps in the design process.

Presenting these parallels alone is not enough to impact students, they need to be given the opportunity to practice the ethical decision-making process. Whitbeck proposes a four components of a small group discussion to allow students to try out the process. Her recommended discussion points are:

1. *Practice in thinking through what additional information might be relevant and the difference that it would make. Here the participation of experienced practitioners is invaluable to new members of the scientific professions - What seems to be the problem? If it is not your problem but creates one for you, what is your problem?*
2. *Practice envisioning alternative interpretations of the situation so as to avoid premature action that could prove disastrous if the situation were other than one supposed. - What could be going on here?*
3. *Practice 'brainstorming' about possible courses of action to take and the possible consequences, that is, uncritically putting forward a range of ideas about what one might do and then redefining or discarding them in light of their consequences and implications - What can/should you do and how do you go about it? (This is a question of both ethics and feasibility.)*

4. *Practice comparing the advantages and disadvantages of various courses of action. Think (and talk) through what to do in case of the most likely and the worst case responses to each of the proposed actions* [5].

These topics very closely mirror the design-focused conversations that MIT MechE students are already engaging in during the first weeks of Course A. It is possible that the course could incorporate Whitbeck's practice process by utilizing the existing team structure and lab sessions. One hour of each teams' lab session could be dedicated to covering each of the practice steps, with the added benefit that teams already work with faculty instructors and professional engineering mentors during each of their lab sessions, which would fulfill Whitbeck's suggestion to include experienced practitioners in the discussions. The schedule in Course A is highly demanding of students, with a very full curriculum, so incorporating an hour of ethics conversations is a large commitment, but the introduction of this ethical decision-making process early in the term plus the opportunity for student to practice applying the process is likely the best way for students to retain the information and develop the ability to apply it in their professional careers.

Incorporating ethics teaching early in the term also opens the door to consistently reinforce the material. The survey results show an important gap in student engagement with ethics in that they rarely considered the ethicality of their design decisions during Course A. Teaching how the ethical decision-making process parallels with the design decision-making process could be a good way to increase the frequency of ethical thinking throughout the course if understanding checks are incorporated into the term.

A consistent check up on the ethicality of their design decisions could increase engagement with ethical thinking and allow students to practice using the ethical decision-making process. In their course at Georgia Tech, Robert Kirkman, Katherine Fu, and Bumsoo Lee require students to submit individual reflections at four points during the course. These assignments asked students to reflect on a recent design decision of their team and develop a:

> *thorough analysis of the context of the decision, a recounting of the team's decision along with an alternative option, and a thorough consideration of both the option and the alternative in terms of its ethical implications [2].*

This style of reflection could be readily incorporated into the Course A curriculum, as students are already required to submit reflections after each of the design milestones in the course. Currently, the reflection assignment looks like this:

> *Think about assumptions/expectations that you and your team made going into the milestone phase as well as the actual preparation and review event. After completing the milestone and seeing the results:*
>
> - *what were a few key moments (e.g. challenges, high points) in the milestone phase?*
> - *were there assumptions/decisions that were important to your success?*
> - *were there assumptions/decisions that you would change if you were to do it again?*
> - *what did you learn from seeing the work/presentations of other teams?*

- *what is your take-home message from the phase? [17].*

Questions like those in Kirkman, Fu, and Bumsoo's course could easily be appended to the Course A reflection assignment, thereby asking students to reflect on ethics more consistently. This offers an opportunity for students to continuously engage with ethics throughout the term and encourages them to recognize that decision decisions should be made with their ethical implications in mind.

Other Improvements

The changes above offer the opportunity for enhanced learning in place of the current processes of sharing definitions and increased engagement in ethical thinking throughout the term. Still, some small changes could further improve the methods of teaching ethics. Rather than introducing ethics material with three cases and asking students which is true, a similar way to motivate the topic could be through surveying alumni who are practicing engineering about their engagement with ethics. A Stanford course called "Ethical Issues in Engineering" employs this technique, using survey questions including "Have you ever been faced with an ethical issue in the course of your engineering practice?" and "Has any employer of yours ever done anything to encourage you to act (or to reward you for having acted) as you believed yourself obliged to do on ethical or social responsibility grounds?" [18]. These questions are a great way to convey that it is completely possible for students to encounter ethical dilemmas during their professional careers, which hopefully then motivates the students to pay attention to and take seriously the subsequent ethics instruction.

Course A already utilizes alumni data in a similar way during the final lecture, where survey results asking alumni when and where they learned different skills, how often they use those skills, and which skills matter most, so relying on the same measures for another teaching point in the course could be a simple addition with a big impact [14].

Chapter 6: Conclusion

This exploration revealed that, while MIT MechE employs a great variety of methods to expose their students to ethics during their time in the upper level engineering design capstone, the intended lessons are not always reaching students. Generally, less than half of the students who came into the course not knowing the meaning of different ethics terms or concepts left the course with enhanced understanding of those terms or concepts. Additionally, only about half of the students took an active role in creating their team's code of ethics, and even fewer reference their code more than once or twice during the term. Similarly, students seldom had conversations about the ethicality of their design decisions, with only 10% of students having these conversations weekly, and 30% having them monthly. This shows a lack of understanding in the power that engineers harness to impact others through their work. Students did have conversations about the safety of their designs more frequently than about ethicality, which shows some promise in their ability to consider impact of a design, even if that consideration is not broad enough to think about ethical implications.

A different approach MIT MechE can take is teaching the parallels between the engineering design process and the ethical decision-making process. This new method could be introduced in lecture, practiced in lab, and reinforced through student reflections. The change would put ethics into a context that engineering students can understand, create a process that students can follow and apply to the variety of ambiguous ethical situations they might encounter, and encourage them to engage with ethics consistently throughout the design process. Additionally, a survey of alumni who are practicing engineering could introduce the topic of ethics while offering students a better sense of the gravity and reality of their future encounters with ethical dilemmas.

Future exploration into the ethics instruction within MIT MechE could greatly improve our understanding of current methods utilized, and could help assess the impact of any changes to the curriculum. Employing incoming and outgoing surveys on ethics to students in Course A would be an excellent first step in getting a better sense of what students gain from ethics instruction. A survey of alumni, as mentioned above, could serve an additional purpose of shining light on any gaps in the ethics instruction by asking what alumni wish they had learned in class.

Course A is an outstanding class and students gain so much from their time in the class, but improving the ethics components can only further develop MIT students into better engineers. When approaching ethics from the design perspective, it can be incorporated seamlessly into the existing fabric of the course and thereby more readily imparted to students.

Appendices

Appendix A: Full Survey

2.THU Study of Ethics Takeaways in [Course A]

This survey is a part of an independent study of ethics teaching in mechanical engineering and is in no way affiliated with the [Course A], course instructors, or course staff.

Students taking this survey should have completed [Course A] during the Fall 2019 term.

No personal details from your survey response will be shared publicly, but the aggregate results and outcomes of the survey will appear in the researcher's undergraduate thesis paper.

1. Which [Course A] team were you on in Fall 2019?

   Mark only one oval.

   - Silver
   - Green
   - Purple
   - Red
   - Blue
   - Yellow
   - Orange
   - Pink

2. How did your team develop your Code of Ethics? For reference, you can find your Code of Ethics here: [course link to codes from Fall 2019].
   Please check all that apply. If other, please explain.

   Check all that apply.

   - [ ] In person through team discussion where everyone could participate
   - [ ] Over messaging (such as slack) where everyone could participate
   - [ ] A small group or an individual--including you--created the code then shared with the whole team to get feedback before submitting
   - [ ] A small group or an individual--excluding you--created the code before sharing with the whole team to get feedback
   - [ ] A small group or an individual--excluding you--created the code and submitted without sharing with the whole team
   - [ ] I do not remember this process

   Other: [ ] ______________________

3. While developing your team's Code of Ethics, what resources do you remember referencing?
   Please check all that apply. If other, please explain.

   Check all that apply.

   - [ ] [Course A] lecture presentation on codes of ethics
   - [ ] Team's codes of ethics from past terms
   - [ ] Professional Codes of Ethics such as the ASME code of ethics
   - [ ] Ethics instruction from another course at MIT
   - [ ] I was not involved in developing my team's code
   - [ ] I do not remember this process

   Other: [ ] ______________________

4. After your team's Code of Ethics was created, how often, if ever, did you or your teammates reference your code as it pertained to *team dynamics*?

If other, please explain.

Mark only one oval.

- At least weekly
- At least monthly
- Once or twice during the term
- Never
- Other: ______________________

5. After your team's code of ethics was created, how often, if ever, did you or your teammates reference your Code of Ethics as it pertained to *design decisions*?

If other, please explain. Remember to consider all potential products from your term, not just your final product.

Mark only one oval.

- At least weekly
- At least monthly
- Once or twice during the term
- Never
- Other: ______________________

6. How often, if ever, did you or your teammates have conversations about the *ethical or moral implications of your design decisions*?

If other, please explain. Remember to consider all potential products from your term, not just your final product.

Mark only one oval.

- At least weekly
- At least monthly
- At least once or twice during the term
- Never
- Other: ______________________

7. How often, if ever, did you or your teammates have conversations about the *safety implications of your design decisions*?

If other, please explain. Remember to consider all potential products from your term, not just your final product.

Mark only one oval.

- At least weekly
- At least monthly
- At least once or twice during the term
- Never
- Other: ______________________

8. Which of the following could have you answered--with reasonable degree of confidence--before taking [Course A]?

Check all that apply.

- [ ] What is the purpose of professional codes of ethics?
- [ ] What is an ethic?
- [ ] What is a value system?
- [ ] How do personal, professional, and societal value systems differ?
- [ ] How do values and preferences differ?
- [ ] What is a principle?
- [ ] What is a canon?
- [ ] What do ethical dilemmas in engineering look like in professional practice?

9. For which of the following did you *gain an enhanced or improved understanding* after their presentation in [Course A] Lecture?

Check all that apply.

- [ ] What is the purpose of professional codes of ethics?
- [ ] What is an ethic?
- [ ] What is a value system?
- [ ] How do personal, professional, and societal value systems differ?
- [ ] How do values and preferences differ?
- [ ] What is a principle?
- [ ] What is a canon?
- [ ] What do ethical dilemmas in engineering look like in professional practice?
- [ ] I do not remember seeing this material in lecture
- [ ] I likely did not attend this lecture

10. In which of the following schools have you taken courses that taught or emphasized ethics?

If other, please explain. Please do not include [Course A] in your response

Check all that apply.

- [ ] I have not taken any courses that taught or emphasized ethics
- [ ] School of Engineering
- [ ] School of Humanities, Arts, and Social Sciences
- [ ] School of Architecture and Planning
- [ ] School of Science
- [ ] Sloan School of Management

Other: [ ] ______________________

11. Please list the course number(s) here if this applies to you

____

Appendix B: Complete results from survey Question 9 for students who initially could not answer the given question

What is the purpose of professional codes of ethics?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	21	
Gained an enhanced or improved understanding after seeing the material in lecture	10	48%
Did not gain an enhanced or improved understanding after seeing the material in lecture	5	24%
Did not attend the lecture or do not remember seeing the material in lecture	6	29%

What is an ethic?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	28	
Gained an enhanced or improved understanding after seeing the material in lecture	11	39%
Did not gain an enhanced or improved understanding after seeing the material in lecture	11	39%
Did not attend the lecture or do not remember seeing the material in lecture	6	21%

What is a value system?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	23	
Gained an enhanced or improved understanding after seeing the material in lecture	8	35%
Did not gain an enhanced or improved understanding after seeing the material in lecture	11	48%
Did not attend the lecture or do not remember seeing the material in lecture	5	22%

How do personal, professional, and societal value systems differ?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	27	
Gained an enhanced or improved understanding after seeing the material in lecture	11	41%
Did not gain an enhanced or improved understanding after seeing the material in lecture	10	37%
Did not attend the lecture or do not remember seeing the material in lecture	7	26%

How do values and preferences differ?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	30	
Gained an enhanced or improved understanding after seeing the material in lecture	8	27%
Did not gain an enhanced or improved understanding after seeing the material in lecture	15	50%
Did not attend the lecture or do not remember seeing the material in lecture	7	23%

What is a principle?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	41	
Gained an enhanced or improved understanding after seeing the material in lecture	13	32%
Did not gain an enhanced or improved understanding after seeing the material in lecture	22	54%
Did not attend the lecture or do not remember seeing the material in lecture	6	15%

What is a cannon?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	56	
Gained an enhanced or improved understanding after seeing the material in lecture	8	14%
Did not gain an enhanced or improved understanding after seeing the material in lecture	38	68%
Did not attend the lecture or do not remember seeing the material in lecture	10	18%

What do ethical dilemmas in engineering look like in professional practice?	Number of Students	Percent of Students (in this subset)
Could not answer the question before the course	29	
Gained an enhanced or improved understanding after seeing the material in lecture	19	66%
Did not gain an enhanced or improved understanding after seeing the material in lecture	5	17%
Did not attend the lecture or do not remember seeing the material in lecture	5	17%

References

[1] Bowden, P., 2010, "Teaching Ethics to Engineers--A Research-Based Perspective," European Journal of Engineering Education, **35**(5), pp. 563–572.

[2] Kirkman, R., Fu, K., and Lee, B., 2017, "Teaching Ethics as Design," Advances in Engineering Education, **6**(2).

[3] Bero, B., and Kuhlman, A., 2011, "Teaching Ethics to Engineers: Ethical Decision Making Parallels the Engineering Design Process," Science And Engineering Ethics, **17**(3), pp. 597–605.

[4] Beever, J., and Brightman, A. O., 2016, "Reflexive Principlism as an Effective Approach for Developing Ethical Reasoning in Engineering," Science And Engineering Ethics, **22**(1), pp. 275–291.

[5] "OEC - Teaching Ethics to Scientists and Engineers: Moral Agents and Moral Problems" [Online]. Available: https://www.onlineethics.org/Resources/instructessays/teaching.aspx#problems. [Accessed: 23-Apr-2020].

[6] "OEC - Teaching Ethics Across the Engineering Curriculum" [Online]. Available: https://www.onlineethics.org/Resources/instructessays/curriculum.aspx. [Accessed: 23-Apr-2020].

[7] Mitcham, C., 2009, "A Historico-Ethical Perspective on Engineering Education: From Use and Convenience to Policy Engagement," Engineering Studies, **1**(1), pp. 35–53.

[8] "Criteria for Accrediting Engineering Programs, 2020 – 2021 | ABET."

[9] Perlman, B., and Varma, R., 2001, "Teaching Engineering Ethics," pp. 6.940.1-6.940.11.

[10] Dyrud, M., 2005, "Ethics 101," pp. 10.588.1-10.588.7.

[11] Génova, G., and González, M., 2016, "Teaching Ethics to Engineers: A Socratic Experience," Science & Engineering Ethics, **22**(2), pp. 567–580.

[12] Houston, B., 2006, "Ethics A Tough Choice," pp. 11.599.1-11.599.6.

[13] Lynch, W. T., and Kline, R., 2000, "Engineering Practice and Engineering Ethics," Science, Technology, & Human Values, **25**(2), pp. 195–225.

[14] "2.009 Master Schedule" [Online]. Available: https://web-cert.mit.edu/2.009/www/schedule/ScheduleChart.html#current. [Accessed: 27-Apr-2020].

[15] "Course Description" [Online]. Available: https://web-cert.mit.edu/2.009/www/courseinfo/CourseDescription.html. [Accessed: 27-Apr-2020].

[16] "2.009 Team Code of Ethics" [Online]. Available: http://web.mit.edu/2.009/www/codeOfEthics/codeOfEthics.html. [Accessed: 27-Apr-2020].

[17] "2.009 Milestone Reflection" [Online]. Available: http://web.mit.edu/2.009/www/assignments/DesignNotebookReflection.html. [Accessed: 28-Apr-2020].

[18] "OEC - Expectations and Experiences of Ethical Issues in Engineering: A Survey of Stanford Engineering Students and Practicing Engineers" [Online]. Available: https://www.onlineethics.org/Education/instructessays/mcginn.aspx. [Accessed: 20-Apr-2020].