An Engineering Ethics and Safety Course Integrated with Professional Skills

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Abstract

This paper presents a team taught engineering ethics and safety course developed for chemical, computer, and electrical engineering students but open to any undergraduate student at sophomore level and above. The students in the course explored the relationships between ethics and engineering by applying classical ethical frameworks and decision making to engineering issues encountered by engineers. Additional course coverage included quality management concepts (ISO 9001) relating ethics to workplace and product safety. The basis of the course was to afford the students the capability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. The students were evaluated in 5 categories (1) weekly reading/writing briefs; (2) weekly presentations/discussions; (3) individual quizzes (4) midterm project; and (5) final project. As such, the majority of the class was based on teamwork and team activities including peer evaluations. The presentations and discussion integrated industry professionals. Three professionals presented and discussed engineering professional ethics standards, safety in remote vehicular space craft, and legal concerns of ethics and safety at a corporate level for a defense company. Safety was covered using American Chemical Society and OSHA guidelines for both chemical and electrical safety in the academic laboratories and in industry. In addition, fault tree analysis was taught using examples such as the partial nuclear melt down at Three Mile Island. Finally, quality management tools were integrated into the course to calculate process capabilities, moving average, and range charts based on archival data created by students. This was followed by testing of the additional new data to determine when operator intervention is required.

Keywords

Engineering Ethics, Engineering Safety, Quality Control, Teamwork.

Introduction

Ethics guides all aspects of an engineer's job from proper safety, process and product design and quality management. It is sufficiently integral that to maintain a Professional Engineer status, one needs to take additional ethics courses every two years.[1] The National Society of Professional Engineers not only has information for case studies and education opportunities for ethics[2] but also has a 24 hour licensure and ethics hotline.[1] Many corporations have added an Ethics/Compliance Officer as part of its management team.[3][4] Although the position(s) are not always well defined or uniform across corporations[5], the growing importance and emphasis on ethics, compliance, social justice and oversight of potential biases in the growing influence of Artificial Intelligence is significant. The value of the position is to help create a better environment for all employees in the company. It also provides an avenue for serious flaws to be sounded out internally with a proper process in place so that these issues can be rectified by the company. It also provides someone to internally act as a point person to understand changes in legality for issues involving corporate ethics and to provide a way to disseminate that information to everyone in the corporation, and to suggest better ways to handle ethical dilemmas.

While there is a growing emphasis on ethics in industry, many alumni have not felt adequately prepared for ethical issues in their careers.[6] Education on ethics in engineering has lagged significantly. The first standard codes of ethics were 1914 for American Society of Civil Engineers.[7] Yet it was not until 2000 that ABET formally requested ethics as part of criterion 3f "understanding of professional and ethical responsibility"[8] and officially became a requirement for accreditation of an engineering program. However, while Professional Engineers have to take Ethics classes every 2 years to maintain their licenses[1], ABET did not make any such requirement on ethics having to be taught as a stand-alone course. How to exactly cover this criterion and in what manner was and is still dependent on the specific educational program itself. [7] [8] Programs covered ethics in a wide manner of methods.[7] However, it was unclear exactly how and in what class(es) it was covered even by administrators of the programs.[7] The purpose for having ethics courses was primarily driven to meet ABET accreditation requirements.[8] ABET likewise admitted in 2016 that it was having issues in evaluating the criterion covering ethics[8].

The National Academy of Engineering in 2016 published a book collecting what it considered best practices in ethics education for engineering students.[9] The approaches were predominantly heavy in case studies with group discussions, and also included role playing and problem based learning.[9] A survey of ethics education from 2000 to 2015 found 80% of publications involved case studies.[8] National Society of Professional Engineers assists greatly by posting a large number of case studies online.[5] Case studies do help in meeting the desired outcomes from students for increased ethical sensitivity or awareness and an improvement in ethical judgment or decision making.[8]

Generally, it can be assumed that through the use of case studies combined with dedicated and inspirational teaching, students gain a better understanding of ethics and how best to argue or decipher an ethical dilemma. The question now is what technical tools are educational programs providing to assist the students in answering their ethical problems in industry or academia? In developing the ethics course, the authors have found few examples beyond team work building exercises in aiding students in making real changes in their future job places.[12] This in essence is not surprising especially given that when a survey of ethics education through 2015 found that ethics was taught only 50% of the time in a course and that classes could often be short courses.[8] The apparent implication is that any technical tools to assist students with handling ethical dilemmas would be found elsewhere in other classes in the engineering curriculum.

As corporations move towards more cross functional groups for product development, engineers will be tasked to do an evaluation of not only their team members but of themselves too. As stated in Loignon et al, "Nearly half of U.S. companies and 81% of Fortune 500 corporations use team-based work structures".[10] They also state that, "Recruiters consistently rate the ability to work in teams at or near the top of the list of qualities they seek in job candidates".[10] As such, 360 Peer Evaluations are more prevalent in all work forces as a professional feedback tool on teamwork. Students need to be able to work well in teams. Ethics guides your personal development and interaction with your colleagues. Having proper ethics training helps a student be a better team member, and to help in mitigating conflict resolutions internally. The importance of team work has even changed how companies screen potential employees. For example, British Petroleum requires its potential entry level engineers to do three group exercises as part of its hiring evaluation process.[11]

A design engineer is expected to see flaws in a process or product design and be on the lookout for where there are possibilities of serious damage or injury. From learning National Society of Professional Engineering ethics codes, an engineer realizes the paramount importance of putting public safety as a priority. In addition, the engineer also needs the tools to be able to properly assess the risk assessment at hand. This course teaches students fault tree analysis with probabilities for intermediate events and final accidents. The probabilities are coupled with appropriate severity numbers so that risk prioritization numbers can be calculated. Given these tools, the design engineer can use them along with a well-constructed ethical argument.

Based on personal experience, one of the authors in their first Process Engineering job at a custom extrusion plant dealt with off specification product being mixed in with "quality" product so that overall average of the material was still barely within specifications. Clearly this was not ethical. It is envisioned that after taking an ethics course, the goal would be that the engineer would not only feel compelled to make an argument against this practice but have the proper theory to argue against it. Another element that can help is teaching the young engineers some Quality Management, and provide tools such as how to develop/design moving average and range charts so that product variance could be reduced, eliminating the problem of off-spec material at its root cause. This could help engineers lead a push to get the company to move towards ISO9000 certification or similar.

This paper is the curriculum for that course. The focus here is to go beyond teaching students the proper theory and methodology to be able to properly argue and solve an ethical dilemma. The goal is to deliver professional tools to the students to help them solve ethical situations they will face in industry or academia. The professional skills included in the course were team work with inclusion of 360 peer evaluations, fault tree analysis with calculations of risk priority numbers, and quality control techniques of setting up moving average and range charts for process variables using archival data and calculating process capabilities. Key elements of the course are presented in the course structure section followed by a section of course assessments with some observed results.

Course Structure

The course begins with a focus on the understanding of core ethical frameworks using case studies. Subsequent subsections discuss other elements considered in the course such as personal standards, professional standards, corporate ethics, safety, and quality control.

Core Ethics

The text book used was by Martin and Schinzinger, Ethics in Engineering, 2nd Ed.[12] The book has a great selection of small and larger case studies that are thought provoking and explain the intricacies of ethics theory and methodologies quite well. The focus was on introduction of ethics, moral reasoning, and moral frameworks and utilitarianism. Supplemental coverage on practical field experiences was provided through guest speakers.

The material was covered primarily by having students work in teams writing short briefs and giving presentations to the whole class. Typically, the group presentations covered a new topic for each group so more material was discussed as a class. Students were required on their own still to read all appropriate chapters beyond their specific brief subjects. One to two quizzes were given for each chapter of material covered. Prior to doing the briefs, a group discussion was done and ground rules developed by the students on how they should be led, what was appropriate participation, and in event there is some conflict how to resolve it. Students did a great job in following the guidelines throughout the course.

Student groups were given two larger case studies. One was giving a more detailed midterm presentation and the second was a research paper.
Midterm presentation topics:

a. Using Drones as a Warfighter (Global Justice)
b. Chernobyl, Fukushima and Three Mile Island (Commitment to Safety)
c. Artificial Intelligence & Algorithm Bias (Computer Ethics)
d. ExxonMobil's position and action on Climate Change (Environmental Ethics)

Research paper topics:

a. How is social media impacting freedom of speech, information gathering and reporting in United States versus Europe?
b. How voter registration, voting rights, and methods of voting are handled in the United States historically and currently?
c. What is the sustainability of the solar energy from production process to implementation and through its disposal?
d. Is constructing more nuclear (fission) power plants the best way to address climate change?
e. How smallpox vaccination was done worldwide versus how the United States is handling Covid-19 vaccinations?

For both larger case studies, one to two references on each subject were provided to the students to help them get the project initiated. All groups were required to do additional literature review.

Personal Standards

One of the objectives of the course was personal improvement for all involved. Students submitted their resume for review as part of introduction to ethics and a preliminary to the topic of truthfulness. Instructors made comments and returned it to the students for additional submission. In addition, students did peer evaluations twice during the course where they evaluated themselves as well as their team mates.

Professional Standards

The student groups were each given a different professional ethics standard to research and provided a brief presentation to the class. Areas covered were AICHE, IEEE, ASME, and NSPE.[13],[14],[15] At the end of the group presentations, a general discussion on what areas were common to all professional groups, and what differences were there was done. The discussions also delved into whether they state the same requirements with the same emphasis.

The external presenter on professional standards was William A. Brown Sr., P.E. He currently serves as Chairman of the Engineering Advisory Board at Hampton University, and retired as the highest ranking civilian engineer in Army Corps of Engineers. A consummate professional with the highest integrity, Mr. Brown Sr. commanded the attention and respect of the students. He drove home the point again and again that ethics is what he does. It is in every aspect of his work and his job, and that to continue to be a Professional Engineer required periodically taking more ethics courses. Students thoroughly enjoyed his talk and asked many detailed questions. The presentation included a follow up quiz developed by the presenter for the class.

Corporate Ethics

The material for this area was done both by the textbook and supplemented too by another outstanding outside speaker, Ms. Britta Brown Whitehead who works as a Compliance Officer at HII Newport News Shipbuilding. She went into a myriad of ethical issues from military design flaws to new legal landscape for ethical violations by corporations, and discussed how management can be held criminally accountable for gross ethical violations at any company level. She focused on the triangular approach to ethics, quality, and compliance leading to the concept of the fraud triangle. The approach looks at ethical risk based on perceived pressure, rationalization and perceived opportunity. A quiz on the material accompanied the talk.

Safety

The last third of the course delved into safety. Although discussed earlier in the course, here the students got into the actual standards of safety for chemical, electrical and computer engineers both in academia and industry. [16],[17],[18] Supplementary materials both online and from other textbooks were used. [19],[20] For example, electrical engineering industrial standards were done by students completing online material and quizzes from OSHA. [21] We had a guest speaker, Andre Smith, Engineering Project Manager at Science Systems and Applications Inc. His presentation was “Nuclear Powered Space Systems for Deep Space Exploration” in which he serves as the Group Lead to NASA’s Goddard Space Flight Center. He discussed the safety and design of radioisotope power sources for space applications. A follow up quiz was given.

The authors wanted to go deeper to cover design flaws in a systematic manner. Fault tree analysis and severity numbers were covered with the students. An in-class exercise for a power grid failure that had several different pathways to final power loss was used to demonstrate the fault tree analysis. [22] As one part of a final project, students then completed an exercise doing an in depth analysis on partial nuclear melt down for Three Mile Island. [23]

Quality Control

Final topics covered were for quality management and especially control. Constant improvement within an organization and for its product quality falls completely under the umbrella of ethics. Material covered was calculation of process capabilities, and design and implementation of moving average and range charts. [24],[25] As the second part of a final project, students developed and assessed moving average/range charts for a process variable. Then they calculated process capabilities for laboratory results.

Assessments and Results

The course assessment for grade was achieved in 5 categories of (1) weekly reading/writing briefs; (2) weekly presentations/discussions; (3) individual quizzes (4) midterm project; and (5) final project. All of the categories contributed equally to the final grade in the course. In addition to these categories, student peer evaluations captured student input on teamwork as well as an informational ethics survey.

Pre-Survey

A 25-question survey was administered at the beginning of the course to mainly ascertain the students' thoughts about engineering ethics. Some of the captured responses from the students presented below based on a 5-point Likert scale. These results represent 15 students (9 sophomores, 4 juniors, 2 seniors). The table below shows a summary of the student responses on select questions.

Table 1

	Strongly Agree	**Agree**	**Neither Agree/Disagree**	**Disagree**	**Strongly Disagree**
Question 2: Ethics is very important to me.	46.67%	46.67%	6.67%	0%	0%
Question 4: Do you feel your generation is more ethical than previous generations?	13.33%	26.67%	26.67%	33.33%	0.00%
Question 7: A person's culture plays a large role in her/his ethics.	46.67%	40.00%	13.33%	0%	0%
Question 8: A person who is not religious can be very ethical.	53.33%	40.00%	0%	6.67%	0%
Question 11: Have you ever felt "punished" (lower grade, ostracized by peers, loss of promotion, job loss, no pay increase) for making an ethical, but unpopular decision	20.00%	33.33%	20.00%	26.67%	0%
Question 12: Education should play a big role in teaching students about ethics	20.00%	40.00%	33.33%	6.67%	0%
Question 22: Engineering ethics are typically dealing with straight forward situations that simply require moral fortitude of character.	0%	66.67%	20.00%	13.33%	0%
Question 23: By the time people reach college age it is too late to teach them about ethics.	0%	6.67%	26.67%	40.00%	26.67%
Question 24: Ethics should play a central role in engineering design.	20.00%	46.67%	33.33%	0%	0%
Question 25: Faculty and instructors incorporate ethics training into their classes.	0%	26.67%	60.00%	6.67%	6.67%

Generally, the students felt engineering ethics was important to them and the majority thought education should play a significant role in teaching ethics. 67% of the students considered ethics to be playing a central role in engineering design with the other 33% indicating that they are not sure. It would have been interesting to provide an opportunity to capture the students' thoughts at the end of the semester. In the future, the plan is to do a pre- and post-survey as well as to embed the survey questions in subsequent courses. Another interesting feedback was that the students were not sure whether faculty were incorporating ethics training in classes. This trend could be attributed to the majority of respondents who are underclassmen but it still needs consideration in coordinating with other faculty. Question 11 posed the best opportunities to learn from students experiences. In the future, the discussion of student experiences on being punished for being ethical will be incorporated for discussions.

Weekly Reading/Writing Briefs

Every week students were assigned a chapter with case studies to read and provide written brief summaries expected to be within one to two pages in length. The evaluation of the written briefs was adopted from Garrick Louis at the University of Virginia (personal communication syllabus for SYS 6041 Ethics on Engineering Practice and Research course). The written briefs worth 20 points each (Figure 1) were expected to:

- Provide key concepts in the chapter. Accurate and complete representation of the ethical issues. (6 points)
- Provide positions on the issues rationally based on the readings and clearly stated. (6 points)
- Use of external references other than the assigned readings to support or refute points in the discussion of the issues. Quantity and quality. Cited within the text. (4 points)
- Include original ideas not already stated in the readings. (4 points)

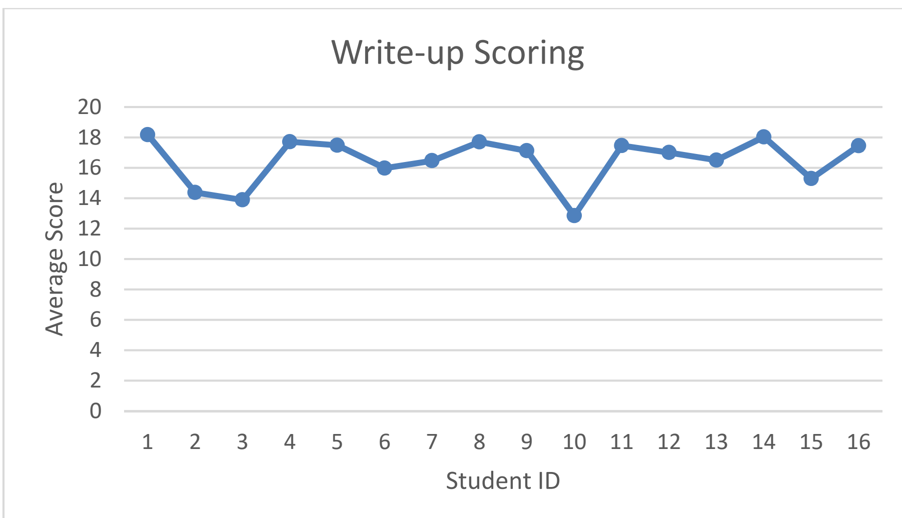

Figure 1: Average Score of Weekly Writing Briefs per Student

In the beginning of the semester the students struggled with providing complete write-ups and the average scoring does reflect that struggle. Most of the early submissions lacked some of the elements expected from the rubric. As the semester progressed, improvement was noted and in the future cohorts, samples will be provided so that they would have a reference. Some of the differences in scoring were based on students not submitting their write-ups.

Weekly Presentations/Discussions

The material summarized in weekly write-ups was also expected to be orally presented and discussed during the class sessions. The oral presentations opened a platform for the whole class to engage in open discussions. The presentations were graded under the same rubric as the writing briefs. The only difference was individual adjustment from team score due to discussion. The evaluation included taking into consideration how they presented and responded to class questions.

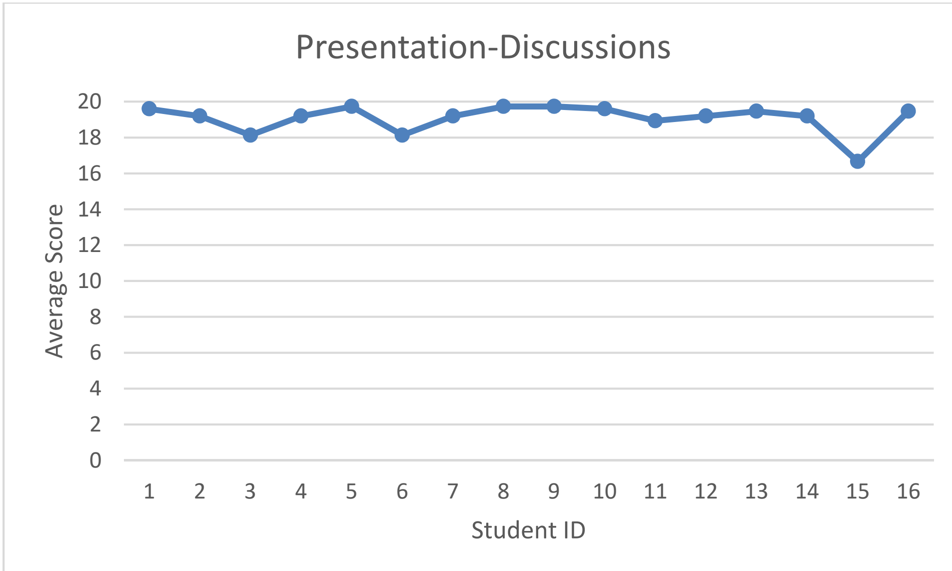

Figure 2: Average Scores for Oral Presentation per Student

When presentation and discussions initially took place, the teams were taking too long to communicate their thoughts. The class eventually established ground rules for presentation and discussions. For anyone to earn points in presentation/discussions, participation was required. For safety, one presentation highlight was students completing a video on any aspect of safety. Overall the students did an outstanding job with the videos getting an average score of 89.4.

Individual Quizzes

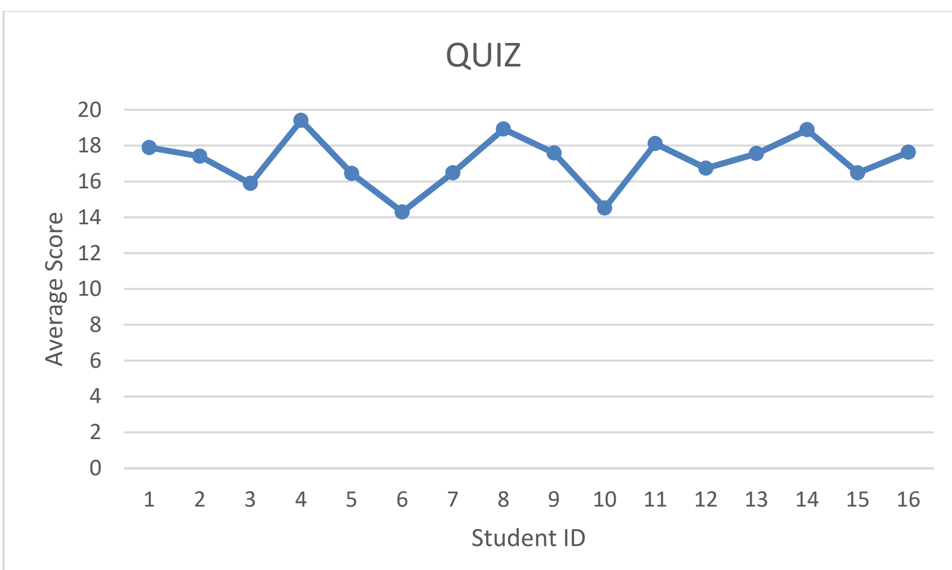

Figure 3: Average Scores for Individual Quizzes

The element of quizzes was a multiple choice assessment tool that captured information delivered by guest lectures as well as key concepts that students were expected to know. In Figure 3 is the performance summary on the concepts evaluated through quizzes. Student identification numbers across other evaluation categories shows a performance correlation.

Midterm Project

Each team was expected to demonstrate an understanding of the background of their case by providing an overview, clearly identifying and defining the ethical engineering problem as well as key stakeholders impacted in the case. Case presentation focused on relevant facts through offering different moral viewpoints and their analysis. The elements of relevant facts could include commitment to safety, workplace responsibilities and rights, truth and truthfulness, computer ethics, and environmental ethics among others. Reasonable assumptions in defending or assailing identified competing moral viewpoints had to have basis in relevant facts. Finally, the teams presented a best course of action by using facts, reference cases, best practices, and original opinions. These areas represented 80 percent of project grade. The final 20 percent was split between individual and teamwork assessments. Overall the midterm presentations were excellent with an average of 91% with a 3.8% standard deviation.

Final Project

The final project was a two-part activity that included a safety element using fault tree analysis and a quality management component using moving averages. The point distribution for the fault tree analysis project was 50% fault tree diagram, 30% calculating probabilities for all intermediate and final events, 10% for calculating risk prioritization numbers, and 10% on student conclusions. The average was an 83.5% with a standard deviation of 10.2%. All but one group did very well on the fault tree diagram. All groups successfully calculated the event probabilities. The biggest challenge was students calculating the risk prioritization numbers. The difficulty was using the provided Severity, Occurrence, and Detection Table[26]. In future, more practice on using this table will be done in class.

The second part of the final project was on application of quality control. This was an individual activity. The point distribution for the quality control project was 10% calculating one-sided process capability, 15% two-sided process capability, 20% annotating archival data, 30% developing the means, warning, and action lines for the moving average and range charts, and 25% was determining when to intervene using new set of process data for the charts they developed. The average was an 85.7% with a standard deviation of 16.0%. The students correctly calculated all process capabilities. The area the students struggled most was when a person should intervene based on charting the new data. There were minor issues in annotating and setting up charts based on archival data.

Peer Evaluations

A peer evaluation approach was also used to learn how the teams worked together including the individual contributions through the eyes of teammates and self-reflection. Team reorganization took place after the first half of the semester; therefore, each member could be identified where there is consistency in the positive or negative performance. The questions asked included the following and three additional opinion-ranking questions for each team member's contributions:

1. Giving credit/recognition to others for their contributions
2. Using tact when disagreeing with others
3. Contributing ideas to help the team become more effective
4. Keeping commitments made to others
5. Listening carefully to others
6. Expressing ideas in organized and understandable manner
7. Interest to working with the same peer in other projects

The peer evaluations revealed that the members who excelled in first team also excelled in the new team while those who performed at the bottom of their teams were not viewed in the best light in their new teams either. The average for first group peer evaluations was a 77.1 % with a standard deviation of 12.2% while the second group had an average of 80.5% and a standard deviation of 12.8%. These evaluations indicate that there are opportunities for intervention for low performing students within the team by the 3.4% improvement. Also, it indicates that reshuffling the teams between projects might not be as first thought. Perhaps early intervention and scoring rather than waiting after major group project is finished will help the underperforming students. The other consideration is to assign the midterm project earlier and have the peer evaluation completed prior to the project completion.

Discussion and Future Considerations

Overall a great deal of material was covered in a fun and engaging class. Students greatly enjoyed the interactions and discussions. Ground rules worked very well and will be implemented in subsequent semester. In addition to ground rules, the introduction of group contracts will be added to help improve the team working dynamics. For the future, the authors are also exploring external collaboration with ethics centers and other departments teaching ethics and safety at their universities. The treatment of the course pre-survey will be augmented with a post-survey to compare the student perspectives' progression through the course. Another consideration is to introduce life cycle analysis as another tool to support engineering ethics and safety.

Acknowledgments

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