Integration of Ethics, Sustainability, and Social Responsibility Components in an Undergraduate Engineering Course on Finite Element Analysis

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Abstract In this work, we use a series of case studies to introduce ethical thinking, environmental sustainability, and social responsibility in a level 3 undergraduate engineering course. Specifically, in teaching the principles of Finite Element Analysis, used to perform engineering and performance analysis of designs, we introduce several real-world engineering ethics situations closely connected to the technical topics taught in the class. In taking up each case, the instructor provides a context, and the underlying micro-ethics and macro-ethics dilemmas are outlined. Students in two different cohorts are given the same problems. In the first cohort, the students submit an individual commentary following an analysis and self-reflection. In the second cohort, the students prepare a commentary in groups following a detailed deliberation between the peers. From the analysis of the commentaries of the two cohorts, we found that students in the second cohort had more evolved and rich commentaries. This cohort demonstrated a more developed moral imagination, significantly stronger ethical reasoning skills due to the exchange of ideas and knowledge between their peers, and facilitation by the faculty member. We also found that these debates and discussions help students hone their negotiation, strategic planning, public speaking, and evidence-presenting skills. Students also learn to empathize with peers' views and opinions, honing their collaboration and teamwork abilities while arriving at a consensus on open-ended problems.

Keywords: Ethics, sustainability, social responsibility, finite element analysis, engineering curriculum.

1. Introduction

The engineering profession requires the application of engineering competencies in an ethical manner. The current state and the complexity of the field of engineering require the graduates to undertake engineering work within the framework of technical, social, human, and environmental issues. As a result of the complex interplay of these various sectors, it is critical for an engineer to understand the ethical problems, identify relevant socio-technical systems, understand and empathize with different perspectives, appreciate value conflicts, understand the constraints, and eventually engage in reasoned negotiations to determine plans/actions. Thus, reasoning and critical thinking are very important for an ethical engineer.

In several educational institutions and departments, the modern engineering curriculum is evolving to introduce ethics, sustainability, and social responsibility education. The most common mechanism seems to be the stand-alone ethics course [1,2], whereas the introduction of engineering ethics in technical courses is highly recommended [3]. Apart from stand-alone courses, other approaches to introduce this education include embedded courses [2,4] and team-taught courses [5]. With respect to the pedagogical technique to teach engineering ethics, Hamad et al. [6] have presented a detailed literature review highlighting numerous approaches such as case studies, collaborative and challenge games and role-plays, debates, group discussions, presentations, codes of ethics, online instruction, multimedia packages, videos and simulations, and traditional teaching methods.

A literature review shows several drawbacks with the current approach to teaching engineering ethics. At the core of it is the lack of simulation of today's workplace in which most engineers work in teams. Therefore, it is essential not just to teach ethical thinking on an individual level but also to do that in a collaborative setting [2]. Bucciarelli [2] noted that most teaching in this domain uses case studies and focuses on individualized training, failing to prepare our students for responsible professional practice adequately. Typical characteristics of treatment of such problems include focusing on the individual actor, analyzing the scenarios in the framework of the ethical codes, usage of traditional moral philosophy, and an assumption that a win-win situation exists in which the ethical dilemma can be solved in a satisfactory manner [7].

This individualistic approach to teaching ethics has been questioned by other researchers too, such as Conlon and Zandvoort [7], who rightly argue that this is inadequate to prepare engineers for ethical, professional, and social responsibility. Mitcham [8] has urged to reconsider this individualistic approach that is often taught using simplified cases to impart sensitivity training, resolving ethical dilemmas, and considering whistleblowing as an essential key to help engineers adhere to the codes. Several others have presented arguments against the individualistic approach [9-15].

Bucciarelli [2] advocates the inclusion of social and political dimensions and recommends integrating ethics problems into the engineering course. Mitcham [8] supports the inclusion of analysis and transformation of institutional arrangements and policy directives to train engineers. In fact, it is becoming clear that while we train engineers to value and prioritize cost, efficiency, and schedule, there is severe neglect of integrating and providing equal importance to ethics consideration. Specifically, there is a need for the inclusion of two types of ethics analysis in the engineering curriculum. The first is the micro-ethics which is the individualistic training. The second, and often the neglected one, is the macro-ethics training in which we focus on the collective social responsibility of the engineering profession and societal decisions about technology [13]. In doing so, several researchers advocate the pursuit of ethics education informed by science, technology, and society, to aid the integration of macro-ethics in the curriculum [5,13,16-19].

Education on environmental sustainability (ES) is important to tackle complex environmental problems, as we balance human needs and ecological well-being. With pressing ecological and health crises, it is urgent that we reevaluate the fundamental ethics questions, human position with respect to nature, and (re)design our society to ensure that the aspirations of human beings are met while being in harmony with nature [20]. Education for sustainable development promotes sustainable societies that is in balance with nature, has social justice, and yet is economically viable [21,22]. Alvarez and Rogers [23] categorized the sustainability curriculum in the literature with the following emphases/theme (i) definitions [23] (ii) implementation [24], and (iii) discourses [25, 26]. Among others, the popular approaches to teach ES include a constructivist style [27-29], and community-oriented active learning pedagogy to teach ES is proposed by [30].

Based on the above literature review and fully understanding the importance of integrating ethics, environmental sustainability and social responsibility within the technical curriculum, in this work, as a preliminary step, we use the *embedded approach* to teach *ethics* in Finite Element Methods (FEM) course that is taught to 3rd year undergraduate students in an engineering technology program at McMaster University. FEM is often used to perform numerical analysis of engineering problems in structural analysis, heat transfer, and fluid flow. With the evolution of computing power, numerous industries place a significant emphasis on conducting computational investigations using FEM to make critical engineering decisions. To train our graduates to undertake engineering work within the framework of technical, social, human, and environmental issues, we have integrated ethics components into some of the technical problems that the students investigate in this course. Thus, our objective is to introduce a simulated work environment that requires ethical thinking, environmental sustainability, and social responsibility considerations, in addition to technical skills. To the best of our knowledge, there is no course on FEM that includes ethics components in the manner we do in this offering of FEM.

In the ensuing sections, we present the details of this *embedded approach* to teach engineering ethics. Specifically, in Section 2, we describe the materials and methods used to conduct this study. This includes the course descriptions, the details of the three specific case studies, and the two different procedures followed in conducting the ethics studies with two different cohorts. In Section 3, we present the results of this pedagogical experiment in the form of an analysis of the student commentaries, from the two cohorts, on the three cases. We also present our learning and the future course of action to evolve the current pedagogical approach. The overall findings and outcomes are summarized, and pertinent conclusions are drawn in Section 4.

2. Materials and Methods

As an initial step, engineering ethics education was embedded in the course titled *Finite Element Analysis* offered in the 3rd year undergraduate program in Automotive and Vehicle Engineering Technology. This is a non-traditional engineering program at McMaster in which, in addition to the technical content, the focus is also on inculcating business and technology management skills. The course is offered once a year with an approximate registration of around 60-75 students. The details of the course content, the pedagogical methodology applied, and the outcomes are described in detail in the ensuing sections.

2.1 Course Design

The technical content of this course focuses on teaching the theoretical principles of finite element analysis to study spring systems, trusses, beams, frames, and heat transfer analysis. The key learning outcomes that were expected out of this course are:

1. Apply mathematics, science, and engineering to design.
2. Learn the mathematical formulation of the finite element method.
3. Perform engineering analysis of systems.
4. Apply finite element tools for the analysis, design, and optimization of engineering systems.
5. Solve structural- and thermal- engineering problems using the finite element approach.
6. Provide hands-on experience using finite element software methods to model, analyze and design mechanical, thermal, and automotive systems.

In addition to the technical content, keeping in mind the larger agenda of graduating engineers who are socially responsible, we introduced a dimension of ethics and sustainability in the course through the labs. More precisely, the course has six lab exercises in which the students are trained to solve an engineering problem using the ANSYS software. These are typical real-world engineering problems. As an extension of these lab exercises, we have introduced several ethics and sustainability-related cases on which the students are required to provide their commentary. Three examples of ethics-related problems included in the course as described below:

(a) *Aircraft Fuselage Design*: In this question, a hypothetical scenario is created in which the students, as an authorized engineer, have to weigh in on two scenarios relating to the materials used in manufacturing an aircraft panel. Specifically, they have to choose between an expensive but environment-friendly material and a material that is toxic for the environment but meets the company's demanding goals of low-cost manufacturing. The purpose of this exercise is to help students consider sustainable design principles, keep environment and social responsibility in mind, and propose a design based on principles of micro-ethics in the absence of any governing codes of ethics. This case also brings to the fore the significance of whistleblowing and the need for the participation of engineers to create professional codes and draft policy frameworks.

(b) *Autonomous Vehicle Design*: In this case, the students are coding an autonomous vehicle's maneuvering decisions during an imminent crash situation and outline the strategy to defend such decisions in the event of a court summons. Specifically, the students were asked to decide on a maneuver based on three scenarios, i.e., veering left to hit school children, veering right to drive into a restaurant, and going straight and hitting pedestrians. In all three cases there is a high probability of injury to or loss of human life. The primary objective of this exercise is to train students to develop ethical algorithms that mitigate societal risks, use judgment and reasoning that appeal to core human values of empathy and care, and train them for consequence management.

(c) *Space Shuttle Reentry*: In this case, instead of the original *Challenger Space Shuttle* ethics problem, the students are required to debate the consequence of a choice of a specific hypothetical parameter value in their design calculations that varies the calculated survival percentage of the crew at the time of reentry from 60% to 95%. The case assumes that the engineers do not have any prior scientific knowledge of the parameter. The ethical dilemma is to determine how to agree on a value and report the survival percentage to the crew. To a more significant point, they are asked to reflect on whether a practicing engineer should be content with an accuracy of 99% in his/her work. Thus, this exercise aims to emphasize the significance of ethical operating procedures, including transparency, informed judgment, careful consideration of consequences, and setting high moral operational standards.

Thus, collectively, these questions aim to draw students into simulated real-world situations that require careful consideration, judgment, and strong reasoning abilities. These are essential traits of a successful engineer that will help them make ethically sound decisions and have a positive impact on the environment and society.

2.2 Procedure

The course was taught to two cohorts over a period of 13 weeks, and each week the class met for 3 hours. The first cohort had 66 students, and the second had 76 students. For the first cohort, these questions were posed as an extension of the lab exercises. The students had to submit a report for each lab, and these reports had to include a section on the ethics questions associated with the lab exercise. They had to work individually on the ethics questions and submit a commentary on them as part of their report for the lab assignment. They were permitted to discuss and debate with their classmates on the cases to form an opinion, reflect on the cases, and use their judgment to prepare the commentary. Students could submit the commentary along with the rest of the lab report a couple of days later.

In the case of the second cohort, a significant variation was introduced for these case studies. More precisely, during the last 40 minutes of the course, the students were divided into random groups of 4-5 students. Each student had to engage in active discussions within their group, and each group had to prepare a collective commentary for the three cases. Unlike the first cohort, the students had to submit this commentary by the end of the class. Thus, unlike in the first cohort, the case studies were submitted independent of the lab report.

3. Results and Discussion

To either cohort, the concepts of ethics, environmental sustainability, or social responsibility was not explicitly discussed or taught in the course. The only key difference is the larger amount of interaction that the students in the second cohort had via the in-class group discussions. The commentaries produced by Cohort-A were very brief because the students largely perceived the commentary as a small part of a more extensive report for that specific lab exercise. As a result, most commentaries were just about a paragraph or two. The considerations were also not very elaborate because the students mostly worked on it individually and did not debate or discuss the possibilities with their peers. For example, in the *Aircraft Fuselage Design* case, some students saw this from a design perspective and presented the best design without many details on the environmental considerations. Others introduced the sustainability and environmental concerns to propose the designs, but after some shallow analysis. In the *Autonomous Vehicle Design* case, students were largely appreciative of the value of human life and showed priority on saving young children over adults. Further, students presented design solutions that would result in more material damage than the loss of human lives. In the *Space Shuttle Reentry* case, once again, most students were sensitive to the impact on human life and were empathetic in their decision. Most reports also indicated that in situations where human lives could be at stake, the accuracy levels of the applications should be very high.

Overall, from the commentaries from the first cohort on the three cases, it was clear that there was some level of introspection and analysis, and opinions based on an ethical framework. However, by and large, there was a deficiency of broad thinking to handle such open-ended questions that required considerations of several other non-technical factors. Clearly, the lack of a constructivist environment, as advised by other researchers in the literature [27-29], in which students engage in debates and discussion with peers, deprives the students of an opportunity to experience alternative viewpoints and other ideas that they could explore. Such a broad exposure to multiple ideas, information, and opinions would have helped them write a more substantial commentary. Additionally, perhaps with stringent deadlines and demands from other courses, they lacked adequate opportunities to deliberate with their peers on such open-ended issues, outside the class. As a result, the overall quality of the commentary was lackluster.

On the other hand, Cohort-B submitted very extensive and some very interesting commentaries. It was clear from the writings that each group had an intense discussion before drafting the commentary. For instance, in the *Aircraft Fuselage Design* case, their thought process was very clear when most of the students based their choice of a particular design on three aspects, namely, biodegradation time, cost, and relative quantity of waste. For example, a group argued that although one of the options given to them produced 18% higher waste, it did not negatively impact the environment anymore over a long period than an alternative option. They made a strong case for their choice by comparing not just one aircraft but the overall functioning of the industry, drawing pertinent comparisons with the automotive industry. Another group discussed the impact on employees, livelihood, and society to justify their recommendation of a particular design solution. Such arguments are a clear indication that the students focused on macro-ethics issues while determining an optimal choice.

In the *Autonomous Vehicle Design* case, the groups presented various analysis criteria before choosing a maneuver. Some of the design considerations were the possibility of speed manipulation, the height of the pedestrians to determine children versus adults that can be measured via sensors, type of restaurant walls (brick, concrete, or glass), etc., to make a collision decision. In picking each maneuver choice, the students clearly described the anticipated consequences of collision and their preference for the least damage. Some commentaries included probabilistic analysis in which they account for the fact that adults might be able to quickly reposition themselves to avoid being hit by a vehicle, embedding this into the decision-making algorithm while making a maneuver. Some groups also drew from historical statistical data on the impact of collisions at various speeds to make their decision. The commentaries clearly highlighted the fact that the algorithm is being designed with due consideration and judgment. The significance they attach to human life in their design considerations was also very evident. Their analysis approach indicated an important focus on macro ethics led by questioning the goal of engineering design and its impact on humans and society.

In the *Space Shuttle Reentry* case, the students were very conscious that although we were discussing just a choice of one parameter, the implications were significant since several lives were at stake. The commentaries brought their empathetic nature to the fore, and several of them advocated transparency in operation and involving the crew in the decision-making process. Their arguments emphasized honesty, transparency, and empathy, and compassion in decision-making in an engineering setting. To a more significant point, the students in one voice underlined the significance of 0% error. They explicitly identified several sectors where the norms need to be tightened to ensure that human life is of utmost value. Once again, this indicates that while solving the individual micro-ethics problem, the students were able to extrapolate the context to the more significant macro-ethics issue that needs attention to serve society well as ethical engineers.

In all three cases, the commentaries evidenced that the students took various approaches and positions before arriving at their opinion. In doing so, sensitivity towards human life, empathy towards others, being gentle on the environment, and the success of the enterprise were some of the considerations that were important to them. The details and depth of the commentaries were evidence that the students significantly got involved in the discussions, and the group discussion helped many of them shape their opinion. This points to the effectiveness of the constructivist setting where through reasoning, the students can develop better arguments and arrive at more informed conclusions/positions. This agrees with the propositions in the literature that advocate this approach to teaching ethics [27-29].

In addition to helping every student make informed decisions and contribute to the commentaries, such exercises evolve their moral imagination, strengthening their ethical reasoning skills by exchanging ideas and knowledge between their peers, facilitated by the faculty member. This is consistent with the findings in the literature that state that ethics can be inculcated in the students through reasoning and cannot be taught to the students by instruction [31-33]. Students learn it from experience, interacting with peers in this case. Further, we have found that using case studies in a constructivist setting and integrating ethics into the technical course is very effective and is consistent with the findings in the literature [34,35].

Finally, these debates and discussions also help students hone their negotiation, strategic planning, public speaking, and evidence-presenting skills. Students also learn to empathize with peers' views and opinions, honing their collaboration and teamwork abilities while arriving at a consensus on open-ended problems. This is also reflected in the informal discussion that we had with the students, who found this a great education experience and acknowledge that it had widened their thinking on the subject.

3.1 Future Evolution

From the results of this preliminary introduction of micro-ethics through three simple cases it was found that integrating the ethics component in the course provides a transformational education experience in which the students learn the subject's technical principles and understand the challenges and implications as they apply the engineering designs in real-world scenarios. From the analysis of the performance of the two cohorts, it was evident that in an interactive and engaging environment, students can broaden their vision and imagination. It also helps bring out the best in the students. Going forward, we would like to do the following: 1. Retain the current active learning environment where students work in groups to produce solutions to such open-ended ethics questions. However, we would like to increase the number of such case studies. 2. The three cases integrated into this course are mainly cast in the context of a micro-ethics challenge, applicable to simple scenarios, with the corresponding macro-ethics issues raised in the discussions. In the future offerings, we would like to introduce explicit macro-ethics cases with more emphasis on environmental sustainability in which students are encouraged to debate and discuss policy decisions and present policy frameworks for important issues in the discipline. This will further help us to transform our students into human-centric engineers who will be impactful at the workplace.

4. Conclusions

In conclusion, we believe that integrating the concepts of ethics, environmental sustainability, and social responsibility components in an undergraduate curriculum alongside the technical content is very well received by the students. To help students evolve their moral imagination and strengthened their reasoning and judgment skills, the open-ended ethics cases should be introduced as an in-class activity in a group discussion format. The active participation helps the students hone their research and evidence-based reasoning, negotiation, public speaking, and evidence-presenting skills. The open-ended problems cast in the context of the technical subject helps them develop a broader view of the subjects' implication and impact in the real world. It also helps them appreciate the non-technical challenges that might be involved in engineering problems and prepares them well for developing and proposing human-centric solutions that have a positive impact on society.

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Biography

Gaganpreet Sidhu has a Ph.D. in Materials Science from Ryerson University, Canada. She is currently a Postdoctoral Fellow and a part-time instructor at McMaster University's W Booth School of Engineering Practice and Technology. Her pedagogical research interests include learning pedagogies, technology in education, and curriculum development. Her technical research interests include computational and experimental analysis of materials, material characterization, and properties of materials.

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