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Assessment of the Impact of Civil Engineering Design Problems for Promoting Ethical Decisions

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1. Introduction

The engineering community has experienced numerous scandals involving illegal as well as unethical engineering practices among well-known companies and government agencies during recent years. The failures with emissions scandal with Volkwagen, Boeing 737 max failures, Oroville dam failure, and lead-contaminated water in the Flint city of Michigan state are some of the ethical lapses that have highlighted the need for engineers to understand the implications. Future engineers are expected to have a strong technical foundation as well as reliable ethical practices. Engineering ethics is defined as: "(1) the study of moral issues and decisions confronting individuals and organizations involved in engineering and (2) the study of related questions about moral conduct, character, policies, and relations of people and corporations involved in technological activity" [1]. Engineering ethics has been increasingly emphasized in engineering curricula. The Accreditation Board of Engineering and Technology (ABET) has specific student outcomes related to ethical considerations. Despite the need for ethical decision-making among the undergraduate civil engineers, incorporating ethics into the curriculum has not been an easy task.

In some academic institutions, ethics courses could be offered by a non-engineering department which may be over-simplified to appeal to a broad range of disciplines and could fall short of experience. A study by Houston et al. in 2006 [2] has suggested using specific discussions that relate to personal experiences such as academic dishonesty they had observed. In their paper, the author also discussed a specific case about a package that was delivered from an opposing counsel that was intended to be sent to his client. This was followed by a discussion of questions that were aimed at slowly eroding the ethical judgment of the audience. This method allowed the audience to realize the slippery slope of unethical actions and their implications.

A recent study by Poor et al. in 2019 [3] was able to incorporate ethics case studies into multiple courses from the first year in engineering to the capstone design course in the fourth year. The case studies were also included in multiple elective courses of various subdisciplines such as hydraulics, structural, geotechnical, and transportation offered in the second, third, and fourth years. This was able to provide continuity in ethics education across the curriculum. The results from the assessment showed that ethics was incorporated successfully into the CE curriculum at the University of Portland (UP) and the students were able to learn about ethics in at least one course every year.

A study by Carpenter [4] has discussed a case study that considers the pollution of a river by industrial discharge from a company manufacturing a product. The author developed an optimization model using the variables such as the cost of treatment, fish, citizens, and profits to shareholders which affects the employees of the company. This optimization model was used to find an ethical solution to the above case study using the "Utilitarian and Respect for Persons" approach. The utilitarian approach strives to achieve the greatest good whereas the respect for persons approach is a concept where all people deserve the right to fully exercise their autonomy. Based on this optimization model, the author was able to develop a solution space for this ethical dilemma in this specific case study.

A recent study conducted by Sleep and Rohwer [5] identifies a case study in geotechnical engineering that assessed the conflict between welfare and safety. The authors of this paper argue that safety could be a hindrance to the welfare of the community as it increases the cost of the design. The authors were able to show through two hypothetical case studies that the cost of foundation repair of a poor client was considerably expensive due to the safety considerations. This additional cost could prohibit the poor client to complete the necessary repairs.

Ethical standards are often confused with obeying the law, religion, culturally accepted norms, and science. These factors can provide standards for ethical behavior but they have their limitations. Law can be corrupted by totalitarian regimes, religious guidelines do not apply to the people who do not practice religion, and ethical concerns could vary across different cultures based on the location and era. Finally, science can help us understand the motivation behind the human decision-making process but scientific advancement has presented ethical challenges as well. For example, the case of gene-editing by Dr. He Jiankui to confer the immunity to HIV was deemed unethical and illegal even if the process itself was scientifically feasible [6]. Therefore, Markuula Center of Santa Clara University [7] has identified the following five distinct approaches for ethical decision-making that applies to all people irrespective of their religious affiliation or cultural association:

1. Utilitarian approach – The type of ethical action that provides the most good and does the least harm. This approach produces a balance of action by minimizing the harm and increasing the amount of value generated for all the stakeholders involved.
2. Rights approach – This approach believes that humans have certain rights based on the nature of their dignity. These rights could include the freedom of choices, privacy, as well as not to be injured or lied to. This type of ethical action that protects and respects the moral rights of those that could be affected.
3. Fairness or justice approach – This type of ethical action believes that all human beings should be treated equally.
4. Common good approach – The type of ethical action that believes that community is good, and our actions should contribute to the compassion and wellness of the community.
5. Virtue approach – This type of ethical action is consistent with certain ideal virtues that provide for the full development of humanity.

Marakuula Center of Santa Clara University does highlight the importance of combining these approaches as there could be disagreements among stakeholders when using one specific approach. They indicate that each of these approaches presents valuable information about the ethical implications for any given problem. This information could be used iteratively to find a feasible solution. This approach will provide the students with the sensitivity required to make good ethical decisions.

Therefore, it is necessary to teach the undergraduate civil engineering students some of the nuances of ethical decision-making as a part of their curricula. Based on the literature review conducted by the authors, case studies had a greater impact on ethical education in the engineering discipline. This enables the students to practice some of the ethical considerations that they could encounter in their professional careers.

In this study, the authors at Rowan University presented case studies, as well as design problems that required the students to review the first canon of ASCE Code of Ethics [8] to make ethical considerations. The goal of these case studies, as well as design problems, is to ensure that the students were able to contextualize the ethical dilemmas and justify their decision-making process. This is an on-going study as we intend to incorporate the ethics modules into various courses in the Rowan University curricula. During the Fall 2019 semester, we were able to include these ethical case studies and design projects in the following Civil and Environmental Engineering courses:

- Fluid mechanics (3rd year)
- Sustainable Civil and Environmental Engineering (3rd year)
- Foundations Engineering (4th year)

Most of the students in the classes have had an ethics module in their freshmen year through a general engineering course as well as a discipline-specific course called: “Introduction to Infrastructure”. In this course, the students were presented with the case studies of the “Flint water crisis” and “The CITICORP building in NYC”. The goal of these case studies was to re-introduce some of the ethical challenges faced by engineers by utilizing their maturity as well as their technical capacity as upperclassmen. The details of the case studies and the design projects are presented in the section below.

2. Case Study Problems

Fluid Mechanics

Fluid Mechanics course is a 3rd-year course that introduces the concepts of fluid properties and fluid flow in conduits. At Rowan University, this is a 2-credit course with one-hour lecture and one lab period every week. The total enrollment in Dr. Jagadish Torlapati’s class was 40 students with 28 male students and 12 female students. The class periods are 75 minutes for the lecture and 165 minutes for the lab period. The students were made aware of the design problem and its ethics component at the beginning of the semester. The complete description of the design problem is presented in the box below. This design problem for Fluid Mechanics involved the calculation of pipe diameter using the Colebrook formula for transporting crude oil. The ethical consideration for this design project involved the consideration of three proposals for the path of the pipe. The proposal I involved a deserted path but expensive whereas Proposal II involved a wildlife sanctuary and Proposal III involved a residential community.

The students were instructed to review the ASCE code of ethics as a part of the design project. There was no lecture period assigned to discuss ethics. The students were informed that the pipelines are 99% safe and were also informed that crude oil has PAHs that can cause cancer. The students were given no specific information about the locations or federal regulations. The goal of the project was to focus on the safety of the three proposals. The students were asked to provide a descriptive answer to justify their proposal choice. Based on the Utilitarian and the

Virtue approach presented above, Proposal I has the least impact on the environment. The instructor expected that students will pick this option after reviewing the ASCE code of ethics.

An oil company is inviting proposals to construct a riveted steel (ε=0.9 mm) pipeline that transports crude oil to a newly constructed refinery. The density of crude oil is 920 kg/m^3 and the maximum allowable velocity in the pipeline is 3 m/s. The kinematic viscosity of light crude oil is 3×10-6 m^2/s. The maximum allowable head loss per meter of the pipe is 0.02 m/m. (neglect minor losses)

Develop an excel file that can compute the diameter of the pipe using the excel solver function. The steps are as follows:

1. Use the Darcy-Weisbach equation to get the friction factor (f) as a function of D
2. Use the Reynolds number equation to get it as a function of D
3. Use the Colebrook equation to find diameter D
4. In excel assume a value for diameter (for example 1 m). Write the left-hand side of the Colebrook equation and the right-hand side of the Colebrook equation in different cells. The difference should be minimized using the Solver function by changing the variable D

Proposal I: The proposed pipeline path has a total length of 7500 m and the location is rock formations that can be difficult to excavate and lay the pipeline. This path is largely deserted and there is no significant impact on the environment
Proposal II: This proposed pipeline path has a total length of 4500 m and the location consists of the forest with wildlife. This is not difficult to excavate. There could be an impact on the existing ecosystems during the excavation process.
Proposal III: This proposed pipeline path has a total length of 2500 m and the location consists of a community that is adjacent to the pipeline path.
For each proposal, compute the total cost of the pipe if the cost per kilometer is $3 million.

Ethical consideration
The first canon of the ASCE code of ethics states: "Hold Safety Paramount". Please review at https://www.asce.org/code-of-ethics/
Based on the code of ethics, what is your choice of the proposal?

Sustainable Civil and Environmental Engineering

Sustainable Civil and Environmental Engineering is a 3rd-year course that presents the fundamentals of environmental engineering, such as solid waste, hazardous waste, and air pollution. At Rowan University, this course is offered as a 3-credit course with two lecture periods of 75 minutes every week. The total enrollment in Dr. Sarah Bauer's class was 32 students with 10 female students and 22 male students. The students were given a short 15-minute lecture about ethical lapses in environmental engineering. Subsequently, the students were assigned a group project that required them to research specific historical events in history that involved major impacts on the health and wellbeing of humans and the environment. The complete list of research topics is presented in the box below.

For this project, students were asked to research their assigned event with regards to what happened, when/where the event occurred, who/what was effected, what lasting effects did the event have, and how could the event have been prevented. The students were given a prompt that required them to specifically identify the ethical component of the event. The goal of this prompt was to have the students justify the ethical lapses in the event occurrence with respect to the first canon of the ASCE Code of Ethics.

In this course, the students were asked to research the topics given in Table 1. The students were asked specific questions as follows:

1. In what region did your event take place? What is/was the population of that region? Include brief information about the country/state/city of your event, including social, economic, and environmental information.
2. What is the environmental concern (e.g. contaminant, pollutant) involved in your event? Include characteristics, including both chemistry and human and environmental health impacts.
3. What is the moral/ethical/social value of your event? Note: The first canon of the ASCE Code of Ethics is "Hold Safety Paramount". What potential moral/ethical lapses took place during your event by engineers and others involved?
4. Did your event impact legislation and/or environmental regulations? If so, what were they?

Team Number	Presentation Topic
1	Great Smog of London, 1952
2	Love Canal, NY Superfund Site
3	Donora Smog of PA, 1948
4	Tar Creek, OK Superfund Site
5	Meuse Valley Smog of Belgium, 1930
6	Pearl Harbor Naval Complex, HI Superfund Site
7	Atlas Asbestos Mine, CA Superfund Site
8	Lipari Landfill, NJ Superfund Site

Foundations Engineering

Foundations Engineering is a 4th-year senior elective course that introduces the advanced concepts of geotechnical engineering such as the design and analysis of foundations. At Rowan University, this is a 3-credit course with one lecture period every week. The total enrollment in Dr. Cheng Zhu's class was 31 students with 28 male students and 3 female students. The class periods are separated into two 75-minute slots with a 15-minute break. The complete description of the design problem is presented in the box below.

In this course, the ethical conflict was the Engineer obtaining a project by underbidding and not completing the project. The Engineer compromised the safety of the project as well as the project itself by falsifying the feasibility study. The students were asked to identify the unethical behavior in this case study and justify their observations.

Ethics Discussion (Individual)

The first canon of the ASCE Code of Ethics states that "Safety is paramount".

If Engineer A was one of several consultants asked by the client to submit proposals for a feasibility study for this construction. To increase the chances of getting the assignment, Engineer A submitted a proposal with a very low cost, which was about half the realistic cost for the work. The reasoning behind the low cost was that the consultant who got the feasibility study would be better placed to win the subsequent—and far more lucrative—design competition (providing, of course, that the client decided to go ahead with the proposed facility).

Engineer A won the contract for the feasibility study and found that the study required far more time and expense than originally envisioned. The contract payments covered only about 40 percent of the actual costs. However, the most depressing part was that Engineer A's study revealed that the soil condition is much more complicated than expected. This could compromise the overall safety of the project.

In other words, it was not economically feasible to construct the proposed building on the site, and Engineer A's final report explained this fact. Engineer A had spent several months on a project that had cost money to complete.

Question: Was Engineer A's behavior ethical? And why?
Please explain in a short paragraph, including observations of unethical behaviors (in your opinion) (<150 words).

3. Assessment Results

The students were asked to complete a short survey at the end of the design project to assess whether the ASCE Code of ethics influenced their proposal choice for Fluid Mechanics. Similar surveys were assigned in two other courses as well. This assessment was like the study performed by Sleep and Rohwar [5].

1. Answer the following question based on proposal choice:

   "ASCE's code of ethics first canon influenced my final proposal choice"

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

2. Please explain your selection above.

The results from the assessment study for all three courses are presented in Figure 1. The total enrollment and the demographics for each course are presented in Table 1. The demographics information for sustainable civil and environmental engineering is not available as the surveys were conducted anonymously in this course.

Table 1: The enrollment and the demographics information for the surveyed courses.

Course	Enrollment	Responses	# Male	# Female
Fluid Mechanics	40	38	26	12
Sustainable CEE	32	25	NA	NA
Foundations Eng.	31	22	19	3

The average and standard deviation for each course is presented in Table 2. There were 40 students enrolled in the Fluid Mechanics course and the total number of survey responses obtained was 38. Similarly, the total number of responses obtained from Sustainable Civil and Environmental Engineering and Foundations Engineering was 25 and 22, respectively. It can be seen from the Figure 1 that most of the responses agreed that discussion related to the first canon of the ASCE Code of ethics has impacted their ability to make ethical decisions.

For the Fluid Mechanics course, about 85% (65% strongly agree and 20% agree) of students agreed that reviewing the ASCE code of ethics has influenced their proposal choice in Fluid Mechanics. Besides, the students that picked the responses 1 and 2 did so because they already knew the safest option and did not need to review the ASCE Code of ethics. The average and standard deviation values of all the responses for Fluid Mechanics courses were 4.5 and 0.9, respectively. Most of the students recognized that Proposal I was the safest option after reviewing the first canon. One student picked proposal II as a middle ground and needed more information whereas another student picked Proposal III saying that the pipeline would be safe which we believe is a failure to adhere to the first canon.

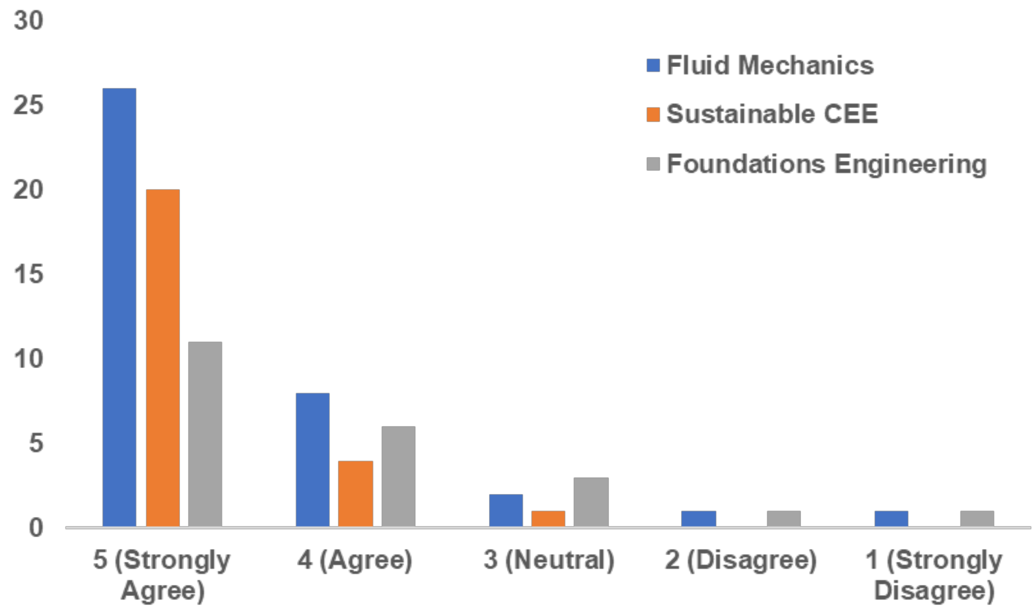

Figure 1. Assessment results for survey questions for Fluid Mechanics, Sustainable Civil and Environmental Engineering, and Foundations Engineering courses.

For the Sustainable CEE course, about 96% (80% strongly agree and 16% agree) of students agreed that reviewing the ASCE code of ethics has influenced their ability in making ethical choices. The average and standard deviation values of all the responses for the sustainable CEE course were 4.68 and 0.85, respectively.

For the Foundations Engineering course, about 77.3% (50% strongly agree and 27.3% agree) of the students agree that reviewing the ASCE code of ethics has impacted their ability to judge the engineer's actions. The average and standard deviation values of all responses for the Foundations Engineering course were 4.14 and 1.12, respectively.

Table 2: The average score and standard deviation from the assessment

	Average	Standard Deviation	Total Responses
Fluid Mechanics	4.50	0.90	38
Sustainable CEE	4.68	0.85	25
Foundations Engineering	4.14	1.12	22

Assuming a neutral (3) response from the students as the null hypothesis. The average response values obtained from this survey were statistically significant ($p<0.05$) and it can be implied that educating the students about the ASCE code of ethics has helped them make ethical decisions in the assigned case studies and design problems.

4. Discussion

We were able to implement case studies and design problems to simulate ethical decision-making in three civil and environmental engineering courses. The case studies and design projects chosen for the courses presented the students with ethical dilemmas that enabled the students to identify the ethical conflict. The results from the design problems in Fluid Mechanics course indicate that the students picked the safest proposal even if this was the most expensive proposal. The students were also able to successfully identify the ethical conflicts in various presentation topics they researched for the Sustainable Civil and Environmental Engineering courses. The students were also able to identify the engineer's ethical lapse in obtaining a project for Foundations Engineering.

Based on the results from the surveys and reading the student survey responses, it was observed that all of them value safety. Several students also mentioned that they chose civil engineering discipline to help and protect the environment as well as the communities. Some studies also recognized the value of safety without the need to check the ethical canons.

There are some limitations to this study as the design problems, particularly for Fluid Mechanics and Foundations Engineering, were designed with one correct answer that was obvious to the instructor. Particularly, the Fluid Mechanics design project could have been implemented in other locations (Proposal II or III) if enough safeguards were in place to ensure safety. This limitation was somewhat mitigated by the descriptive question in the survey that asked the students to explain the ethical conflict. Besides, the students had no restrictions to choose the correct answer. In real-life, the employees could be pressured by an authoritative figure, a manipulative peer, or be presented with financial incentives. This could adversely impact the decision-making process and impair the professionals from choosing the ethical option. The competition between companies also contributes to ethical lapses in professional careers. We tried to capture this in the Foundations Engineering design project. However, this problem needs to be expanded further to make the ethical dilemma less obvious.

We intend to incorporate design problems in the future semesters for these engineering courses as well as other courses during the coming semesters. The overall goal of this study to incorporate ethics modules with case studies and design problems in different civil engineering disciplines courses. The problems presented in this course will be improved based on the feedback received for the next year.

The case studies will be simplified without technical computations and could be presented to freshmen engineering students next year. This will enable us to re-introduce these problems as upperclassmen with increased maturity as well as technical capacity to re-evaluate these ethical dilemmas.

In conclusion, this study was able to show that students can recognize the ethical conflicts presented in the case studies and the design problems for the three civil and environmental engineering courses. The students were also able to choose the option that promotes safety when this option does not pose any restrictions. These case studies can be used by other civil engineering faculty to promote ethical decision-making among the students. These case studies will be improved to create complex scenarios for ethical education and training of students in civil and environmental engineering curricula.

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