Integrating Environmental Impact and Globalization into Senior Capstone Courses in Mechanical Engineering

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***Abstract*— This Innovative Practice paper describes assessment done in a senior project course at San José State University (SJSU). Today, environmental justice and environmental impact have been clearly elevated in its importance in engineering education by its reference in several current ABET Student Outcomes. This paper discusses the integration of an assignment in environmental impact into the mechanical engineering (ME) senior project course sequence. This study looks at student achievement data in Spring 2019 and Spring 2020. In this article, we compare the student achievement of the SLO related to environmental impact as well as analyze the essays of students from Spring 2019 and Spring 2020. As our assessment results show, most students either met or exceeded the criteria for this assignment in the ME senior project class. Over the past two years, 311 students (89%) either met or exceeded the criteria for this assignment out of the 346 students.**

Keywords—environmental impact, general education, mechanical engineering education; Engineering codes of ethics; senior project courses

I. Environmental Impact and Engineering Education

Engineering is the process of solving problems through the application of science and mathematics. The design process starts with a practical problem and ends with the creation of an application, device, or other technological output that addresses the problem. Through the design process, engineers must consider a variety of constraints, including the economic, environmental and societal impacts of that technology throughout the product's lifespan. From manufacturing, through use, to disposal, engineers have an obligation to determine of the technology is appropriate. An appropriate technology is one that solves a societal problem without many adverse negative impacts or where the technology has more positive impact than negative [1].

Evaluating the appropriateness of a technology requires great consideration of pro/con dynamics. The concept of sustainability and its regular application to the engineering design process only evolved in the 1980s, though the concept of sustainable yields in agriculture are traced back to the early 20th century in Germany [2]. In 1987, sustainability was defined in terms of sustainable development by the Bruntland Commission of the United Nations. Sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [3]. With this definition, engineers were better able to frame their design considerations in terms of environmental impact in a consistent manner. The concept and importance of sustainability was further bolstered in 1991 when the First National People of Color Environmental Leadership Summit drafted and adopted the Principles of Environmental Justice. In this groundbreaking document, environmental justice was defined through 17 principles that call for equal environmental protection under the law and equal involvement in environmental decision-making processes for all people and communities [4]. With these documents and definitions in hand, engineering could better consider the environmental impact of their designs in a consistent, equitable manner.

Today, environmental justice or impact has been clearly elevated in its importance in engineering education by its reference in several ABET Student Outcomes, though that was not always the case. ABET did not expressly call out environmental justice factors until the 2009 updates to Student Outcomes a-k. Prior to that update, Student Outcome "c" stated that students must have "an ability to design system, component or process to meet needs within realistic constraints" and Student Outcome "h" stated that students must have "the broad education necessary to understand the impact of engineering solutions in a global and societal context." Current ABET Student Outcomes 1-7, which were updated for 2019 accreditation cycles require that students recognize environmental factors in both their design considerations and as part of their ethical and professional responsibilities [5]. Now, not only is environmental impact identified as a critical design aspect in several ways, but it is also identified in the context of an engineer's ethical and

professional responsibility, which is a significant increase in the relevance and importance of environmental impact in engineering.

Several professional associations include sustainability as a requirement. The National Society of Professional Engineers (NSPE) code of ethics includes language that links to sustainability and environmental justice or environmental impact. A fundamental canon and the first rule of practice of the NSPE code of ethics [6] is to "hold paramount the safety, health, and welfare of the public." More directly, under the Professional Obligations section, item 2d directly mentions the need for sustainability— "Engineers are encouraged to adhere to the principles of sustainable development in order to protect the environment for future generations."

According to Mulder, Segalás-Coral, and Ferrer-Balas [7], the first sustainable development courses were usually lectures that were added onto existing engineering course. A comprehensive review of the literature on integrating sustainability topics into engineering coursework was done by Thurer and his colleagues in 2018 [8]. They found, after evaluating 70 papers that presented case studies on the integration of sustainability and engineering, that most of the cases focused "on creating environmental awareness and system thinking when identifying problems and solving them." Bielefeldt et al. [9] conducted a national survey in 2016 to assess the ways that ethics and societal impacts were taught in senior capstone classes in the U.S. There were 1,216 faculty members who responded to the survey; of these, 40% indicated that these topics were included in senior project courses. However, sustainability or sustainable development was included only in 30% of the institutions (61 instructors) when senior project courses were the only place ethics was discussed and in 53% of the institutions (486 instructors) where ethics was included both in the senior project and in other courses.

II. Development of the Integrated General Education Model for Engineering

In the spring of 2013, the SJSU College of Engineering proposed changing existing capstone courses from a two-part sequence (a proposal course followed by an execution course) to a package of four courses that integrated engineering design content with upper-division General Education (GE) Learning Outcomes in two areas: Self, Society, and Equality in the United States (Area S) and Culture, Civilization and Global Understanding (Area V) [13]. The learning outcomes of these GE areas are shown in Figure 1. In a traditional engineering program, social justice issues are usually separated from engineering coursework and often included as humanities or social sciences electives. Thereby, in the engineering students' minds, they are not associated directly with engineering coursework [14]. In designing this sequence of courses, SJSU engineering faculty purposely sought to integrate engineering concepts and social and global issues together in a series of courses. The undergraduate engineering degree is considered as the professional degree in the U.S. Therefore, most students graduating from undergraduate engineering programs in the U.S. will become practicing engineers. The underlying assumption of this curricular revision was that engineers need to understand "social and humanistic matters along with the technical, and communicate effectively and synergistically with persons having all sorts of backgrounds…Engineering should therefore be built upon the foundation of a broad and liberal undergraduate education." [15].

The Department of General Engineering created the two overview courses for this senior project integration sequence. In these two courses, students are challenged to understand the relationship of engineering to the broader community, both in the U.S. and worldwide. In addition to the assignments in this course, the engineering faculty have created linked activities in the senior project courses that allow the student to apply these concepts to their engineering disciplines.

The two overview courses take a case study approach in order that students might appreciate the social, ethical and cultural perspectives. Over the course of the year, there are case studies that specifically address each student learning outcome Areas S and V (see Figure 1). The first two courses in the four-course sequence for mechanical engineering (ME) students focus on the Area S GE Learning Outcomes in the fall semesters. The second two courses focus on the Area V GE Learning Outcomes in the spring semesters.

Area S GE Learning Objectives (GELOs)
S-GELO1: Describe how identities (i.e., religious, gender, ethnic, racial, class, sexual orientation, disability, and/or age) are shaped by cultural and societal influences within contexts of equality and inequality. S-GELO2: Describe historical, social, political, and economic processes producing diversity, equality, and structured inequalities in the U.S. S-GELO3: Describe social actions which have led to greater equality and social justice in the U.S. (i.e., religious, gender, ethnic, racial, class, sexual orientation, disability, and/or age). S-GELO4: Recognize and appreciate constructive interactions between people from different cultural, racial, and ethnic groups within the U.S.
Area V GE Learning Objectives (GELOs)
V-GELO1: Compare systematically the ideas, values, images, cultural artifacts, economic structures, technological developments, and/or attitudes of people from more than one culture outside the U.S. V-GELO1: Compare systematically the ideas, values, images, cultural artifacts, economic structures, technological developments, and/or attitudes of people from more than one culture outside the U.S. V-GELO3: Explain how a culture outside the U.S. has changed in response to internal and external pressures.

Fig. 1. SJSU GE Learning Outcomes for Areas S and V

When the four-course sequence integrating GE outcomes was set up, assignments in the original capstone courses that were meant to satisfy existing "soft" ABET outcomes were modified to align with the SJSU Areas S and V GE Learning Outcomes. New assignments and content were created for the companion courses that were taught by non-engineering faculty. The four-course package reduced the number of units required to graduate by four units. The four-unit savings in GE

were used along with other unit cuts and efficiencies to create 120-unit engineering programs. While the original impetus behind this combination of capstone courses to integrate GE Learning Outcomes into engineering was to save units, the reason it was implemented in this manner was that it has been shown that students often do better when engineering topics are applied to real-world social issues and because the new ABET criteria integrated social and global issues with the design outcomes. Thus, this package was the best way to meet the new integrated ABET outcomes in a manner that enhanced students' educations [16].

III. MATERIALS AND METHODS

This article focuses on one assignment which relates to environmental impact in the ME senior project course sequence. There are two capstone design courses for the BS degree in ME. The first course in the sequence is offered in the fall semesters and the second course is offered in the spring semesters. There are six individual writing assignments related to social and global considerations in the two ME senior project courses, and the ME assignments build on the content in the two overview courses in General Engineering.

Each module in the overview courses has an accompanying essay and each essay is followed by a complementary assignment in the senior ME project sequence. Figure 2 shows the two complementary assignments for Module 3. The ME assignments are designed to challenge students to recognize environmental factors in both their design considerations and as part of their ethical and professional responsibilities which are part of the ABET student outcomes [5].

As background for the ME project class, an oral presentation is made by a ME faculty member covering the NSPE Fundamental Canons, as well as the American Society of Mechanical Engineers (ASME) Fundamental Canons. The presentation is followed by small group discussions and presentations about relevant case studies. In response to COVID-19, SJSU moved all courses online on March 16, 2020. As a result, instruction for the environmental impact curriculum and the related assignments were moved online as well. When the classes moved online, the delivery of the content changed. Instead of lecturing, students watched a video generated by one of the faculty members about engineering ethics and read an article related to whistle-blowing [17] before class. To capture student interest with a related current event, students then read two additional web articles related to whistle-blowing concerns in the recent Boeing air disasters [18-19]. Online class time included an in-depth discussion of the ethical issues surrounding these Boeing disasters.

Area V GELO3: Explain how a culture outside the U.S. has changed in response to internal and external pressures.

Overview Class Assignment: Reflection Paper 3

Give an account of your own values infrastructures that explain your intentions behind the design of your senior project. Assume that your senior design project is going to be adopted in a country outside the US and Canada. Consider the potential for conflict at the level of differing values infrastructures between you as a designer and the adopting population as end users. In your write up, be sure to:

1. Describe what you are building for your senior project.
2. Explain: why you are making it?; how are you making it?; for whom are you making it?
3. Assume that your design will be adopted in a country outside the US and Canada. Pick one country only.
4. Give an account of your own values infrastructures that best explain your intentions behind your senior project. Consider the intentions behind your design and the intentions of your targeted end users. Can you anticipate or foresee unintentional consequences in your design? Can you foresee whether your design will be used ethically or unethically?

Mechanical Engineering Individual Writing Assignment 3

Research one of the renewable energy projects listed below: Narmada Valley Dam Project (India), Three Gorges Dam Project (China), or Nam Theun-Hinboun Hydropower Project (Laos).

1) Describe the cultural and social factors that led to these projects, both internal and external to the country. Describe how these projects have evolved and influenced the culture of the country where they are located.

2) If you were working on one of these projects and were a member of the National Society of Professional Engineers, what aspects of their codes of ethics would affect your work? In what way? Make sure that you address each of these topics separately in your paper, and cite the NSPE codes that apply.

Fig. 2. A comparison of the assignment in the overview and mechanical engineering courses

In the engineering ethics/environmental impact writing assignment, students are asked to apply what they have learned about ethical obligations of engineers to major environmental projects around the world – the Narmada Valley Dam Project (India), the Three Gorges Dam Project (China), and the Nam Theun-Hinboun Hydropower Project (Laos). Student achievement of Area V GELO-3 (see Figure 1) is evaluated in this assignment, in addition to assessing ABET Student Outcomes related to ethical issues in engineering.

IV. RESULTS

The ME Department offers several sections of its senior project class each year. The number of sections for each ME course increased from six in Spring 2019 to seven in Spring 2020. The enrollment across all ME senior project sections decreased from 183 in Spring 2019 to 166 in Spring 2020. Figure 3 shows the student achievement of the SLO related to environmental impact for the three semesters—GELO 3 of Area V of SJSU's General Education program.

We considered this GE sequence successful if the number of students meeting or exceeding the criteria for each GE Learning Outcome remained high. As can be seen in Figure 3, the number of students either meeting or exceeding the criteria for GELO 3 has remained high over the two semesters.

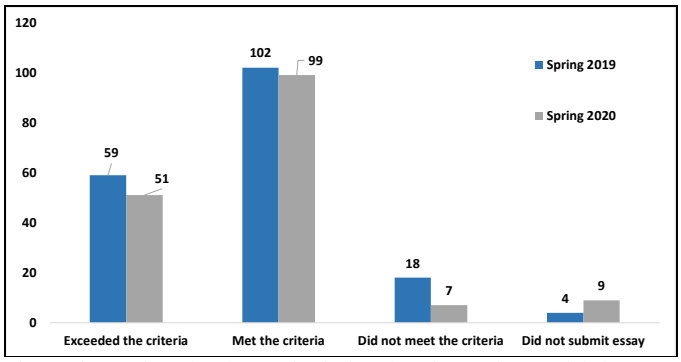

Fig. 3. The number of senior mechanical engineering students and their ratings on the assignment criteria

In the senior project assignment, students had to choose one of the three dam projects for their analysis. For each spring semester, essays from students who had exceeded the criteria were downloaded and grouped by the dam project chosen. Overall, more students discussed the Three Gorges Dam Project in China than the other two projects, Narmada Valley Dam Project (India) and Nam Theun-Hinboun Hydropower Project. The research team was interested in how the students addressed environmental impact in their essays. To determine the ways that students addressed environmental impact, the team read all 110 essays that exceeded the criteria from Spring 2019 and Spring 2020 (see Table I). The names of students were anonymized using the NOAA 2016-2020 Atlantic Hurricane name list [20], starting with the 2020 names and moving backward to the 2016 names.

Dams were chosen for the ME Area V GELO-3 assignment because they have been the subjects of debate around the world when they are planned and built [21]. According to Del Bene, Scheidel, and Temper [22], social and environmental conflicts are increasing in both number and intensity. Engineers are often caught between the desire to build dams to provide access to water and the consequences of these dams on the people living in the target area. Indeed, the National Academy of Engineering's (NAE) grand challenges is providing access to clean water for people worldwide [23]. The NAE notes that about one out of every six people worldwide do not have access to water. Because of the impacts large dam projects have on people and the environment and the increasing use of hydro projects in providing clean water and hydroelectric power to communities in need, they are ideal cases for students to explore the role engineers play in these types of impactful projects.

TABLE I. Number of essays reviewed that received a rating of "Exceeds criteria" in Spring 2019 and Spring 2020 for each dam project

Project	Spring 2019 "exceeds" No. essays	Spring 2020 "exceeds" No. essays
Three Gorges Dam	41	30
Narmada Valley Dam	8	15
Nam Theun-Hinboun	10	6

A. Three Gorges Dam Project

The Three Gorges Dam was originally proposed on the Yangtze River by Dr. Su Yat Sen in 1919 but was not approved until 1984 when the Chinese government was ready to undertake the construction of the world's largest hydroelectric dam [24]. One of the most important reasons to build the Three Gorges Dam was to produce more power for a country that was too reliant on dirty coal power plants and to control the severe floods which happened seasonally on the Yangtze river. In 1998, one such major flood caused 3,000 deaths and affected almost 200 million people while also destroying tens of thousands of kilometers of farmland [25].

The Three Gorges Dam is situated on the Yangtze River. The water backed up by the dam submerged large areas of the Qutang, Wu, and Xiling gorges for some 375 miles upstream, which has allowed large oceangoing freighters to navigate 1,400 miles inland from Shanghai [26]. The construction of the dam began in 1994 and took twelve years to complete. In 2012, all of the dam's 32 turbine generators went online and were producing 22,500 megawatts of electricity, making it the most productive hydroelectric dam in the world.

1) Student Responses to the Impact of the Dam on China

The team analyzed 71 student essays about the Three Gorges Dam that exceeded the Area V GELO 3 evaluation criteria. Most students focused on the negative impact of the dam on the river and its people. A few students (see Brett ~ Spring 2020) also mentioned the positive effects of the dam on China. Overall, almost all of the students discussed environmental impact, although only a few situated the discussion in terms of justice. Most students used the phrase "environmental impact" when describing the impact of the dam on China (see Nana Spring 2019).

Nana ~ Spring 2019-"…Moreover, the dam poses risks such as bursting or overflowing with heavy rain, which the lives of millions of people who live in the downstream will be in danger…."

Bret ~ Spring 2020-"Aside from the negatives, the Three Gorges Dam have also made positive influences in China's culture. With the help of the power generators from the dam, China was able to avoid 100 million tonnes of gas admissions into the atmosphere…"

B. Nam Theun-Hinboun Hydropower Project

The Nam Theun-Hinboun Hydropower Project is a dam built in Laos on the Mekong River and its neighboring tributaries for the purpose of the commerce of clean electricity [27]. The driving factors of this project are not only limited to producing energy exports to supply the Lao government, but to also generate protected careers and ecosystems for the indigenous people of Laos. The Nam Theun-Hinboun Hydropower Project was initially proposed in the early 1990s and was opened to the public by 1998 [30] and expanded in 2012 [28]. The Nam Theun-Hinboun Hydropower is part of Laos' plan to serve as the energy generator for Southeast Asia. Since the expansion of this project in 2012, there has been increasing environmental degradation in the valley [29]. In addition, the fish populations have decreased and have led to additional food insecurity issues among the local populace.

1) Student Responses to the Impact of the Nam Theun-Hinboun Hydropower Project on Laos

Sixteen student essays from the two semesters addressed the Nam Theun-Hinboun Hydropower Project. Many students talked about the resettlement of people on the river and the drastic declines in fish catches after the hydropower plant was built. Franklin (Spring 2020) noted that the hydropower project also had an impact on the income levels of people living near the project.

Franklin ~ Spring 2020-"…more than 29,000 people in 71 different villages, which consisted of mostly subsistence farmers, lost fisheries, rice fields, vegetables gardens and fresh drinking water supplies because of the dam …"

C. Narmada Valley Dam Project

The Narmada Valley Dam Project is a large-scale project in India that aims to create more than 3,000 dams in the Narmada Valley area. This project spans three Indian states: Gujarat, Maharashtra, and Madhya Pradesh because the Narmada river runs through them. The Narmada River is a 1,312 km long river that travels through the northern part of India and into the Arabian Sea [30]. This project was conceived by the heads of the three Indian states mentioned above to provide clean drinking water and power to poverty-stricken residents who live in drought-prone areas that experience very little rain and have no stable power supply.

The government created a Narmada Water Resources Development Committee composed of hydrological engineers to develop plans for the proposed dams. The final report of the committee recommended that the largest dam be built in Gujarat since it is the state that experiences the most drought out of the three impacted states and because it would also yield the most profits. This conclusion was supported by the World Bank, which provided the Indian government with a loan amounting to $450 million in 1985 so they could build a dam in Sardar Sardovar.

1) Student Responses to the Impact of the Narmada Valley Dam Project on India

The faculty team analyzed 23 student essays about the Narmada Valley Dam Project from Spring 2019 and Spring 2020. The students noted several issues about this project. Approximately one quarter of a million people lived on the now-submerged land. Also, many families were not appropriately compensated with land similar to what they lost (see Pablo Spring 2019). Another issue with the project was the loss of cultural sites, including temples and places of religious and cultural significance (see Philippe ~ Spring 2020).

Pablo ~ Spring 2019-"…The land that is given to them is uncultivatable or waterlogged in hundreds of cases. Many more have not been given sufficient land. Many others have been given fragmented or encumbered land. Most sites do not have adequate drinking water or sanitation or health facilities…"

Philippe ~ Spring 2020-"…This was a big blow to how these villages live, because their cultural traditions and livelihood were wiped out in an instant …"

V. Discussion

As our assessment results show, most students either met or exceeded the criteria for this assignment in the ME senior project class (see Figure 3). An examination of student essay content shows that students are able to not only identify social and environmental impact issues within these dam projects, but they are able to effectively evaluate them within the context of engineering codes of ethics. Despite either meeting or exceeding the criteria set through the rubrics for this assignment, the depth of the individual student's analysis of the issues related to the dams varied significantly. ABET EAC Criteria 2 [5] is the student outcome of "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."

The assignment in this study is used to partially meet this student outcome for ME. In reviewing the essays, we noted that few of the "Exceeds Criteria" essays discussed all of the relevant ABET student outcomes. ABET EAC Criteria 2 [5] is "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." The overview class assignment (see Figure 2) askes the student to discuss the consequences of the student's senior project with the ME subsequent assignment asking students to discuss the cultural and social factors. Taking these two assignments as a whole, it is clear that the two assignments should be revised so that students "apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare" in their response to the overview class assignment. As well, the instructions for the subsequent ME assignment should ask students to discuss the "global, cultural, social environmental, and economic factors." A revision of these essays would align more directly with the ABET EAC Criteria.

While the results of the current assignments demonstrate achievement of both the General Education Area V Learning Outcome 3 and the ABET Student Outcome within the engineering curriculum (partially), it is unclear as to the long-term effects on student knowledge and professional conduct these assignments may have. Further, since all of these three projects were built in Southeast Asia, it is unclear as to how relevant the students believe these projects are to them as they embark on engineering careers.

This finding is promising to future work and development in the course curricula across the ME senior design project course sequence. Since this assignment has now been utilized for several years and a sufficient number of students have participated in the assignment, the research team is planning to follow up with these students via a survey or interview to see if they still recognize issues related to environmental impact in engineering and/or have seen these issues in their careers. Additionally, the team plans on revising the ME 195B lecture content for this unit to address sustainability and environmental impact more directly, including emphasis on the life cycle of their designs. Other additions to the

curriculum may include a follow-up on this assignment in class after the essay is due, where students discuss potential ramifications of upholding ethical canons in their professional careers, such as the possibility of losing a job, and potential actions to take when facing ethical dilemmas with clients or supervisors. As well, we intend to discuss revising these assignments for future classes.

VI. Conclusion

The creation of the 4-course senior design project sequence at SJSU aligns with the review of the literature on integrating sustainability topics into engineering coursework done by Thurer and his colleagues in 2018 [8]. The goal of the ME Module 3 assignment is to foster an awareness of the environmental concerns inherent in engineering projects and the ethical obligations of engineers in upholding standards of sustainability, social justice, and environmental impact. This ME assignment is the last of six social justice assignments over the course of the two-semester senior design project classes. During the revision of the ME senior project courses, the goal was to interweave the social and global issues into the original course materials so that the courses might better meet the ABET criteria in addition to general education learning outcomes. As Nieusma [14] notes, integrating social issues into engineering courses directly could break down the artificial boundaries between humanities, social sciences, and engineering.

VII. Limitations

This project was conducted at one university to address multiple issues, the reduction of the number of units in the BS degree to 120 units, changing student outcomes for ABET-accredited programs, and enhancing students' achievement of ABET outcomes. There are limitations of the approach relative to assessing the impact of this intervention. Although having a large number of undergraduates enrolled in ME, other universities address the ABET Student Outcomes in diverse ways. Therefore, the results may not be transferable to other institutions.

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