Strengthening Sustainable Design Principles in the Civil Engineering Curriculum

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Strengthening Sustainable Design Principles in the Civil and Environmental Engineering Curriculum

Abstract

Sustainable design principles are starting to become part of professional engineering designs. To prepare students to be competitive in the workplace, it is prudent that undergraduate programs incorporate sustainable design principles throughout curricula. It was the vision of the Civil and Environmental Engineering (CE) Department at Rose-Hulman Institute of Technology to weave sustainable design principles throughout our civil engineering undergraduate curriculum, with the expectation that the civil engineering students incorporate sustainable design principles in a more thoughtful and logical manner in their civil engineering projects.

The CE Department has previously reported the incorporation of sustainable design principles from freshman to senior years and its impact on our students' understanding of sustainability. However, we found that many students still struggled to incorporate *social sustainability* in their capstone project designs. In response, we created and implemented a community engagement engineering module for our Codes and Regulations course. The module consisted of analyzing case studies and finally applying sustainable design principles, with particular emphasis on social sustainability, to capstone projects.

We used pre- and post-course surveys to assess if the community engagement engineering module impacted students' learning. Additionally, we assessed preliminary senior design project reports from a social sustainability perspective, comparing reports from the intervention cohort with the three previous cohorts.

Introduction

Sustainability concepts are important to everyone. The most widely known definition published by the United Nations World Commission on Environment and Development (UNWCED) in 1987, states that sustainable development *"is the development that meet the needs of the present without compromising the ability of future generations to meet their own needs"* [1].

Additionally, addressing social sustainability meets some of the eight Millennium Development Goals published by the United Nations in 2015, specifically, Goals 7 and 8, *environmental sustainability* and *global partnership for development* respectively[2]. The broad vision of these goals are to fight poverty in developing countries. To achieve these goals, the United Nations is currently assisting developing countries to focus more on sustainable projects relevant to the community. Hence, there is the pressing need to equip civil engineering students with the broader understanding of sustainability concepts if the long-term goals are to be achieved.

Many civil engineering programs now teach the three pillars of sustainable design in their curriculum to better equip civil engineering students in their decision making to consider sustainability issues. The three pillars of sustainable development are *social development, economic development* and *environmental restoration*. A major challenge to this integration is adding to the workload of the existing curriculum. In some cases, introducing the new concepts

requires the loss of essential course material. Consequently, many civil engineering departments have successfully integrated sustainable design principles through *course modules*, and *project based learning*[3]. A recent study by Litchfield and Javernick-Will compared the career interests and experiences of students and practicing engineers who participated in Engineers Without Borders (EWB) to the career interests and experiences of those who did not participate in EWB. The authors found that socially engaged engineers bring diversity, robust professional skills, and new applications for engineering – especially for improving developing communities – to their work. However, the study also highlights that if engineering work does not fulfill students' and practitioners' need for socially engaged work, these engineers leave the profession. This loss of talent was particularly significant for female engineers[4].

Although a successful implementation of sustainable concepts requires valuing all the three pillars, it has been shown that economic and the environmental dimensions are often over-emphasized while the social dimension is underemphasized[5].

The Rose-Hulman Institute of Technology (RHIT) Civil and Environmental Engineering (CE) Department opted to integrate appropriate sustainability concepts into the existing course curriculum in addition to having sustainability course taught at the sophomore level. Integrating these concepts within the curriculum provided a better appreciation of the holistic nature of sustainability in civil engineering applications. However, we found that many students still struggled to incorporate *social sustainability* in their capstone project designs. Therefore, the goal of this paper is to discuss how we created and implemented a community engagement engineering module for our Codes and Regulations course with particular emphasis on *social sustainability*, to capstone projects.

Motivation for RHIT CE Department

Sustainable design principles or a Triple Bottom Line analysis of sustainability that incorporates *social*, *environmental* and *economic* factors are finding their way into professional civil engineering practice. For our students to be successful in their professional practice regardless of the career path they choose, it is prudent that undergraduate programs teach students not only sustainable design concepts, but also how to apply these principles to civil engineering projects.

The RHIT CE Department has been working for years to weave threads of sustainable design principles throughout our curriculum. We introduce sustainable design principles in the freshman year in "Sustainable Civil Engineering" and "Freshman Design" and include them throughout design courses, culminating in the senior capstone design course.

Implementation in Required Courses in the CE Curriculum at RHIT

As previously reported[6-8], after intentional inclusion of sustainable design principles at the freshman and sophomore level, students have demonstrated the ability to understand and explain the principles. However, preliminary observations at the senior level indicate a lack of deeper learning of these concepts. Additionally, the integration of these concepts in their projects has typically been done during the technical design phase as opposed to the conceptual phase. More concerted efforts to move students beyond comprehension to higher learning levels according to

Bloom's taxonomy – application and analysis – have been underway and are currently being assessed. Furthermore, the CE Department has identified required courses in the curriculum as key areas where students are taught sustainable design concepts. The intent is to demonstrate to the students that sustainable design concepts permeate to some degree every stage of the engineering design process. Additionally, having these concepts taught in multiple courses will adequately prepare them with a deeper knowledge to deal with the sustainability challenges.

Table 1 provides a brief description on how sustainable design concepts are specifically addressed in some of the civil engineering required courses beyond the freshman level.

Table 1: **Sustainable Concepts Addressed in CE Required Courses**

Course Name	Brief Description of Course Content	Academic Level
Sustainable CE Design	Introduction to sustainable design of civil engineering systems. This course emphasizes the need for students to understand why sustainable design is important by discussing the science and the application of sustainable design.	Sophomores
Civil Engineering Materials	Student teams are required to design a traditional concrete mix to be used for a new construction. The teams must identify specific areas they can change in their mix design to make it more sustainable.	Sophomores
Construction Engineering	As one of the assignments, students are tasked to plan the construction of a facility in a remote location while minimizing the impact on the surrounding environment	Juniors
Structural Mechanics	Through assignments, students identify potential societal impacts of a project. Throughout the quarter, classroom lectures highlight the breadth of impacts from all three pillars (both positive and negative impacts are addressed).	Juniors
Water Resources Engineering	As part of a course-long project, students must use both traditional and low-impact design approaches to manage stormwater runoff for a development, and compare the approaches technically and in terms of all three pillars.	Juniors
Engineering Economy	The course presents tools for quantifying economic benefits and costs of a project so that prudent choices can be made.	Seniors

Implementation in Senior Capstone Design Course

The CE Department undertakes a yearlong senior capstone design project. The expectations in the fall quarter is familiarization with the project, client and proposal preparation. Additionally in the fall quarter, each student team is required to develop three preliminary design solutions; each of three solutions must be focused on one of the three pillars of sustainable design: *Social Focused*, *Environmental Focused* and *Economic Focused.* The teams are then required to list the characteristics of each of the design options. Although this approach may seem unrealistic to the practicing engineer, the intent of this exercise was to encourage the teams to thoughtfully identity ways to incorporate the three pillars in their project. To complete this exercise, the teams then make a final recommendation of their design option, which is a blend of the three options initially developed. After completing these key aspects of their project in the fall, the students proceed into the winter quarter to begin work on their technical designs.

Community Engagement Module in Codes and Regulations Course

Specifically to strengthen students' abilities to apply sustainable design principles of the social domain, the Civil Engineering Codes and Regulations course, a co-requisite to Senior Capstone Design, was identified as an appropriate course where we could implement a Community Engagement module. The Codes and Regulations course has historically complemented our Senior Capstone Design course, and while it has morphed over the years, it has remained a place where topics not covered elsewhere that are important to civil engineers – especially for students embarking on an open-ended capstone project – could be taught. Additionally, the Codes and Regulation course is taught in the fall quarter, hence the students team are able to incorporate all the key aspects of sustainable design concepts early on in the design process.

We developed a module to teach the importance of considering social sustainability at the *outset* of design for successful projects. The test run of our Community Engagement module occurred in the fall term of 2016 as the initial course module. Our intent was to jumpstart students' consideration of sustainable design principles – especially social impacts – as students met with their project clients, began their desk studies, and in general learned about their capstone projects. Our intent was to give students examples and tools they could use to consider and assess social impacts of their projects. Additionally, we had guest speakers with a wealth of experience on humanitarian projects share project experiences with the teams. The intent was to emphasize to the students that incorporating social sustainability in a project requires concerted efforts between the project team and key stakeholders.

Our case study-based module focused on active learning and application to students' capstone projects. Our approach intended to remove students from their prior experiences to allow them the freedom and space to develop their ability to assess project success (here, defined as sustainability) of international humanitarian engineering projects. Through reading questions, in-class analysis and discussion, and finally application to their own capstone projects, students had opportunities to explore two published international case studies and prior capstone projects at RHIT, as detailed in Table 2. Students determined stakeholders and examined motivations, obstacles, outcomes and potential improvements for all of these case studies. After much discussion, students analyzed the economic, environmental, social/cultural, and technical

sustainability of the case study projects. We intentionally chose international cases for students to evaluate, to take them out of their comfortable frame of reference or experience so that they could analyze and draw conclusions about the cases as an outsider. Finally, to close the loop, students' analyzed how they might consider using sustainable design principles, with special attention to optimizing the social impacts of their own senior design projects by answering questions similar to those used previously for the various case studies. Specifically, students identified how they might engage stakeholders of their projects to maximize positive social impacts and minimize negative ones, as well as assess their efforts by developing measurable indicators. To ensure all students were engaged and contributed this last application exercise was performed in two parts: individually and in senior design teams.

Table 2. Case study and classroom activity components of the Community Engagement module.

Type of Case Study	Name of Case Study	Activities
External Humanitarian Engineering Project	*The Stranger's Eyes*[9] *Sika Dhari's Windmill*[9]	Reading and analysis questions, Discussion, Application to senior capstone design projects.
RHIT Senior Design Project	*Imagine.Nation Zimbabwe*[10]	Discussion, Application to senior capstone design projects.

Assessment Methods

For a single cohort of students, the CE class of 2017, we assessed in several ways to what degree students learned and were able to apply social sustainability concepts as a result of the Community Engagement module.

Surveys

First, students' understanding of and their perception of the importance of social sustainability was assessed using pre- and post-course surveys. Table 3 contains the survey questions. From these questions we were primarily able to determine (1) students' abilities to articulate examples of social sustainability as compared to economic and environmental, (2) students' determination of importance of social sustainability as compared to economic and environmental, and (3) when students think it is most useful to consider societal impacts of a project.

Table 3. Pre- and post-course survey questions asked of Codes and Regulations students.

1	Sustainable design principles can be categorized in three pillars: environmental, economic, and social. *List four examples related to each of the three pillars.*
2	As a design engineer, *rank the examples* you have identified in question 1 in order of importance to you: *1 (most important) - 12 (least important)*
3	I think approximately (circle one) *0, 20, 40, 60, 80, 100* % of design effort should go to evaluating the appropriateness of a project (i.e. background research, community assessment, and follow-up) versus only the technological aspect of the project.
4	I think it is most important to incorporate the three pillars of sustainable design concepts at the (circle one) *preliminary stage, during the design, after the design is completed, or during construction.*
5	I can give several examples of ways well-intentioned engineering can do more harm than good: *1 (strongly disagree) - 5 (strongly agree)*
6	In considering appropriateness of projects, I am able to recognize and consider community characteristics that should influence the design of a project: *1 (strongly disagree) - 5 (strongly agree)*
7	If I find a project to be inappropriate after evaluating it against a community's needs, resources and environment I am able to determine what alternatives might be more appropriate: *1 (strongly disagree) - 5 (strongly agree)*

Direct Assessment

Additionally, to assess students' abilities to apply social sustainable design principles to their senior capstone design projects right from the outset, members of the CE Board of Advisors (BOA) rated the students' senior capstone design desk studies according to a rubric we developed (Table 4). Five BOA members agreed to participate in our project to rate senior capstone design desk studies, but only two BOA members were able to complete the rating. However, the two BOA members who did participate have many years of practical consulting and international engineering experiences that made them highly qualified raters. These BOA members rated desk studies from the current plus the previous five years according to our rubric to allow us to observe improvement in students' consideration and most importantly, application, of societal impacts in their initial capstone designs.

We acknowledge that the raters did know the year of the artifacts, as that was how they were grouped in the folders dispersed for the raters. Thus, it is possible that the raters could have bias towards improvement with time. Next time, we would conduct the survey differently by keeping the year hidden, as well as calibrating the two raters by using an intra-rater reliability check every 10 artifacts.

Table 4. Rubric for rating Senior Design Desk Study artifacts in terms of to what degree student teams address the societal impacts of their projects.

Student teams…	
describe **HOW** and **WHY** they will address the societal impacts of their project. Discussion describes specific measures of how these impacts will be achieved.	6
describe **HOW** they will address the societal impacts of their project. Discussion describes specific measures of how these impacts will be achieved.	5
give an example or two of the societal impacts of their project, but they do not justify or elaborate further.	4
give an example or two of the societal impacts of their project that may not be completely reasonable or thought through.	3
mention societal impacts of their project as a separate item to consider in design, but they do not provide examples or any further detail.	2
mention societal impacts of their project, perhaps only in passing or in a sentence with all three pillars of sustainability.	1
do not discuss societal impacts of their project.	0

Reflection

Finally, we reviewed students' reflections of how the Community Engagement module impacted their understanding of and ability to incorporate preliminary social sustainability principles in their senior design projects. At the end of the term the students were asked to reflect on how the Community Engagement module informed their preliminary capstone project work:

- Give some examples of how the Community Engagement module informed your desk study.
- Give some examples of how the Community Engagement module informed your conceptual design approach.
- What did you like / what was helpful about the Community Engagement module?
- How could we make the Community Engagement more helpful for senior design?

Results and Discussion

The findings from all assessment methods are summarized and interpreted in the following sections, along with our reflections on our Community Engagement module implementation and its outcomes.

Pre- and Post-Course Survey

The first outcome of our survey was intended to reveal how well students could describe examples of social sustainability. Based on students' prior exposure to sustainable design concepts in CE courses, we expected that students could more easily invent examples related to environmental sustainability than social sustainability. In the pre-survey findings, "aesthetics", "visual appeal" or similar simple, visual-based descriptors were common as social sustainability

examples. Post-course, students were able to better articulate examples, resulting in an overall 38% reduction in these simple "aesthetics" type listings (Table 5). Additionally, we found a 56% reduction in an "aesthetics" type listings for the first example. In place of the simple visual-based descriptors, students provided a wide variety of examples of the societal impacts of projects. These results indicate that through the study of cases, students became more aware of the societal impacts of projects and, conversely, how culture might inform project design. Furthermore, students acquired the language and ability to articulate their ideas to describe societal impacts of projects. Finally, given that the post-course surveys were administered at the end of the quarter and the Community Engagement module assignments were completed by week three, students appeared to retain the key concepts at least for the short to medium term.

Table 5. Frequency of students listing "aesthetics" or a similar visual-based example for a social sustainability example (survey question 1, Table 3).

Rank of Student-generated Social Sustainability Examples	Pre-Survey		Post-Survey	
	N	*Count*	*N*	*Count*
1	36	**16**	36	**7**
2	36	5	36	4
3	36	2	36	3
4	36	1	36	1
Total		**24**		**15**

Subsequently, we were able to determine to what degree students believed the importance of social sustainability compared to economic and environmental sustainability in successful projects. After students generated their 12 sustainable design examples, they ranked them in terms of importance. Table 6 reports the pillars associated with the students' first and second ranked topics. No major differences were observed in terms of which pillars were represented in the students' first choices, and all three pillars were fairly evenly prioritized both prior to and after the course. However, for second choices, we observed more students prioritizing social sustainability post-course as a result of deprioritizing environmental sustainability. This movement in priority indicated that our emphasis on social sustainability impacted how students discriminated between competing constraints. Knowing that students could better articulate societal impacts in the examples they developed post-course, they may have been able to thus choose those examples as critical aspects of design. An increase in prioritizing economic sustainability was also observed post-course.

Table 6. Results for survey question #2 (Table 3).

Question: Rank, in order of importance, the 12 sustainable design examples you generated (four for each pillar of sustainability: economic, environmental and social).								
	#1 Ranked Topic				**#2 Ranked Topic**			
	Pre-Survey		Post-Survey		Pre-Survey		Post-Survey	
	N	*%*	*N*	*%*	*N*	*%*	*N*	*%*
Economic	9	29.0	9	29.0	8	25.8	11	35.5
Environmental	12	38.7	10	32.3	22	**71.0**	13	**41.9**
Social	10	32.3	12	38.7	1	**3.2**	7	**22.6**

The second outcome of our survey was intended to reveal how much time should be devoted to, and the timing of, social sustainability consideration. Table 7 describes students' perception of the appropriate amount of time necessary for evaluating social sustainability. Post-course, the student paradigm shifted from believing that less emphasis should be put towards evaluating the appropriateness of design solutions to greater emphasis. In other words, students shifted toward recognizing that a community should be involved from the beginning of a project to incorporate their input and ensure a successful project. Results in Table 8 describe that students realized the importance of considering sustainable design concepts as early as possible in the design process. Prior to the course, students could recognize the importance of considering sustainable design principles during the preliminary or design stages, however, as a result of the course, 84% of students indicated that these principles needed to be considered as early as possible, an increase from 52%. This increase was found to be significant based on the z-score.

Table 7. Results from survey question #3 (Table 3).

Question: I think approximately ___% of design effort should be put towards evaluating the appropriateness of a project (i.e., background research, community assessment, and follow-up) versus only the technological aspect of the project.				
	Pre-Survey		Post-Survey	
	N	*%*	*N*	*%*
0%	0	0.0	0	0.0
20%	8	**25.8**	5	**16.1**
40%	14	45.2	14	45.2
60%	7	22.6	8	25.8
80%	0	**0.0**	3	**9.7**
100%	2	6.5	1	3.2

Table 8. Results from survey question #4 (Table 3).

Question: I think it is most important to incorporate the three pillars of sustainable design concepts __.				
	Pre-Survey		Post-Survey	
	N	*%*	*N*	*%*
During the Preliminary Stage	16	**51.6**	26	**83.9**
During the Design	13	**41.9**	5	**16.1**
After the Design is Completed	0	0.0	0	0.0
During Construction	2	6.5	0	0.0

NOTE: Examining differences in proportions between those who selected "during the preliminary stage" on the pre-survey and post-survey, the z-score was 2.72, $p<0.01$.

The third outcome of our survey was intended to reveal the importance of being able to identify design alternatives to apply stakeholder input, and how design components could affect stakeholders. The results summarized in Tables 9-11 demonstrate that as a result of our course, students were better able to provide examples of how well-intentioned engineering projects could

do more harm than good (Table 9), examples of how community characteristics could influence the design of a project (Table 10) and what design alternatives might remedy an inappropriate design (Table 10). These results show a significant shift from students split between not being sure and just being sure (students selected "neither agree nor disagree" or "agree" with the statements) to students feeling confident that they could do these items (students selected "agree" or "strongly agree" with the statements). This significant change in student perception were based on a paired samples t-test. In short, students became enlightened towards, and better able to describe, how they would consider and implement social sustainability.

Table 9. Results from survey question #5 (Table 3).

Question: I can give several examples of ways well-intentioned engineering can do more harm than good.				
	Pre-Survey		Post-Survey	
	N	*%*	*N*	*%*
Strongly Disagree	0	0.0	0	0.0
Disagree	3	**9.7**	0	**0.0**
Neither Agree nor Disagree	14	**45.2**	5	**16.1**
Agree	14	**45.2**	20	**64.5**
Strongly Agree	0	**0.0**	6	**19.4**

NOTE: A paired samples t-test showed a significant difference ($p<0.001$) between the pre-survey (M=3.35, SD=0.66) and the post-survey (M=4.03, SD=0.60).

Table 10. Results from survey question #6 (Table 3).

Question: In considering appropriateness of projects, I am able to recognize and consider community characteristics that should influence the design of a project.				
	Pre-Survey		Post-Survey	
	N	*%*	*N*	*%*
Strongly Disagree	0	0.0	0	0.0
Disagree	2	**6.5**	0	**0.0**
Neither Agree nor Disagree	9	**29.0**	4	**12.9**
Agree	18	**58.1**	24	**77.4**
Strongly Agree	2	**6.5**	3	**9.7**

NOTE: A paired samples t-test showed a significant difference ($p<0.05$) between the pre-survey (M=3.65, SD=0.71) and the post-survey (M=3.97, SD=0.48).

Table 11. Results from survey question #7 (Table 3).

Question: If I find a project to be inappropriate after evaluating it against a community's needs, resources and environment I am able to determine what alternatives might be more appropriate.				
	Pre-Survey		Post-Survey	
	N	*%*	*N*	*%*
Strongly Disagree	0	0.0	0	0.0
Disagree	3	**9.7**	0	**0.0**
Neither Agree nor Disagree	9	**29.0**	4	**12.9**
Agree	18	**58.1**	25	**80.6**
Strongly Agree	1	**3.2**	2	**6.5**

NOTE: A paired samples t-test showed a significant difference ($p<0.05$) between the pre-survey ($M=3.55$, $SD=0.72$) and the post-survey ($M=3.94$, $SD=0.44$).

Direct Assessment of Senior Capstone Design Desk Studies

Two civil engineering practitioners on our board of advisors rated senior capstone design desk study submissions from 2012 to 2016. Using a common rubric (Table 4), the raters evaluated artifacts from the past five years in terms of how well the student teams' considered societal impacts. Our rubric was intentionally broad for it to apply to a variety of different projects over five years, however this resulted in differing calibration between the two raters. However, comparing the ratings of each individual rater over the past five years, much progress has been made in addressing societal impacts. Table 12 summarizes the practitioners' average ratings.

Table 12. Practitioners' average ratings of senior design desk studies in terms of how well societal impacts were incorporated.

Year	*N*	Rater 1 Avg	Rater 2 Avg
2012	9	0.1	1.9
2013	8	0.6	3.8
2014	8	2.9	5.3
2015	8	3.4	5.9
2016	9	3.1	6.0

Figure 1 illustrates the trend in the averages and the spread in the ratings by each rater over the five years of artifacts. It is important to note that while the mean increased nearly every year for both raters, there was at least one artifact that received a score of zero through year 2014. In general, as we improved instruction and expectations over the years in both Senior Capstone Design and Codes and Regulations, the spread of responses decreased. However, it is important to realize that even in 2016 with our intervention, one report received a score of one, as rated by Rater 1; based on our rubric (Table 4) this team did not mention societal impacts of their project, and only mentioned the concept of social sustainability in passing or in a sentence with all three pillars of sustainability. Moreover, based on Rater 1, we still have work to do, as in 2016 only one team received a score of five; most artifacts received a score of three by providing an

example of the societal impacts of their project that may not be completely reasonable or thought through.

Particularly large increases in the ratings are observed between the years 2013 to 2014. In year 2014, students were explicitly asked to prepare an "Economic, Environmental and Social Considerations" (EESC) assignment as part of their desk study, which, while it required students to document how their design met sustainability criteria, as instructors we still felt that students were overlooking the societal impacts in a way that was meaningful for their design. We noticed that students, after already completing their project research and desk studies or even after beginning their conceptual designs, would determine how they were incorporating societal impacts instead of considering social needs and concerns up front to inform their research and conceptual project designs. However, clearly, inclusion of societal impacts in senior capstone design desk studies was severely lacking five years ago, and changes that we have implemented over the years in senior capstone design and other classes has enabled our students to be able to articulate the concepts of sustainable design, including the societal impacts.

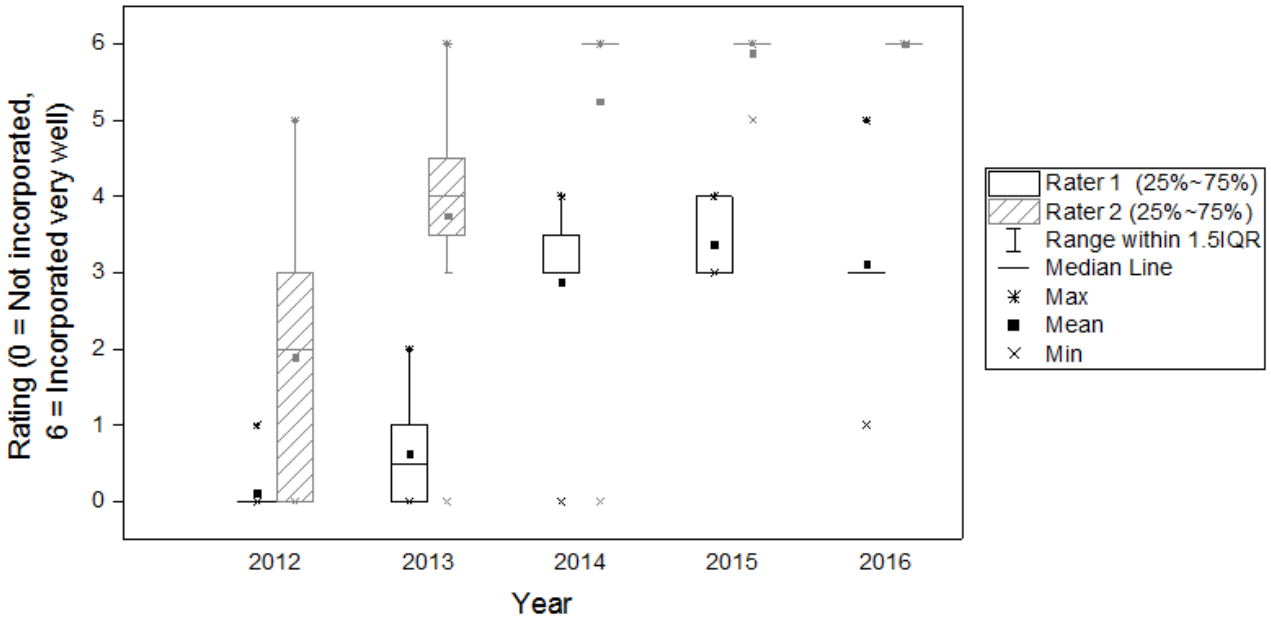

Figure 1. Practitioners' ratings of senior design desk studies in terms of how well societal impacts were incorporated. Data pertaining to Rater 1 is black, and data for Rater 2 is gray. The filled-in squares denote the mean and the median line represents the second quartile (50th percentile) within each year of rated desk studies. The top and bottom of the boxes are the first quartile (25th percentile) and third quartile (75th percentile). The whiskers represent the third quartile + 1.5*IQR (interquartile range). The spread of rating scores is shown by the asterisks (max value) and the Xs (min value).

Based on direct assessment, while we do not see evidence that our intervention in the Codes and Regulations course (corresponding to year 2016) was helpful, it was not harmful. We recognize that our intervention was small relative to students' exposure over their academic careers and, perhaps more importantly, we only assessed teams' desk studies. Our direct assessment opportunity was limited due to substantial changes in the senior capstone design course over the years; for example, we were unable to assess the final conceptual layouts because of significant

changes in design option analysis that directly impacted students' final layouts. However, reflecting on our interactions with students, students seemed more attentive to social or cultural preferences. At the very least, students had the language to express possible benefits or issues with, or alternatives to, their designs.

Student Reflections

Students reflected on what they learned in the Codes and Regulations Community Engagement module and how it translated to the beginning of their senior capstone design projects. Below are summaries of some of the more common or insightful student reflection excerpts.

Give some examples of how the Community Engagement module informed your desk study?

- From the module, I learned that for the desk study it was crucial to understand the people being served as well as the technical aspects of their surroundings; for example, my team thus investigated the culture of the potential users of the facility.
- It forced me to think about how our design would affect our community.
- We consulted with not only our client, but also the plant operators about what aspects of the plant were already good and what could be improved in the expansion.
- It made us think, before design, about the main project goals, and helped us realize how important it is to understand fully what the client is asking for.
- We sought the opinion of the users and received a survey of pilots' opinions.
- It showed me the importance of research prior to the actual design phase.
- Conceptually, we tried to meet our clients' needs more than just assuming we knew what they needed.
- During our site visit we made sure to ask the operators what their preferences were.

Give some examples of how the Community Engagement module informed your conceptual design approach?

- It helped my team figure out what social aspects to include.
- It allowed us to look at the info we had and utilize it.
- We wanted to change the wastewater treatment to an activated sludge system but the operators really wanted to keep the sequencing batch reactor system regardless of efficiencies. We will design the sequencing batch reactor.
- It helped us identify detailed questions to ask of our client about what they needed, wanted, didn't want, etc.
- I realized that we weren't just providing a design, but something that will affect people.
- It caused us to give more weight to human factors, at least initially.
- We attempted to meet the needs of all of the identified stakeholders.
- It was good to see more than just the technical side of design, which is what we typically focus on.

What did you like / what was helpful about the Community Engagement module?

- It provided examples of what not to do and evidence that even though a solution might seem like the best to the designer, it may not be for the users which is important for the success of the project.
- It was helpful to have the community engagement module at the same time we were developing design options.
- I liked that the case studies were exaggerated examples to get the point across; they were very clear.
- Without the module, I would never have thought about how beneficial it is to be supported by the community.
- The case studies provided perspective on how others approached designs and told valuable lessons for how we could perform well.
- It helped me to think beyond the current needs of the community; we considered the ability and interest of the community to maintain the campus.
- It enlightened me to the fact that people in different places view things differently and that people local to an area prefer particular things.
- The real life examples allowed me to learn from others' mistakes so we could minimize our own.
- I liked that it was interactive and was tied into our individual capstone designs so we knew exactly how these factors could influence our projects.
- I found the portion of the module that focused on client want vs. need to be most helpful.

How could we make the Community Engagement more helpful for senior design?

- Focus more on creating appropriate designs (vs. failed examples).
- Provide more examples of actual prior senior design projects where teams performed particularly well or poorly with respect to community engagement.
- Have case studies that correspond to work in the United States.
- Do more; expand the module!
- Have teams meet with professors individually outside of class time to ensure we are on the right track for how to incorporate societal impact.
- Shorter homework assignments; more case studies, but fewer required responses.
- Require that each team actually engages with the community where their project is located, in some tangible way.

Overall, students were positive about the benefits of the Community Engagement module and in fact wanted more case study examples. We were pleased that students were able to identify examples of how the module informed their approach to their research and subsequently, their designs.

Conclusions

From our student survey, as a result of our module, we found that (1) students became more aware of and able to describe the societal impacts of projects, (2) students learned that early and adequate time and attention should be given to the social aspects of engineering projects, and (3)

students could provide examples of the consequences of poor social analysis and of alternatives to remedy an inappropriate design.

From our board of advisors' rating of senior capstone design desk studies, we revealed the progress we have made towards having students articulate and address societal impacts in their desk studies over the past five years. While we do not see evidence that our intervention in the Codes and Regulations course impacted students' desk studies as evaluated based on our rubric, students' reflections described positive benefits of the module. In 2014, senior capstone design instructors asked students to prepare an EESC appendix to describe the sustainability aspects of their projects, which did help make the sustainability aspects easier to assess. This study was not meant to be an all-encompassing study of the changes to students' curricula relating to sustainability; we do acknowledge, however, that changes in courses across the CE curriculum and courses outside of CE could have impacted the results. However, students were readily able to connect and translate how the module informed their research and conceptual designs for their capstone projects, indicating tangible benefits of the module on student learning.

Future Considerations

We plan to include our Community Engagement module in future teaching of Codes and Regulations. Based on student feedback, we plan to add a series of case studies consisting of prior senior design projects to build on the one prior capstone project we included this year. Since many of our capstone projects are based in the United States (U.S.), these will provide concrete examples for the students in the initial phases of their capstone design, as well as examples that demonstrate the difficulty in characterizing, understanding, and meeting the needs of people that students' might initially think they know about just because they are located in the U.S. Similar to our approach with the international cases, students will analyze the capstone project cases to describe their successes and areas for improvement.

Beyond Codes and Regulations, we plan to collaborate with the instructors of freshman design to put more emphasis on the social impacts of the students' projects. Freshman design is a suitable space for this intervention since the freshman prepare only conceptual designs. Currently, sustainability topics focus on the sustainability of materials and construction. Even if students are unable to interact with a community, they should be able to describe how, and the need for, their plan to assess societal impacts and conceptual design elements that account for impacts, positive or negative.

As instructors for Codes and Regulations, we believe that our course is a liaison between students' previous coursework and their senior capstone design course. It is our responsibility to ensure students are connecting the various design experiences and triple bottom line analyses that they have completed over their academic careers to their senior capstone projects. We hope that by working with freshman design instructors and encouraging faculty to consider social impacts as often and as much as the environmental and economic impacts (e.g. during term-long projects) across the curriculum, our treatment in Codes and Regulations we will be a reemphasis of the application of these concepts, not an introduction. Knowing that it is easier to quantify economic and even environmental sustainability aspects of projects, we can require students to be specific in how they will consider and measure social impacts. Quantifiable metrics for societal impacts may need to be indirect, and students may need to be more creative and

conscientious in identifying them. However, students can practice developing these tools by generating sustainability metrics for the cases we analyze. The analysis of these cases will provide them the tools and confidence for creating metrics for their capstone projects even before they begin their conceptual designs.

Moving forward, we will use this year as a baseline and assess for improvement in subsequent years as we are able to make in freshman design. Overall, we hope that our students will graduate with the idea that engineers have a responsibility to wear their "sustainability hat" through all design stages. Our goal is for students to inherently perform sustainable design analyses as they implement the design process.

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