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Senior Civil Engineering Students' Views on Sustainability and Resiliency

In recent years, civil engineering education and workforce development have evolved to include a greater emphasis on sustainability and resiliency. Sustainability balances economic, ecological, and societal needs by being responsive to community impact, human health, and the environment. Resilient infrastructure lasts, retaining functional and structural capacity and supporting interconnected transportation, energy, water, and social systems after a distress event. While many undergraduate civil engineering programs address sustainability, it tends to be limited to individual courses, and resiliency concepts are rarely incorporated. To address these shortcomings, we are incorporating sustainability and resiliency conceptual threads and activities throughout our curriculum, from our first-year engineering course through senior design.

To understand the effectiveness of this initiative, at the beginning of this project we conducted interviews with senior civil engineering students to collect baseline data on our current students' views and understanding of sustainability and responsibility. Thematic analysis of these interviews suggests that there is significant variability in students' understanding of sustainability, with some students recognizing that sustainability involves tradeoffs between economic, environmental, and societal needs, while others tended to conflate sustainability with environmentalism. While students reported encountering sustainability in a portion of their undergraduate courses, they generally did not learn about how sustainability related to much of their technical coursework such as structures, soils, or transportation. Most current students have little conceptual understanding of resiliency which is not surprising given that it is not addressed in any substantial way in our current curriculum. This provides clear evidence of the need for greater exposure to both sustainability and resiliency and understanding the relationship between these practices as part of the undergraduate civil engineering curriculum.

By incorporating sustainability and resiliency throughout the undergraduate civil engineering curriculum, students will be better prepared to address these topics as part of their senior design projects, and in their future careers.

Introduction

Industry, government, and the public are increasingly expecting to see civil engineers present sustainable infrastructure and technology solutions. However, civil engineers may find themselves not adequately prepared to provide answers [1]. The American Society of Civil Engineers documented the need for horizontal thinking among civil engineers [2], which could relate to gaining a broader systems view addressing environmental, economic, and social needs for current and future generations. In addition, the Accreditation Board for Engineering Technology (ABET) requires curriculum that directly addresses sustainability through criterions 3(c) and 3(h). Criterion 3(c) states, "*an ability to design a system, components, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and* ***sustainability***" while criterion 3(h) states, "*the broad education necessary to understand the impact of engineering solutions in a global,* ***economic, environmental, and societal*** *context*" [3]. Incorporating sustainability as part of ABET requirements ensures that students are prepared for sustainability challenges; however current civil engineering curricula are not fully equipped to achieve these goals.

The concept of resilience is usually associated with extreme events during the life of a civil infrastructure. Natural and human-made hazards cause extensive damage to civil infrastructure, which may take months or even years to repair at significant inconvenience to the public[4]. Hazard events include natural and induced earthquakes, tsunamis, hurricanes and typhoons, wildfires, human made explosions, and others that result in damage to buildings, road and railway infrastructure, communication and transmission lines, and water conveyance systems [4], [5]. In addition, large numbers of human lives are lost from these events. Recent hazards have included earthquakes in Haiti, China and the U.S.; hurricanes in the U.S, India and others; and wildfires in the western U.S. These have shaken infrastructure performance, and caused major inconvenience and often-serious health and safety issues for affected populations [6]. Considering the demands and challenges that professional engineers face in integrating resilience into civil infrastructure designs in both current and future practice, we believe it essential to incorporate resilience content into the CE curriculum, with the goal of preparing future engineers to create resilient designs and manage infrastructure assets in the face of limited resources.

In most current undergraduate civil engineering (CE) curriculum, the standard approach is to either provide a thin coverage of sustainability aspects or add a course to the curriculum with sustainability as a main focus. Resiliency concepts are rarely incorporated explicitly in to the curriculum. There are several reasons for this. First, rigorous professional credentialing already results in curriculum crowded with content and requirements. Second, typical CE curriculum includes five sub-disciplines, so seamlessly marrying S&R contents across open-ended design problems in geotechnical engineering, structural engineering, transportation engineering, water resources engineering, and environmental engineering presents challenges. Hence, the curriculum must incorporate these topics as part of existing courses, and in an innovative manner, while still satisfying traditional curriculum needs. To address these shortcomings, we are incorporating sustainability and resiliency (S&R) conceptual threads and activities throughout our curriculum, from our first-year engineering course through senior design. In order to effectively measure the effectiveness of this initiative, at the beginning of this project we conducted interviews with senior civil engineering students to collect baseline data on our current students' views and understanding of sustainability and responsibility. This paper presents the results from these interviews.

Background

Academics first introduced the sustainability lens as a technical topic in upper level courses. Schools such as Carnegie Mellon University, Syracuse University, and Arizona State University have successfully implemented sustainability concepts into CE freshman and sophomore courses, as well as a general engineering freshman course. Schools like The University of Texas at Arlington have developed multidisciplinary senior design projects with a sustainability focus. Aurandt and Butler [7] successfully introduced sustainability concepts into core engineering courses while maintaining the original course objectives, but noted a general absence of educational materials and learning tools available to integrate sustainability into the core courses. Allen et al. [8] conducted a survey that demonstrated that universities were then offering a total of 64 sustainability-focused courses in civil, architectural, and/or environmental engineering. However, most of the courses were upper-level electives. Bielefeldt [9] proposed an alternative approach in incorporating sustainability early on in the curriculum and reported that

sustainability awareness was present in subsequent assignments even when instructors did not specifically prompt students to include sustainability. Robinson and Price [10] noted that even though faculty members introduce CE students to sustainability concepts in freshmen and senior design classes, students were unable to demonstrate sustainable design principles. In order to counter this, they adopted a structured strategy where they introduced a freshmen design course "introduction to sustainable design principles" in year one, followed by a sophomore-level course in "sustainable civil engineering design." In the future, they also intend to add discipline-specific sustainability concepts to junior-level courses and to evaluate student performance in senior design projects. While this approach is similar to what we are proposing in term of focusing in each year of the civil engineering program, we believe that many institutions will not look favorably upon adding new courses to existing curriculum.

Faculty at several institutions are leveraging stand-alone educational materials such as those available through the Center for Sustainable Engineering's website [11], Sustainable Engineering Education Key Resources Repository [12] and other such sources. They have implemented these materials into their curricula in various courses for freshmen, sophomores, and seniors [13]–[15]. However, as described in Table 1, these existing approaches present several problems.

Table 1: Problems with infusing sustainability and resiliency into the CE curriculum

PROBLEM	DESCRIPTION
Junior-year Gap	Most civil engineering programs implement sustainability concepts in freshmen, sophomore and senior years, which clearly indicates a junior year gap. Students gain sub-discipline specific knowledge during the junior year. It would be prudent to show students how S&R applies in each of these sub-disciplines.
Weak Transitions	Designers created a number of modules with specific courses in mind, but with no apparent focus on the transition from one course to the next; this lack of flow makes it harder for students to maintain a focus on S&R as they progress in their education.
Insufficient Sub-discipline Coverage	The majority of these learning modules focus on one or two CE sub-disciplines (environmental and transportation); there is clear lack of modules in sub-disciplines such as geotechnical engineering.
Thin Resiliency Content	The majority of these modules focus on sustainability, with little to none on resiliency.
Conventional Instructional Design	Many of the learning modules use conventional instructional design. While it may be effective to use traditional approaches in some courses, active learning strategies could be more effective in others.

Project Overview

To address the shortcomings described in the previous section, this project aims to transform undergraduate Civil Engineering (CE) education by instilling Sustainability and Resiliency (S&R) concepts across the curriculum at Boise State University. CE education and workforce development requirements have evolved in recent years to include a greater emphasis on these concepts, with industry, government, the public, and professional associations and accreditation organizations increasingly demanding these skills. In brief, SUSTAINABLE infrastructure balances economic, ecological, and societal needs by being responsive to community impact, human health, and the environment. RESILIENT infrastructure lasts, retaining functional and structural capacity and supporting interconnected transportation, energy, water, and social systems after a distress event. While some universities are addressing these issues, existing

solutions tend to apply only to individual courses, leverage conventional instructional design approaches, and fail to address the flow connecting these critical concepts across courses. Further, resiliency is generally not addressed, little emphasis on either concept is incorporated into junior year courses, and some CE sub-disciplines require greater attention. To address these shortcomings, the project team is redesigning the syllabi for 12 selected courses that build from freshman to senior years. We will evaluate existing material, integrate content, and design new learning modules that use active learning-based instructional strategies, and are based on evidence-based practices. The primary products of this project will be the active learning modules (ALMs) and design tasks that will facilitate the incorporation of sustainability and resiliency topics across a range of civil engineering courses to develop students' knowledge and understanding of these topics and be better prepared to develop sustainable and resilient designs as practicing engineers.

Methods

As part of the baseline data collection for this project, we interviewed students enrolled in the civil engineering senior design capstone course in the Spring and Fall 2017 semesters. We emailed students enrolled in the courses inviting them to participate in an interview related to their knowledge of sustainability and resiliency. Three students each semester volunteered to be interviewed. Participants received a $20 gift card in appreciation of their time.

To guide the interviews, we developed a semi-structured interview protocol. The interviews began with asking about students' experiences learning about sustainability and resiliency in their civil engineering courses, and describing their understanding of sustainability and resiliency. The second part of the interviews focused on how their undergraduate education shaped their views on sustainability and resiliency, and the interviews concluded with an exploration of the participants' perceptions of how sustainability and resiliency relate to the work of practicing civil engineers, and how they plan to use what they know about sustainability as a civil engineer. The interviews lasted between 15 and 50 minutes length, depending on the depth of students' experiences with sustainability and resiliency, and their willingness and ability to talk about those experiences. All interviews were recorded and transcribed verbatim.

We analyzed the interviews inductively using sensitizing concepts [16] derived from the previously presented literature on sustainability and resiliency. The interviews were open-coded to capture the different ways that the participants understood and encountered sustainability and resiliency concepts, followed by axial-coding to group similarly coded material together both within and across the transcripts included in the dataset to identify the themes presented in the following results section.

Results

Analyzing the interviews yielded four themes related to sustainability and resiliency. First, the participants varied widely in their understanding of sustainability and resiliency. For Participant 1, sustainability is "just a way to make sure your construction practices are compatible with the environment." When asked to elaborate more, he said:

> Like, if you look forward to the next generations make sure that, uh, the environment, like trees for example, water resources, natural resources, make sure that they are being, um… Not saved for the next generations, but just… How… Just make sure that the next generations are going to be able to have the same resources that you have natural resources.

Almost all of the participants recognized the connection between sustainability and protecting the environment. In mentioning next generations, Participant 1 recognizing the role of time and planning for the future in sustainability, which was echoed by Participants 2 and 3:

> Participant 2: I believe sustainability is just making sure when we're designing for now or doing something right now we have to think about how it's going to affect the future, can our children's children be able to live in and even survive what we did today and think about the future consequences or benefits of our project that we're doing now.

> Participant 3: I would say, sustainability is something that doesn't take away from itself but it… is something that lasts, and is something that contributes to itself to keep it going forward.

Participant 4 described the intersection of time and environment, and felt sustainable design was design that lasted a long time in order to minimize environmental disturbances.

> I've had a couple internships and I've seen what goes into doing some of these larger projects and the importance of creating a design that's going to last a long time without having to go in and re-disturb the environment is the important thing there. Every time you bring equipment in, every time you disturb wildlife it starts it over, it's never a good thing

Participant 5 also equated sustainability with design that lasts and long-term planning, but also felt that minimizing resource use and figuring out ways to reuse materials or infrastructure are important to sustainable design.

> Sustainability is creating and designing options that…best reuse facilities that make it so the design life or the effects of the infrastructure that we're implementing are little to none and they actually focus on providing options that help the world be designed for, I guess an infinite amount of time…using resources as little as possible and making sure that when you design something you really do look down the road and see how is this going to help diminish the use of resources in the long run

Participant 4 recognized that sustainability involves tradeoffs between environmental considerations, longevity, and the cost of a project.

> Sustainability, within the context of Civil Engineering is the development of designs and practices that minimize environmental impact and also provide the longest-term solution to a problem. It's kind of a balancing game between that and basically the cost of the project.

Participant 5 also described sustainability as a tradeoff involving cost, and the importance of advocating for sustainable practices when working with clients who may be fixated on the bottom line:

> A client might be wanting to look for a design that is the cheapest, looking for options on ways that they can cut down and make money on a situation and at the same sense those aren't mutually exclusive, being able to cut down and not be spending as much money, it's not completely different than being sustainable, a lot of times those can be the same thing but in those situations where you really do have to push and be an advocate for sustainability

A second theme that emerged from our analysis was the participants general lack of ability to articulate a relationship between sustainability and resiliency. Participant 4 initially struggled with defining resiliency, or drawing a distinction between sustainability and resiliency:

> Resiliency, I guess what I would say it is probably, it seems the same as sustainability to me. I'm guessing there was a difference that wasn't defined for me there at some point throughout my curriculum.

When pressed on the distinction between resiliency and sustainability, he replied:

> I think without resiliency you can't have sustainability. Because you're always going to have, particularly now you're going to have more extreme situations that are going to occur. If you just want to take an example of weather, it seems like we have more storms that are more sudden, come more frequently or the river's really high or things like that. Without the ability of a design to be resilient to those adverse conditions the design won't really sustain that well

This again demonstrates his conception of sustainability as primarily being about creating designs that have a long lifespan, and resiliency as the ability of a design to withstand adverse events in order to ensure longevity. Participant 3 described a similar situation, where he said the key difference between sustainability and resiliency had to do with resistance to failure over different periods of time.

> Resiliency is like, I picture it as something that's able to withstand, like, I picture sustainability as like, a time frame, and then resiliency is like, in the moment, what it's able to withstand in that moment.

Participant 2 was the only person we interviewed who was able to describe a clear tradeoff between sustainability and resiliency. He sees resiliency as the ability of a design to resist damage and degradation over time, but also recognizes that making something last can involve building practices that are worse for the environment.

> Some businesses do not have the right initiative, I guess would be the best way to say that, to make sure they're taking care of the environment instead of just making sure, hey

> this is the cheapest way and strongest way to make sure that this building lasts for 70 years. That's good. That'll be resilient to everything but not necessarily great to the environment so I feel like they could go with each other sometimes, because some of your sustainability is you're going to make sure that this lasts this long for everybody to use and make it easy for them to be able to repair it but then on the other hand, sometimes to make it resilient you're going to have to use some chemicals and make it environmentally detrimental.

A third theme that emerged was the variety in participants describing where they learned or encountered sustainability and resiliency concepts. Some students attributed their knowledge of sustainability and resiliency entirely to their senior design project. This exposure came through either working on projects that focused explicitly on environmental issues such as wastewater treatment or mine reclamation, or being responsible for the environmental portion of their team's design project. Given the relationship between sustainability and the environment described by several of the participants, they reported their environmental engineering class as another major source of their knowledge about sustainability. Several participants mentioned Case Studies, a 200-level course, as another source of sustainability knowledge. However, they described this course as mostly providing examples of failed projects that were not sustainable, as opposed to evidence of good sustainable design practices. Finally, Participant 4 was the only student who reported consistently encountering sustainability in his upper-level design courses, such as Asphalt Design and Transportation systems design. However, he also felt that these courses had relatively little effect on his views of sustainability:

> For me I just, I've grown up my whole life thinking we should conserve what we have, particularly, natural resources is a good example…. I wouldn't attribute that to my courses. I think they kind of taught me how to make designs more sustainable but didn't really change why I think they should be sustainable.

The relationship between sustainability and resiliency and the work of practicing engineers was the final theme that emerged from our analysis. For most participants, this echoed previous statements equating sustainability and longevity, seeing sustainability in professional practice as the need for creating designs that last:

> Participant 3: I guess to incorporate sustainability and resiliency into my future career I would, you know, be designing things to last. Uhm, not designing to just fix the problem, but also designing it to fix the problem and, you know, keep fixing the problem 10 years down the road.

For Participant 2, the inclusion of sustainability in the civil engineering code of ethics provided evidence of the importance of sustainability to the work of practicing engineers. He said:

> It's in there, it's in the code of ethics. You're supposed to think about your sustainability and as long as we practice those fundamental cannons, that's what you're supposed to look into all the time and make sure that you're in the interests of the people now, interests of your business and interests of the people of the future, that's what you're supposed to do.

Conclusions

Despite sustainability being recognized as an important topic in civil engineering, a sample of senior civil engineering students showed that students varying significantly in their understanding of sustainability and the importance of sustainable design practices. Students often equated sustainability with environmentalism or a general sense of needing to protect the environment for the future by developing designs that are engineered for longevity. While some students recognized the economic tradeoffs inherent in doing sustainable civil engineering design, none of the respondents were able to articulate a clear, coherent understanding of sustainability as involving tradeoffs between economic, environmental, and social factors. Most of the participants demonstrated a similar lack of understanding of resiliency, with most participants either unable to define resiliency or simply seeing resiliency as the ability of a design to resist damage, without considering other aspects of resiliency such as the ability of a design to recover from an adverse event and how to mobilize resources to reduce recovery time. The participants also did not describe consistently encountering sustainability and resiliency throughout their undergraduate civil engineering curriculum, and several participants attributed their knowledge of sustainability to individual experiences such as internships or specific roles on their senior design projects.

This lack of consistent understanding of sustainability and very limited understanding of resiliency and the relationship between these two topics provides strong evidence of the need for incorporating sustainability and resiliency throughout the undergraduate civil engineering curriculum. We are addressing this need through the creation of Active Learning Modules designed to infuse sustainability and resiliency across 12 required and elective civil engineering courses. This will lead to students who better understand sustainability, resiliency, and their relationship to each other, and are better equipped to incorporate sustainable and resilient design practices in their civil engineering careers.

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