AC 2012-3715: RENEWABLE AND EFFICIENT? MECHANICAL ENGINEERING STUDENTS' CONCEPTIONS OF SUSTAINABILITY AND ENGINEERING

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Abstract

The importance of sustainability to engineering work cannot be denied. Consider, for example, that in the 2011 State of the Union address, President Obama pledged that 80% of the energy used in the United States will come from clean energy sources by 2035.[1] Perhaps unprecedented, we face enormous problems like global climate change, poverty, overpopulation, diminishing resources, and pollution, to name a few. The dominant view of engineers' role in this current state of affairs is that of problem solver, or rescuer, such that engineers need only "design their way out" of any problems we face as a global society. Rather than a reactionary focus, engineers must be proactive and contemplative and emphasize sustainability as a top design constraint to be considered thoughtfully in terms of people, nature, and future generations. A focus on sustainability must be as heavily weighted as cost, aesthetics, ease of use, etc. But, if we are to get there, we must first change the culture of engineering education.

Currently, engineering education treats sustainability as one of many design constraints that likely receives consideration in a classroom module, typically in a capstone design class. One lesson is hardly enough to instill in students the importance of sustainability and sustainable design considerations. While some colleges of engineering have taken on grand educational initiatives to educate students about sustainability and the importance of sustainable design,[2-3] we still have an uphill climb to truly transform engineering education to be more focused on sustainable, systems-oriented design, and problem solving.

One first step to transforming the culture is to learn how students view sustainability and its relationship to engineering. This is especially important since notions of sustainability and sustainable engineering are wide and varied.[4] In this paper, we present Mechanical Engineering students' conceptions of sustainability and how sustainability relates to engineering. Mechanical Engineering, in particular, is a discipline representing great potential in terms of advancing sustainable solutions to our global environmental problems. Yet, the majority of design projects rely on fossil fuels and old technologies that will continue to add CO_2 to the atmosphere. Thus, Mechanical Engineering offers a space for increased attention to sustainability.

We surveyed sophomore Mechanical Engineering students in an energy systems design class to gauge their views on sustainability and its importance to engineering. This represents the preliminary phase of a multi-year project on organizational change in the Mechanical Engineering Department. Results from this study will help us develop a targeted, integrated curriculum designed to teach students the importance of sustainability to engineering from a systems-oriented perspective.

Background

To foster a culture of sustainability within engineering, Vanasupa et al. call for the development of sustainable thinking including an ethic of social responsibility, a vision for a sustainable future, a systems perspective, and resource consciousness.[5] They argue that specific pedagogical techniques such as service learning, promoting global awareness, providing perspective on design constraints, and using tools to evaluate and assess a design's impact, will promote sustainable thinking.[5] At a basic level, the development of an attitude of social responsibility is necessary for engineering students to problem solve in ways that consider the social and environmental impact of their decisions and designs. Unfortunately, as Rugarcia et al. point out, engineers often fail to account for the social, ethical, or moral consequences of their work.[6]

Hoffman, et al. conducted an analysis of published sustainability principles and a summary of the sustainability principles being taught in engineering courses with the goal of understanding what counts as sustainability knowledge.[7] They found that the published sustainability principles encompassed six themes: traditional environmental engineering goals, specific items to protect or improve, ethics and guiding beliefs, social and societal aspects, engineering design criteria, business perspectives, and values. On a more micro scale, three common notions of sustainability were present in each principle: (1) safety, toxicity, and health, (2) eliminate or minimize/manage waste, and (3) resource conservation. The second part of their analysis looked at the congruency of the published principles with what is being taught in universities. An analysis of published course descriptions showed that most courses with "sustainable" in the title or description emphasized traditional technical engineering or environmental engineering including topics like energy and economic sustainability. Of note, descriptions of societal impacts typically invoked the "triple bottom line" of society, environment, and economics.

Broad competence in sustainability is imperative to foster the interdisciplinary collaboration necessary to innovate and solve global problems. However, Allen at al., report that the focus of sustainability education in engineering focuses on immediate environmental and social impacts of designs at the expense of a long-term systems and process view of sustainability.[8] One way to advance sustainability knowledge is to acknowledge the "human dimension" inherent in all choices engineers make.[9-10] In other words, it seems that the economic and environmental aspects of sustainability are prioritized in education, while the social aspects go largely unexplored. Societal aspects of sustainability are related to quality of life and include health, education, housing, equity, security, and population.

One way for engineering students to begin to appreciate the complexity of problems and the ramifications and consequences of their work is for faculty to encourage systems thinking. Systems thinking is characterized by thinking holistically, including knowledge and idea integration across a range of disciplinary perspectives.[11-13] For example, holistic thinkers consider the interactions of a system with the environment, including physical, economic, and social interactions. In addition to viewing problems broadly and holistically, features of systems thinking include a consideration for interdependence, feedback, and synthesis and analysis of various components.[11-13] Promoting systems thinking throughout the design process will facilitate development of an ethic of social responsibility in that students will need to think about the social, moral, and ethical consequences of their work in addition to the economic and environmental consequences, to ultimately enhance a sustainability focus.

Methods

Our interest in this project was to explore mechanical engineering students' conceptions of sustainability and their perceptions of how sustainability relates to engineering. Data for this project were gathered as part of an on-going collaboration between the College of Humanities and the College of Engineering that characterizes the spiral learning approach associated with the freshman and sophomore curriculum. Students complete four semesters of engineering design where they learn engineering, modeling, statistical analysis, design methodology, and communication skills. At the end of each semester course evaluations are distributed in each course to elicit information about the effectiveness of instruction. Course evaluations from the sophomore class on energy systems design comprised the data set. We tailored questions so they related to sustainability. Specifically, we asked: (1) How do you define sustainability? (2) How does sustainability relate to engineering?

In all, sixty-three students completed the evaluation and responded to these questions. Their responses were compiled in a list that became the data set for analysis. The first author inductively coded the responses to generate themes associated with students' definitions of sustainability. First, open coding consisted of the author reading each response, highlighting key words, and noting general ideas contained within each response. Second, common themes were identified across the definitions of sustainability. The themes that emerged included: energy, products, enduring usability/longevity, and resource efficiency. With these initial themes as a backdrop, the first author coded the data one final time, while using the themes and principles codes for the published statements of principles as illustrated by Hoffman et al.: traditional environmental engineering goals, specific items to protect or improve, ethics and guiding beliefs, social and societal aspects, engineering design criteria, business perspectives and values.[7]

Next, the first author coded students' responses to the second prompt: how does sustainability relate to engineering? As with the first prompt, the responses were inductively coded by reading each response, highlighting key words, and noting general ideas. This allowed the researcher to develop a general picture of students' views. The second phase consisted of the development of categories of students' responses and naming these themes. Students' conceptions of sustainability and the perceptions of the relationship of sustainability to engineering are described below.

Results

Results show that students' conceptions of sustainability overwhelmingly correspond with traditional environmental engineering goals, characterized by a focus on energy/resource renewability. Table 1 provides an overview of the results. Note that the total number of codes exceeds the total number of responses because in some instances, students presented more than one idea in their response.

Table 1. Frequency of definitions of sustainability

Rank	Code	Quantity
1	Traditional Environmental Engineering Goals	32
	Use of renewable or natural energy flows	16
	Use of renewable resources	12
	(Design for) energy efficiency	2
	Eliminate, minimize, and/or manage waste	1
	Pollution prevention	1
2	Engineering Design Criteria	16
	Long term value, durability, reusability, and/or repairability	15
	Life cycle thinking	1
3	Specific Items to Protect or Improve	13
	Resource conservation	7
	Protection of the environment	6
4	Ethics and Guiding Beliefs	5
	Intergenerational equity	5
5	Business Perspectives and Values	4
	Triple bottom line	4
6	Social and Societal Aspects	0

In terms of students' perceptions regarding *how* sustainability relates to engineering, of the 29 students who offered a response, 16 commented about the imperative to design or engineer in a way that minimizes the use of resources or energy, and 9 viewed the relationship in terms of product or system design that is generally sustainable. In other words, students seem to appreciate engineering design that is mindful of the resources and energy used to develop products and systems.

While we cannot be certain of the exact content presented to students throughout the semester, the heavy emphasis on traditional environmental engineering goals could be the result of direct instruction in this area, both in the engineering courses and perhaps in their required chemistry and physics classes. Or, it could simply be that students do not think about sustainability beyond resources, energy, and the environment at a basic level, as opposed to a systems level. Sophomore students might lack the intellectual maturity to think about sustainability and sustainable design from a systems approach. Regardless, the very fact that students have a fairly myopic view of sustainability suggests that there is more work to be done in both educating students and reforming engineering education to include greater attention to a broad notion of sustainability as it relates to engineering.

Implications

We see three important implications emerge as a result of our research. First, students overemphasize resource and energy conservation at the expense of a more sophisticated understanding of sustainability. We speculate that this view of sustainability is related to the curriculum, specifically, the classes currently offered at the freshman and sophomore level. For example, the second author is conducting a concurrent research project about sustainability.

Students' responses to those surveys show that their understanding of sustainability is influenced by their experience in three specific classes: Mechanical Engineering 100, 200, and Engineering LEAP.[i] Upon closer examination of these courses it becomes apparent that there is little emphasis on a systems view of sustainability and in the sophomore class in particular, the few lectures that claim to be focused on sustainability speak specifically to concepts of energy and heat transfer. The LEAP class is a student skills class that introduces students to study skills, writing, and ideas surrounding sustainability. With only a few cursory mentions of the concept of sustainable design in the first two years of students' academic experience, it cannot be expected that they would have developed a sophisticated understanding of sustainability. While acknowledgement of the importance of renewable resources and energy is certainly relevant to engineering sustainability, we argue that this is a rather limited view focused on resources and limiting environmental impact, and thus represents only one small part of sustainability as it pertains to engineering.

Second, students' responses point to a focus on sustainable inputs, rather than an appreciation for product life-cycle, triple-bottom line (a design focus on people, planet and profit), or the five R's of sustainable design (reduce, renew, recycle, renew, and respect), all concepts that encourage more long-term systems and process views of sustainability. That is, students view sustainable engineering as that which minimizes the use of resources or energy, with little consideration for cradle-to-cradle design and the numerous stakeholders who could be implicated throughout the process. For example, the concurrent research project being undertaken by the second author asked sophomore mechanical engineering students to define the concepts of triple-bottom line and to name the five R's. Only one third of the students correctly explained these concepts. If the students are not aware of these larger ideas of sustainability, they will be unable to incorporate these concepts into their designs.

Last, perhaps more important than what students said in the survey, is what the students failed to say regarding sustainability and engineering. There was a complete lack of attention to social and societal aspects of sustainability including a focus on social equity, human rights, elimination of poverty, peace, global awareness, and engineers' involvement in policy making, to name a few. In other words, engineering students equate sustainability with environmentalism, and while this is certainly an important component of sustainability, it is by no means the only aspect that should be considered.

Overall, these three implications point to a general lack of a systems approach to sustainability. As a result, we argue that we must make a concerted effort to enhance undergraduate engineering education at our institution to include holistic understanding and broad problem solving approaches. We heed the call from then National Academy of Engineering (NAE) Chairman, George M. C. Fisher, to develop renaissance engineers who will "change the world to make it a better place and improve the quality of life for all people."[15] We acknowledge that transforming undergraduate education is no easy task and revising engineering curricula as part of a wider cultural change initiative will be met with resistance, as it represents a challenge to identity. We offer two practical recommendations for how to begin this process.

Recommendations

We must shift the way students are taught about sustainability from a narrow focus on energy and resources to include a broad, holistic approach that incorporates ethics, social and societal aspects, and business perspectives. The National Science Foundation has created a support network that will help educators incorporate lessons of sustainability into existing classes.[16] We advocate an integrated, developmental approach whereby students learn about engineering principles, design, systems thinking, and sustainability throughout the undergraduate curriculum, rather than compartmentalizing sustainability into electives and one or two design courses, typically associated with the junior and senior years. If students learn about sustainability throughout their educational career, they will be more likely to internalize sustainability as an important component of engineering identity and will be more likely to value sustainable design.

Interdisciplinary perspectives are necessary to innovate and solve global, complex problems. To this end, we advocate collaboration with people from disciplines other than engineering to afford students the opportunity to think beyond the technical aspects of design. This could include interdisciplinary classes, or more locally, the integration of non-engineering instructors within engineering classes to provide instruction and offer a different perspective.

Conclusion and Future Work

Engineering educators must move beyond a view of sustainability as one design constraint among many. Instead, we must transform engineering education to be more focused on sustainable, systems-oriented design and problem solving. A broad, sustainability-focused education will prepare engineering students to make the world a better place for all people.

This project helped us understand sophomore Mechanical Engineering students' views on sustainability and the relationship of sustainability to engineering. With these results as a backdrop, we are now interviewing faculty and students to develop a more nuanced picture of their views on sustainability. This will help us understand the culture of sustainability in the department so that we can develop a targeted, integrated, developmental curriculum.

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[i] This research is in progress by the second author. While this is a different sample of students, we invoke it here because we speculate that the students we surveyed would have similar responses given the fact that these are required courses and the Mechanical Engineering undergraduates are a fairly homogenous group.