Is Protecting the Environment All There Is to Sustainability?

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Is Protecting the Environment all there is to Sustainable Practice?

Abstract

Current approaches to teaching sustainability in undergraduate engineering programs tend to focus on the environmental pillar of sustainable practice, while de-emphasizing social and economic pillars. Yet, social, economic, and environmental pillars are considered equally important pieces of expert, global perspectives on sustainable development. This study complements previous qualitative studies by showing that this emphasis on the environmental is not only a distinct characteristic of sustainability education in engineering but also exemplifies the preconceptions that engineering students hold about sustainable development and practice. In fact, of a sample of 232 students at a large public research institution in the Pacific Northwest, 40% of students cite the environmental pillar in their definitions of sustainability while 0.4% and 0.9% cite the economic and social pillars respectively. Of the remaining students, 55% correctly spoke of sustainability in general terms; however, their responses did not take into consideration the three pillars and nuances that make sustainability complex. When probing more deeply into how engineering students translate their views of sustainability into their roles as engineers in global society, concerns for the environment continue to dominate over other concerns. In fact, when student responses are situated into a contextual framework of design for sustainability, 57% of students emphasize the role of the Planet in design for sustainability while only 1.7% cite Profit and 7.3% cite People in sustainable design considerations. Engineers most often speak to the importance of increasing energy efficiency, using renewable resources, and improving waste prevention in their responses regarding their professional roles as engineers. In summary, considering student perceptions of their role in sustainability as engineers, these results clearly suggest a need to emphasize the social (people) and economic (profit) aspects of sustainable practice in engineering education.

Introduction

According to the Brundtland Commission[1], "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In today's global society, the resources and energy humankind presently consumes far exceeds the capacity of the supporting ecosystems,[1] Thus, there is little doubt that the current state of development is unsustainable, thus making sustainability of all that we do in the future a critical global challenge to every profession, engineering included. As the consequences of unsustainable 'overshoot'[2] on our planetary resources continues to unfold, it has become increasingly important for educators to introduce students to a common language and vested interest in sustainability during the undergraduate years. For engineering students, meaningful integration of sustainability into the undergraduate curriculum requires not only basing this common language on globally accepted definitions of sustainability but also providing instruction on sustainable practice that is specifically related to the student's future role in society as a professional engineer.

A common language can be based on globally developed definitions and broadly accepted boundaries of sustainability as identified in *Our Common Future* by the Brundtland Commission (Figure 1).[1] In this cornerstone document for sustainable development, written in response to "an urgent call by the General Assembly of the United Nations"[1], the Brundtland commission sets out a global agenda for change. A series of UN summits and conferences which followed the Brundtland Commission sought to encourage sustainability in all major industries worldwide. The Earth Summit in Rio de Janeiro in 1992 continued the work of the Brundtland Commission[3] establishing the current UN Commission on Sustainable Development. The Rio Summit endorsed a global action plan called Agenda 21 that provided a framework for achieving sustainable development[4], and the Johannesburg World Summit on Sustainable Development (WSSD) in 2002 (also referred to as the Rio+10 because it took place 10 years after the first Rio Summit) [3] formalized a widely-used definition of sustainability as being composed of the three pillars of sustainable development - economic, social, and environmental. Present-day sustainability discourse still largely revolves around the inclusion of these three pillars. The environmental pillar focuses on traditional ideas of sustainability, mainly that of individuals and organizations minimizing impact on the environment in all that they do, and includes environmental management and reducing human consumption.[1] The economic pillar of sustainability focuses on economic growth without harm to others and tends to emphasize sustainable economic growth in rapidly changing developing countries and communities[1]. Applied to an economic lens, sustainable development gave rise to green economics, which a UNEP report describes as "one that improves human well-being and social equity, while significantly reducing environmental risks and ecological scarcities"[5]. Lastly, social sustainability emphasizes social responsibility and response so that all actions either improve the lives of others or at least do not harm others. "Social sustainability occurs when the formal and informal processes; systems; structures; and relationships actively support the capacity of current and future generations to create healthy and livable communities".[6] Far from being mutually exclusive, the social, environmental, and economic pillars of sustainability are often shown as three overlapping circles, illustrating that the three aspects are not mutually exclusive but that they instead are mutually reinforcing.[7]

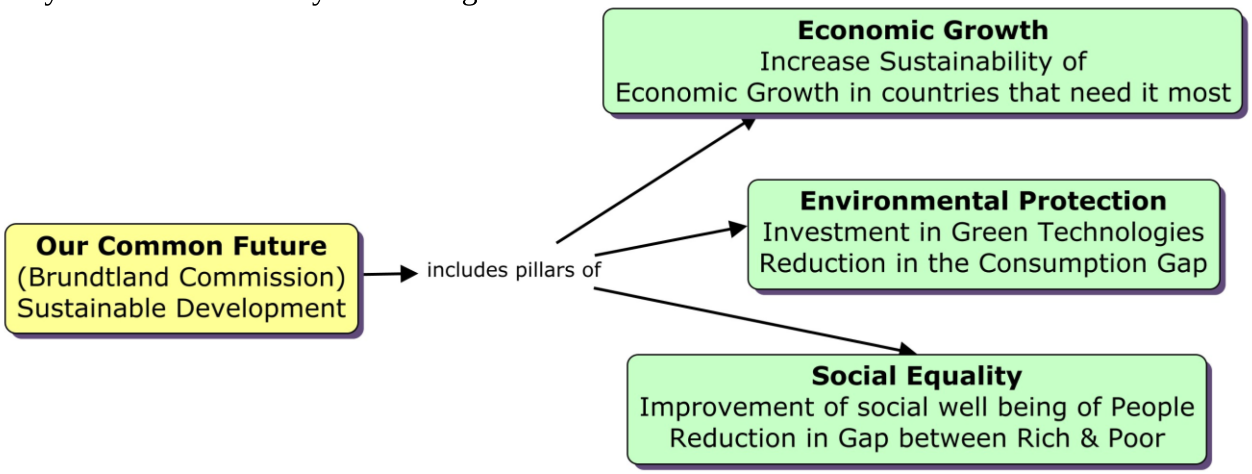

Figure 1: Our Common Future (Conceptual Framework)

Conceptual Frameworks

Across the three pillars of sustainability and independent of any specific pillar, sustainability "concerns the specification of a set of actions to be taken by present persons that will not diminish the prospects of future persons to enjoy levels of consumption, wealth, utility, or welfare comparable to those enjoyed by present persons".[8] This global view of sustainability supports first that sustainability involves action as much as discourse and implies that different actions are to be taken by different individuals, depending on their role in society. While Our Common Future[1] lays a conceptual foundation for defining sustainability and sustainable development in common terms, it does not provide a specific guiding framework for how to pursue sustainable development in specific roles. For this, a more applied framework is necessary.

One such framework that is directly related to the role of engineer is taken from the United Nations Environment Program, UNEP, Ecodesign: A Promising Approach. Design for Sustainability (D4S), also known as sustainable product design[6], provides globally recognized guidelines for designing, engineering, and modifying products in a win-win situation to support continuously increasing sustainability in those products. Three facets of sustainable design are highlighted: People, Planet, and Profit. These three approaches roughly coincide with Brundtland Commissions' designations for the three pillars of sustainability, but provide specific design-oriented facets relevant to pursing sustainable development. The first principle of design, *Design for People*, is driven by the mission to create "opportunities to meet social and equity requirements".[5] *Design for People* emphasizes lifting those in the lower sections of society up to the same level as their peers. This area includes actions that successfully abolish child labor, reduce unemployment for urban and minority communities, reduce income inequalities for women, and increase social opportunities for all people.[5] The second principle of design for sustainability in the engineer's role in society, *Design for Planet,* covers actions traditionally supported by environmental approaches to sustainability that develop technology and products "within the carry capacity of supporting ecosystems".[5] These actions range from reducing fossil fuel use to increasing use of renewable and more efficient energy, cleaning up contaminated and toxic sites, increasing waste prevention and recycling, and stopping deforestation and damage to the ecosystem.[5] Finally, Design for Profit roughly coincides with the economic pillar of sustainability and seeks to create "value for customers and stakeholders in the global chain"[5] through such mechanisms as fair value for customers and stakeholders and fair pricing for materials and goods produced. A full list of design principles that support sustainable product *Design for People, Profit, and Planet* are outlined in the second conceptual framework that guides this research (shown in Figure 2). These actions are used to evaluate preconceptions, misconceptions, and missing conceptions among students about the engineer's role in supporting sustainable development.

This framework, in combination with the Brundtland definition of the three pillars, is used to code, classify, and understand student responses to short answer questions in this study. The three pillars (Figure 1) provide a clear guidance for understanding the responses and create three clear and distinct categories. The Design for Sustainability model (Figure 2) closely follows the three pillars of sustainability and illustrates clear paths for understanding manifestation and application of the pillars.

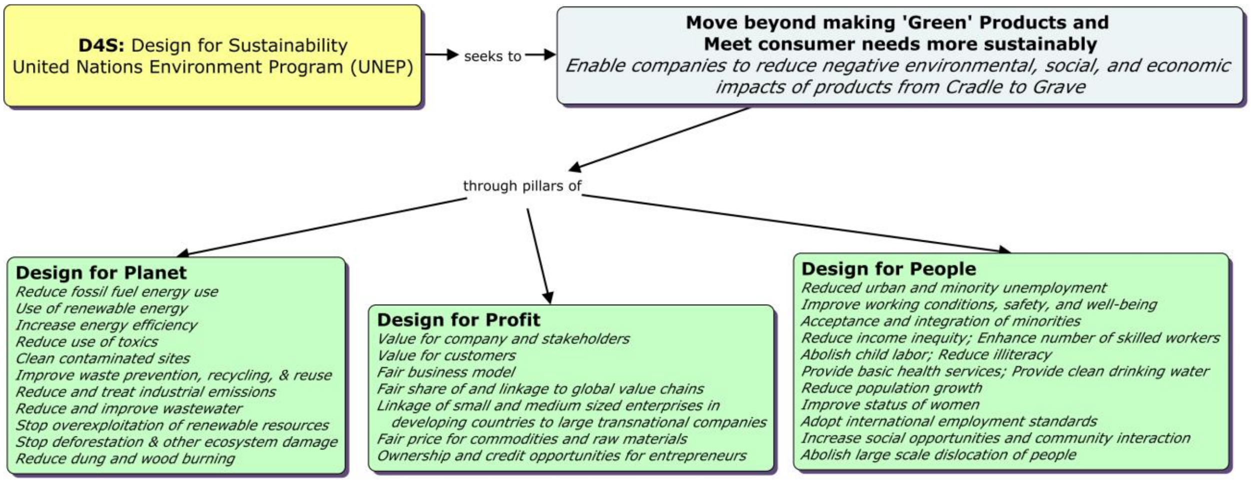

Figure 2: Design for Sustainability (Conceptual Framework)

Background

Most existing sustainability topics, modules, and courses in engineering focus on the environmental pillar of sustainable development while de-emphasizing social and economic pillars. Furthermore, most instruction on sustainability, as reported in the literature, appears to focus on teaching the engineering student to be an engineer who practices sustainable development rather than a consumer who has a role in sustainable practice. In part, this emphasis on the engineer's role in sustainability is a result of the Accreditation Board for Engineering and Technology (ABET)'s mandate that engineering undergraduates complete their degrees having achieved student outcome (c):

> "...an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."[8]

Yet, while these outcomes support the inclusion of sustainability in the curriculum via the university's accreditation process, outcome (c) does not provide specific guidance regarding the scope and limitations of sustainable practice as a topic or set of skills to be integrated into the curriculum. At this point, neither systematic nor broadly applicable tools are available to assess the student's learning of sustainability based on globally accepted definitions of what sustainability is[9]. As a result, most efforts to integrate sustainability content into the curriculum and support sustainable practice among future engineers focus on the environmental aspects of sustainability. Even programs devoted to sustainability via a certificate program or a minor in undergraduate engineering programs have a primary focus on the environmental aspects of sustainability, while neglecting the other two pillars.[10 11]

Arasat has developed two models to outline sustainability teaching a review of 30 papers on sustainability courses.[12] The first is the *Stand-Alone* model and is usually seen during the early development of sustainability education development. This model is characterized by

sustainability course development independent of other classes. These sustainability classes are offered without any attempt to incorporate material and ideas into aspects of other classes, but are classes whose sole purpose is to teach sustainability. This model includes classes like "Climate, Sustainability, and Society" or "Education and Awareness for Sustainability". When integration into mainstream courses begins, the other model described by Arasat emerges and takes a wider view of sustainability education. In this *Integrated* model, sustainability is incorporated into the current curriculum across all levels of a particular engineering program. Examples of curricula which follow the *Integrated* model include the Applied Sustainability and Public Health in Civil Engineering program at Queens University Canada.[12, 13] But, regardless of whether sustainability is taught in a *Stand-Alone* or *Integrated* model, courses which endeavor to highlight sustainability should do so across the three pillars of sustainable practice (economic, social, environmental).

These pillars can be incorporated into the curriculum using one of three major approaches[12]. The first approach, a *singular* approach, is a course in sustainability that teaches only one of the three pillars. The second method is a *dialectic* approach that combines and blends two of the pillars of sustainability. Lastly the most sophisticated of the three is the *consensual* approach where the three pillars are equally taught and integrated in the coursework. Using the *consensual* approach will most effectively teach sustainability, yet a review of courses show very few classes which are focused on social and economic sustainability.

While existing engineering curricula tend to provide some *Stand-alone* and some *Integrated* course content on sustainability, a balanced emphasis on social and economic pillars in addition to environmental impacts is notably absent. The development of courses, modules, curricula and educational materials on the social and economic impacts of technology is often de-emphasized in engineering courses. A search of environmental, social, and economic impacts in research and development of new engineering courses shows a strong tendency to overemphasize the environmental impacts. For example, a search in IEEE Xplore by the term "environmental pillar of sustainability" yields 151 results, while similar searches for "social pillar of sustainability" and "economic pillar of sustainability" yield only one and two results respectively. Some of this wide gap between the environmental and social/economic pillars is likely due to the lack of a common language in engineering that is consistent with global terminology. Broadening the scope of the literature generated in this area, the number of conference and journal publications which focus on social impacts of technology in engineering courses is still quite sparse, with only 22 relevant publications between 1994 and 2015. Of these 22 publications, only 10 specifically address social sustainability. With regard to economic sustainability, a similar search of the economic impact in engineering courses showed only 19 relevant publications. Of these 19, only eight address economic sustainability. Considering research publications involving courses and curriculum where environmental impacts of sustainability are integrated with existing topics (rather than stand-alone) such as energy and water quality further widens this gap between environmental and social/economic concerns, making it clear that, at the present time, sustainability education in engineering is dominated by the environmental pillar of sustainability.

A broader scope in sustainable practice is beginning to emerge in numerous programs that implement sophisticated and more comprehensive sustainability programs and certification programs. However, these programs are at the graduate level and are often not designed for or are unable to accommodate the high numbers of undergraduate students who co-exist with these

graduate programs.[14, 15, 16, 17] Without a doubt, more efforts at including broader and more sophisticated knowledge applied to sustainable practice needs to reach the undergraduate level.[18] In most cases, individual engineering curricula do not need to be altered or overhauled to accommodate sustainable practice. Rather, principles of sustainability can be incorporated at various times and levels into existing courses throughout undergraduate programs, from freshman to senior level.[18]

From the literature, we clearly see that efforts seeking to develop courses and curriculum around the environmental impact of technology and the nature (environment) aspect of sustainability dominate over social and economic impacts and aspects. While, in general, this evidence supports a need for greater emphasis by engineering educators on social and economic pillars, it does not provide sufficient insight into where to begin this shift toward a more balanced perspective on sustainability. In this study, we endeavor to address this gap in the literature first by both (a) exposing which topics and challenges in the environment are neglected by engineering students in speaking to environmental sustainability, and (b) which social and economic aspects of sustainability do indeed make it onto the radar screen for students. Knowing (a) provides implicates for what needs to be added to existing stand-alone and integrated models of sustainability in the engineering curriculum; knowing (b) gives some insight into an appropriate starting point to connect to student interests in social and economic pillars so that comprehensive knowledge can be established while meeting with minimal student resistance.

This Study looks specifically at misconceptions and missing conceptions that students hold regarding sustainability in the context of our two models (Our Common Future and D4S). We asked a wide range of engineering students at a single university to respond to a series of short answer questions in order to explore their conceptual definition of sustainability and to define their role in sustainable practice as an engineer. Our analysis focuses on outlining what's missing, what's over-emphasized, and what's wrong with these views in the context of two broadly constructed models of sustainability. With this insight, we can define a curriculum that, independent of student, teacher, or administrative preferences, can become more aligned with what global experts have to say and recommend doing about supporting sustainable development

Methods

This research is part of a larger, two year, single institution research study that evaluates various tools for teaching sustainability to electrical engineers in order to identify a best practices toolbox for engineers. This pilot program develops interventions for electrical engineering classes that make sustainability central rather than peripheral to engineering education, but the results from our study are likely to be of use to a broad range of other engineering and science fields. We began our understanding of where students are coming from with regard to sustainability by conducting semi-structured interviews and focus groups at multiple levels (sophomore, junior, senior) to understand what students think sustainable technology is and how they think they can contribute to it. Results from this phase of the study were used to formulate the survey and research questions for this study as shown in Figure 3.

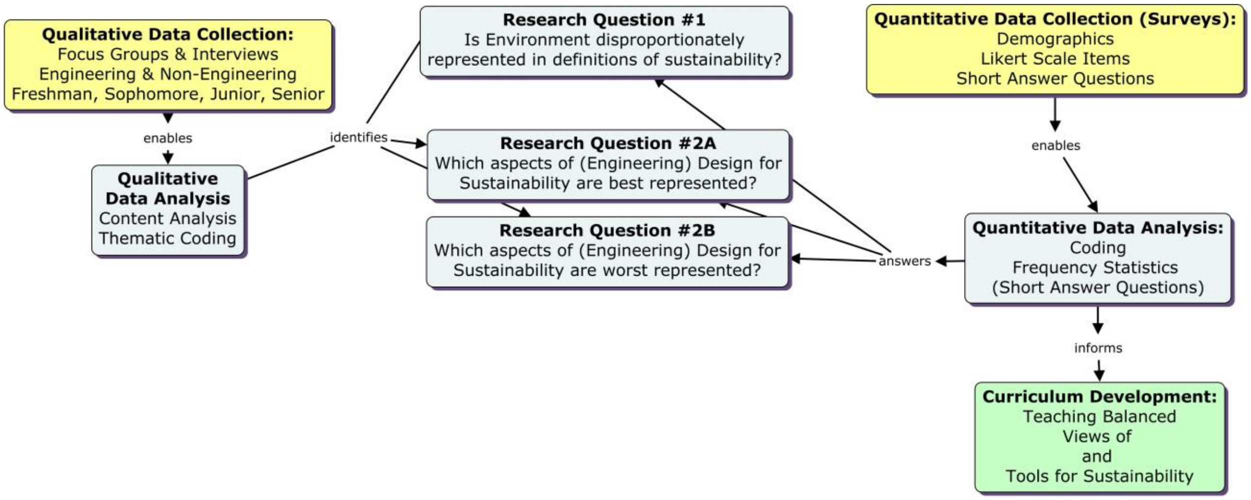

Figure 3: Research Design

A. Research Questions

This phase of our research question addressed two basic research questions.

Research Question #1:

How do engineering students define sustainability (in terms of the common language of three pillars established by the Brundtland Commission and subsequent forums)?

This research question is important because it provides important diagnostic information regarding the preconceptions, misconceptions, and missing conceptions that engineering students bring to the classroom with regard to what sustainability and sustainable practice really are. While previous studies, including one associated with this project,[19] have demonstrated qualitatively that students favor environmental definitions of sustainability, this study looks at a larger and broader engineering undergraduate population to understand whether the results of previous studies are generalizable and indicate that the environmental emphasis is indeed what most students favor in defining sustainability.

Research Question #2:

How do engineering students view their role as an engineer in supporting sustainable practice in terms of the common language of the global D4S (design for sustainability) initiative shown in Figure 2?

The answer to this question complements the first research question by identifying preconceptions, misconceptions, and missing conceptions about what engineers can and should do about supporting sustainable practice in their professional lives. Previous studies[19, 20, 21, 22] have shown that many students think sustainability should not be part of the engineering curriculum. These students are clearly unaware that sustainability is not only part of ABET criteria but also part of the ethical codes of IEEE and other professional trade organizations. This research question delves deeper into which parts of sustainable practice require further emphasis in the curriculum to ensure that engineering students graduate with a clearer and more accurate vision of what their ethical obligations to sustainable practice as professional engineers are.

B. Subjects and Procedures

Random sampling was used to recruit and survey 232 undergraduate students for this study. Participants completed a survey which allowed self-report of perceptions of social responsibility, global competence, global civic engagement, consumer responsibility, sustainability, and professional identity as well as multiple demographic items. The study population was diverse and included a range of engineering majors, ethnicities, and both genders. Characteristics of the study population are detailed in Table 1.

Table 1: Participant Characteristics by Year in School– *N*(%)

	Freshmen & Sophomores	**Juniors**	**Seniors & 5^{th} Years**
Total Participants: *N*	19(8.0%)	136(59%)	77(33%)
Gender: *N*			
Females	5(26%)	26(19%)	14(18%)
Males	14(84%)	110(81%)	63(82%)
Major: *N*			
Electrical Engineering	13(68%)	64(47%)	58(75%)
Computer Engineering	2(11%)	5(3.7%)	3(3.9%
Mechanical Engineering	2(11%)	66(49%)	6(7.8%)
Bioengineering	1(5.3%)	0(0.0%)	4(5.2%)
Civil Engineering	0(0.0%)	0(0.0%)	3(3.9%)
Material Science	0(0.0%)	0(0.0%)	1(1.3%
Industrial Engineering	1(5.3%)	1(0.7%)	2(2.6%)
Self-reported Ethnicity: *N* (%)			
Asian American	12(67%)	68(51%)	35(46%)
Black	0(0.0%)	0(0.0%)	3(3.9%)
Caucasian	5(28%)	46(35%)	37(49%)
Latina/o	0(0.0%)	10(7.5%)	1(1.3%)
Other	1(5.6%)	9(6.9%)	0(0%)
Missing	0(0%)	0(0%)	0(0%)

Across majors, 58% of participants were from electrical engineering, 4.3% of students were from computer engineering, 32% of students were from mechanical engineering, 2.1% were from bioengineering, 1.2% were from civil engineering, <1% were from materials science and engineering, and 1.7% were from industrial engineering. The ethnic composition of the sample was 38% White, 50% Asian, 1.3% Black, and 9.1% other, including Latino/a, Pacific Islander and Native American, and others. 81% of the population was male and 19% was female. No attempt to oversample women or minorities was made in collecting this sample. 8.2% of the sample were freshman or sophomores, 59% were juniors, and 33% were seniors (including fifth year seniors).

C. Instruments

The questions analyzed in this study were included in a survey that included basic demographics and affective indicators including self-efficacy, task value, belonging, and job values that may mediate or otherwise influence the way in which the primary indicators grow and evolve over the undergraduate years. The primary indicators included various measures of sustainability values (e.g. social responsibility, consumer responsibility), and five short answer questions related to how student's define and view sustainability from an engineering perspective. Details regarding the Likert-scale primary indicators in this survey are published elsewhere.[29] Overall, the survey contained 15 demographic items, over 150 Likert-scale questions, and five short answer questions. Three of these short answer questions formed the basis of this analysis:

- How do you define sustainability?
- What do you believe your most important contribution to sustainability will be as an engineer?
- What part of sustainability do you believe you will be least likely to impact as an engineer?

D. Data Analysis

All short answer questions were analyzed qualitatively in order to answer the two research questions. A preliminary coding scheme was developed based on a random sample of 20 student responses that broke the data into categories of responses represented in the data. From this coding scheme conceptual frameworks related to the questions and responses and that are globally accepted to sustainable practice were used to refine the labels and the coding scheme. Finally a third coding of the remaining responses that did not fit into the chosen frameworks were examined to determine which responses were outside of consideration and if any patterns emerged.

Results

Analysis of results organized in two phases (or coding passes). In the first coding pass, student responses to the first short answer question ("How do you define sustainability?") were categorized according to the three basic pillars of sustainability (economic, social, environmental), consistent with answering Research Question #1. These results are summarized in the first block of Table 2. Also, in the first coding pass, answers to the last two short answer questions evaluated in this study (identifying the student's role as an engineering in sustainable practice) were categorized according to design for sustainability (DS4) practices. Consistent with the DS4 framework, the responses were coded into Design for Profit, Design for People, or Design for Planet categories. These coding results are also summarized in Table 2. Representative examples of responses in each category of sustainability (economic, social, environmental) and design for sustainability (Profit, People, Planet) are provided next to elaborate on the results of Table 2.

Table 2: Student Views of Sustainability (First Coding Pass)

	% of Students Responding in Each Category		
	Freshman & Sophomores	Juniors	Seniors
Definition of Sustainability			
Environmental	26%	41%	43%
Economic	0.0	0.7	0.0
Social	5.3	0.7	0.0
Other	69	58	57
Role as Engineer (Most Impact)			
People	11%	7.4%	6.5%
Planet	68	54	60
Profit	0.0	0.7	3.9
Other	21	38	29
Role as Engineer (Least Impact)			
People	11%	25%	17%
Planet	37	27	34
Profit	0.0	9.6	5.2
Other	53	37	42

A. How do you define Sustainability?

Surprisingly, most students did not address any of the three main pillars of sustainability in their responses to this question. Of those that did, most referred to the *environmental pillar*. Many of these answers were both sophisticated:

> "Sustainability is an idea in which processes and products are maintained without over-consuming or putting pressure on environmental resources," (Male, Asian)

and optimistic:

> "The best way to keep the natural life and help the ecology system to remain active and alive. In other words, a way to keep our planet balanced." (Male, Middle Eastern)

while other responses regarding the environmental pillar were brief and basic, but nevertheless reflected a concern for the continued well being of the planet:

> "Sustainability is defined as the ability to use something wisely without destroying the natural environment." (Male, Asian)

> "Not harmful to the environment" (Male, Asian)

> "Being able to consume less than you produce while prolonging the lifespan of our planet" (Male, Caucasian)

These fairly generalized, but nevertheless environmentally focused definitions emphasize "natural life" and the "ecology" of the planet and range from longer complex ideas to simple statements about the importance of the environment. Overall, 110 students included the

environment in defining sustainability. Although most definitions there generalized, numerous students ($N = 42$) defined environmental sustainability more specifically in terms of resource preservation and management.

A small minority of students reflected on the *social pillar* of sustainability in their responses to this short answer question. Responses tended to be generalized such as the following:

> "Sustainability is the ability to sustain any device, instrument, process or an idea for a long period of time with the minimal socioeconomic costs." (Male, Asian)

Most students who mentioned the social pillar of sustainability did so in a generalized context of social equitability and well-being. For instance, while the student above considers the social aspect of sustainability, he made no specific mention of critical elements associated with the *social pillar*, including population control and community improvement. Mentions of the economic pillar of sustainability were even more in a minority and limited to generalized and brief phrases, including the socioeconomic comment noted above.

In equally small minority, students who covered two aspects of sustainability in their responses were drawn to the social and environmental pillars. For example:

> "Sustainability in regards to engineering involves designing and managing systems to not only meet the developing needs of populations, but to simultaneously use energy and resources at a rate that does not compromise the environment or the future needs of humanity." (Male, Caucasian)

While the student's response above encompasses more of the true scope of sustainable development, it still fails to give specifics regarding each individual pillar and the interconnected role these pillars play in sustainable practice.

While a minority of students captured part of the Brundtland definition of sustainability in their responses, a majority of students ($N = 129$) responded in such a way that could only be classified as 'Other'. These students defined sustainability in such general terms that their responses could only be classified outside the conceptual model of Figure 1. Some definitions of sustainability included simple ideas such as:

> "The ability to continue to do something indefinitely or at least so for the foreseeable future." (Male, Asian)
>
> "Sustainability is having a consumption rate be less than the production rate." (Female, Asian)

While reflecting a concern and interest in sustainability, these definitions are highly generalized and do not reflect a common language of sustainability. They suggest that in the curriculum, both college and pre-college, students have either been exposed to conflicting definitions of sustainability, environmentally focused definitions, or no formal definition at all.

B. What will be your most important contribution to Sustainability as an Engineer

It is no surprise that, when asked about their role in sustainable practice as an engineer, students also chose to emphasize the environment, as embodied by the Planet aspect (Figure 2) of D4S (design for sustainability). However, which aspects of Planet they chose to emphasize did vary widely among students (Table 3). Profit and People were also mentioned, but like the previous question ("How do you define Sustainability?"), were much less prevalent than Planet. Data are organized and ranked by frequency in Table 3 according to the design for sustainability principle addressed in each student's response. Many design for sustainability principles were not mentioned by any students but are listed for completeness at the bottom of Table 3. In total, 66.8% of students responded to this question in such a way that their responses could be placed in one or more categories (Planet, People, Profit) and design for sustainability principles within these three categories.

Table 3: Student Views of Sustainability in the Role of Engineer

(Ranked by total number of responses given in each D4S Category of Design for Sustainability)

			# of Responses in Each Category			
Rank	Category	Design for Sustainability Principle	Freshman & Sophomores	Juniors	Seniors	**TOTAL**
1	Planet	Improve Waste Prevention, Recycle	4	14	11	**29**
2	Planet	Use Renewable Resources	1	14	11	**25**
3	Planet	Increase Energy Efficiency	2	9	9	**20**
4	Planet	Reduce Fossil Fuels	1	5	0	**6**
5	People	Increase Social Opportunities	2	4	0	**6**
6	Planet	Reduce Use of Toxics	0	2	1	**3**
7	Profit	Fair Price for Commodities	0	0	2	**2**
8	People	Reduce Population Growth	0	1	0	**1**
9	Planet	Stop Deforestation	1	0	0	**1**
10	People	Control Population Growth	0	1	0	**1**
N/A*	Planet	Clean contaminated sites; Reduce and treat industrial emissions; Reduce wastewater; Stop overexploitation of resources; Reduce dung and wood burning.				
N/A*	People	Reduce minority unemployment; Improve working conditions; Integration of minorities; Reduce income equity; Abolish child labor; Provide basic health services; Improve status of women, Adopt international employment standards; Abolish large dislocation of people				
N/A*	Profit	Value for company and stakeholders; Value for customers; Fair business model; Fair share of and linkage to global value chains; Link small/medium enterprises in developing countries to larger international companies, and materials; Ownership opportunities for entrepreneurs.				

* No students responded in this category when asked about the most impact on sustainability they perceive they will have in their role as engineers

Similar to the results of coding the "How do you define Sustainability" question, a large portion of students (33.2%) defined their role in sustainable practice as an engineer in such a way that no classification within the D4S (sustainable design) framework could be made. These responses were either too general to identify a specific category and principle within D4S or outside the scope of sustainable design altogether. Examples of these non-classifiable responses as well as responses within Planet, Profit, or People are provided next.

Planet

Of the students who responded in a way that could be classified within D4S, 80% of all Freshmen/Sophomores 90% of all juniors and 93% of all seniors favored Planet-based roles as engineers in supporting sustainable practice. Not surprisingly, the Planet category of responses, in addition to having the most responses, also had the most diverse range of responses. Students responded across six separate design for sustainability principles (ranked 1, 2, 3, 4, 6, and 9 in Table 3) within the D4S Planet category in contrast to People (3 principles) and Profit (1 principle).

Many students favored improving waste prevention (recycle, reduce, reuse) as the principle of sustainability that would dominate their role as engineers in contributing to sustainable practice. 29 of 94 classifiable responses were coded within this principle. Some responses were quite simple and general such as:

> "Not wasting a lot of paper or electricity" (Female, Caucasian)

Other students attempted to connect their career interests within their chosen major to reducing waste. For example, one student voiced this inherent opportunity:

> "I want to work with nanotech so I guess making a lot smaller technology would mean less trash" (Male, Caucasian)

Another student did the same with his interests in power systems:

> "My most important contribution to sustainability would most likely be increasing the efficiency of fuel which would reduce waste." (Male, Caucasian)

Other students were quite ambitious in their endeavors to reduce waste:

> "Finding ways to minimize waste in all forms." (Male, Caucasian)

Within waste prevention principles, students who were specific in their responses expressed a diverse range of approaches and perspectives on fitting the goal of reducing or preventing waste in their chosen majors and intended careers.

Ranked just behind the waste prevention principles was the design for sustainability principle of using renewable resources. Twenty-five students talked about how they could impact D4S global objectives by developing, using, or otherwise leveraging renewable resources in their intended careers. As in other analyses, some students were general with regard to their investment in renewables:

> "Increase the efficiency of energy harvesting from renewables." (Male, Asian)

> "Invent reusable energy." (Male, Asian)

while others were more specific about this D4S principle:

> "I interned in power over the summer and worked with renewable energy sources. I feel like if I end up working in that field, that I will be able to help with sustainable energy sources." (Female, Asian)

Students also responded frequently in defining their contribution to sustainable practice as engineers with an investment in principles oriented toward increasing energy efficiency. While the previous responses focused on using renewable (and therefore more sustainable) forms of energy, other students chose to emphasize improving the efficiency of products they would design or support in their careers. Some students were very general in stating this:

> "Creating more energy efficient technology" (Female, Caucasian)

and others spoke directly to power consumption in improving energy efficiency:

> "As an electrical engineer, the most important contribution I can think of is creating devices that reduce power consumption." (Male, Caucasian)

Collectively, when responses reflecting interest in renewable energy were combined with increasing energy efficiency, a significant majority of classifiable responses focused on the use of energy in supporting sustainable development and practice.

Students tended to respond to this question in ways that related directly to a specific technology, career interest, or major interest. For example, electrical engineers tended to view their contribution in terms of energy (renewable sources and conservation through improved efficiency). Only a small minority of responses spoke to reduction of toxics or deforestation in relation to design for a sustainable Planet, despite the fact that these issues are highly relevant to the practices of electrical engineers, especially with regard to rare earth material extraction and electronic waste. Furthermore, despite the wealth of principles expressed within the Planet category, several categories (five) were not mentioned at all, suggesting a limited view of sustainability, not only in the preference to emphasize the environmental but also in defining a limited view within the environmental (Planet).

People

Of the students who responded in a way that could be classified within Planet, People, Profit, only 8.4% favored People-based roles as engineers in supporting sustainable practice. Students responded across three separate design for sustainability principles (ranked 5, 8, and 10 in Table 3). Some students favored increasing social opportunities as engineers. For example:

> “Maybe invent something that will help people's life” (Male, Asian)

> “To provide the necessary skills and resources to a group in such a way that, when a project is finished, it can be sustained by the community and there will be no need for future intervention.” (Male, Caucasian)

The other design for sustainability principles within People mentioned in this study were: reduce population growth and control population growth. For instance:

> “Keeping the family size small. Less people, less environmental resources will be consumed. Also, contribution in reducing pollution.” (Female, Asian)

However, each of these two principles were only mentioned by a single student. Furthermore, a common trend that emerged from this data was for participants to include People (social pillar) hand in hand with Planet (environmental pillar). For example:

> “Gaining the ability to design and manufacture products, and implement projects that benefit society and the environment.” (Female, Caucasian)

> “I believe my most important contribution to sustainability will be to manufacture materials which are friendly to people and environment and make them to spread into more places or countries.” (Female, Caucasian)

In general, analysis of People-based principles of design for sustainability reflect that students are either not aware that social responsibility falls within the engineer's purview or feel ill prepared to address these social concerns. Similar trends were observed for Profit oriented principles, discussed next.

Profit

Only eight study participants reflected on the Profit principle of design in their responses. General statements regarding Profit that could not be narrowed down to specific principles associated with design for sustainability included:

> “Making sure that we use the less costs to complete the mission.” (Male, Caucasian)

> “My most important contribution to sustainability would be making sure that the products I build use the least amount of computing resources as possible.” (Male, Caucasian)

For those that considered Profit in their role as engineers and were specific in their contribution, keeping prices fair for goods and commodities was the main area of focus:

> “Durability and efficiency of a particular system or process, in a cost efficient manner.” (Female, Asian)

Even this response reflects an inherent bias toward traditional orientations toward reducing cost to augment sales rather than serving economic equality among those who manufacture and assemble those products. Thus, when viewed through the lens of profit, we can conclude that engineers rarely consider design for sustainability principles within Profit and when they do, neglect issues of economic equality in favor of more traditional views of the engineer's role in supporting this aspect of sustainable design and practice.

C. What part of Sustainability will you least likely impact as an Engineer?

In this study, participants were also given the opportunity to highlight the responsibilities that they rejected or minimized in their future roles in sustainable practice as engineers. The results of this analysis are summarized in Table 4 in the context of the D4S model shown in Figure 2. Similar to Table 3, responses are ranked according to frequency with which specific design for sustainability principles were expressed in student responses. As in the previous question, many principles within design for sustainability, particularly those related to People and Profit, were not mentioned by a single student.

Table 4: Student Rejections of Sustainability in the Role of Engineer*
(Ranked by total number of responses given in each Category of Design for Sustainability

			# of Responses in Each Category			
Rank	Category	Design for Sustainability Principle	Freshman & Sophomores	Juniors	Seniors	**TOTAL**
1	Planet	Improve Levels of Waste Prevention	1	9	4	**14**
2	Planet	Use Renewable Resources	1	6	4	**11**
3	Planet	Reduce Water Waste	1	1	4	**6**
4	Planet	Stop Deforestation	2	0	4	**6**
5	Planet	Reduce Fossil Fuels	0	3	2	**5**
6	Planet	Increase Energy Efficiency	1	2	1	**4**
7	Profit	Fair Price for Commodities	0	1	1	**2**
8	Planet	Reduce use of Toxics	1	0	1	**2**
9	People	Increase Social Opportunities	1	0	0	**1**
10	People	Population Growth	0	1	0	**1**
11	People	Improve Working Conditions	0	0	1	**1**
12	People	Provide Basic Health Services	0	0	1	**1**
13	Profit	Fair Business Model	0	1	0	**1**
N/A*	Planet	Clean contaminated sites; Reduce and treat industrial emissions; Reduce wastewater; Stop overexploitation of resources; Reduce dung and wood burning.				
N/A*	People	Reduce minority unemployment; Improve working conditions; Integration of minorities; Reduce income equity; Abolish child labor; Provide basic health services; Improve status of women, Adopt international employment standards; Abolish large dislocation of people				
N/A*	Profit	Value for company and stakeholders; Value for customers; Fair business model; Fair share of and linkage to global value chains; Link small/medium enterprises in developing countries to larger international companies, and materials; Ownership opportunities for entrepreneurs.				

* No students responded in this category when asked about the least impact on sustainability they perceive they will have in their role as engineers

<u>Planet</u>

Surprisingly, while many engineers felt they could have the most impact on sustainability through Planet focused principles, they also felt they could have the least impact on sustainability through these principles (and in many cases, the same ones). Seven design for sustainability principles within the Planet category merged in students' responses. In particular, students felt they are least able to improve levels of waste prevention, specifically:

> "Product enhancement in order to avoid pollution" (Male, Asian)

nor reduce the waste stream involved with their engineering activity:

> "Ways to recycle or deal with garbage." (Male, Asian)

Furthermore, students viewed some areas of D4S Planet as highly specialized, believing themselves to be poorly trained to support these facets of sustainable design. For instance, students outside of electrical engineering felt ill prepared to support:

> “The push for "greener" energy such as windmills and solar cells has been less important to me as the efficiency of the products using the energy. I will be the least likely to impact energy production methods.” (Male, Caucasian)

> “Invention of new renewable sources of energy.” (Male, Asian)

Yet, independent of major, engineering students tended to feel they would have little impact on:

> “Endangered species and deforestation” (Male, Asian)

> “Deforestation and desertification as I have no relationship with those areas.” (Male, Asian)

> “I don't think I will be able to help with actual natural resources that much (wood, water, etc.)” (Male, Asian)

> “Water usage” (Male, Caucasian)

Clearly, many students tended to respond to this question regarding the perceived least impact on sustainability by focusing on content outside their own discipline or major (e.g. deforestation). Although students felt powerless to contribute to these principles in their role as engineers, these results are nevertheless promising in that they expand the range of principles that students are aware of regarding design for sustainability. In terms of sustainable design for the Planet, students were relatively clear in where they could and could not impact sustainable practice as engineers. The same was not true for People and Profit.

People

When students reflected on what little they could do to help People, they were generalized in their responses. Overall the majority of the responses in this category (N = 54) could not be narrowed down to specific principle(s) of design for sustainability. Of those answers that were specific enough to classify, students felt they were least likely to engage in design practices that increased social opportunities, reduced population growth, improved working conditions, or provided basic health services. Students felt powerless in:

> “Convincing others the need to be smarter consumers and reduce their consumption. People love to consume and throw away their old things without care. It's hard to get people to see the importance of everyone joining in the effort. Not until we are about to run out of resources will we have worldwide concern.” (Male, Caucasian)

> “Population and overcrowding” (Male, Asian)

> “Impacting the production methods of less sustainability minded countries” (Female, Caucasian)

> “Creating of sustainable food source for other countries.” (Female, Caucasian)

Engineering students clearly did not feel empowered in this area of People, which is disturbing considering the far reaching social impacts of modern high technology.

Profit

Of the total respondents who felt they were least likely to engage in sustainable design related to Profit (*N*=20), only three had responses that could be reduced to specific principle(s) of design for sustainability. In terms of designing for profit only two of the principles outlined by D4S were indicated in the responses. These included fair price for commodities and fair business model. These two principles were expressed as a perceived inability to influence:

> "The standards of other companies/entities" (Male, Asian)

or overcome the profit motive:

> "Sometimes it is more cheap to build something less sustainable, and there isn't much you can do about that. Or if the person giving you the project gives you a project that cannot be sustainable." (Male, Asian)

Responses in this area demonstrate that engineering students feel least empowered to influence Profit and they are least aware of what is involved in the Profit corner of design for sustainability. Ideas focused on value for the investor or the consumer are ignored as well as working to create global networks of business. These ideas can have large impacts of the well being and sustainability of global society, yet engineering students do not appear to see these connections, even when considering what they are least able to influence.

Discussion

Previous research has highlighted the large number of classes focusing on the *environmental pillar* of sustainability while minimizing the importance of the *social* and *economic* pillars of sustainability.[2, 9, 17, 18, 19] This study has provided deeper insight into how and why this disproportionate emphasis is present in student perspectives.

A. Research Question #1:

How do engineering students define sustainability (in terms of the common language of three pillars established by the Brundtland Commission and subsequent forums)?

As suggested in previous qualitative studies, a large number of students emphasize only the ecosystem and environmental aspects of the sustainability puzzle. Yet, the Brundtland Commission and global follow-up summits clearly support a balanced (and inter-related) consideration of three different pillars of sustainability (*social, economic*, and *environmental*). This study confirms the results of previous studies in that a very small minority of students are aware of or see the importance of the *social* and *economic* pillars. Given the opportunity, only 0.9% and 0.4% of our students mention *social* or *economic* pillars of sustainability respectively.

Furthermore, this study also does not show that a majority of students emphasize the *environmental pillar* of sustainability. Only a significant minority (41%) identify environmental implications in their responses to our survey questions. Surprisingly, a majority of students (55.6%) either say they don't know what sustainability is or give responses that are sufficiently vague that it is difficult to identify which pillar or pillars the student is referring to.

These types of responses may show a lack of exposure, a lack of specific understanding, or both with regard to the common language that defines global action and concern for sustainability. What we see here is an understanding of sustainability that is correct in principle but lacks deeper comprehension or knowledge of any common language that can connect the many professionals working to achieve sustainable practice. Without such a common language and without embracing a globally sanctioned view of sustainability, graduating engineers are much less likely to participate in meaningful and effective gains in sustainability with regard to the development of technology, its implementation, and distribution.

When looking at the significant minority of students in this study who emphasize the *environmental pillar*, it is helpful to look at the surrounding culture. Students who participated in this study are on a campus in a developed and affluent country where the environmental aspects of sustainability are more of a concern than economic equality and social responsibility. Second, in this study in particular, students are exposed to a culture where the city, campus, and region in which they live is very "green". While beneficial to supporting environmental responsibility, this skew toward the environment may unwittingly blind students to social and economic aspects of sustainability. For example, of the engineering courses listed under the sustainability category by the university where this study was conducted, there are 58 in civil and environmental engineering and all but one of them (Policy Development, Finance, and Sustainable Transportation), are grounded in the *environmental pillar*. Similarly, when examining the sustainability courses offered in the mechanical engineering department, all of the 13 classes are centered on the *environmental pillar* of sustainability. This curricular focus on the environmental pillar goes along with a campus-wide emphasis on 'Reduce, Reuse, Recycle'. Even the University's Sustainability web pages act to reinforce the singular focus on environmental sustainability.[28] The website highlights the term “green university” so that before students even view the sustainability page, they are reminded that green (environment) = sustainability. Further exploration of the website shows several photographs including members of the community outdoors under giant trees or picking up trash. Even the mascot, a wild animal who indicates a desire to leave only his footprint on the environment, illustrates a clear and biased focus on ecosystem and nature. Surrounded by these environment ideas and images, students are naturally going to associate sustainability with the environment and not the broader, global impact that the three pillars definition can have.

In summary, these institutional and curricular influences on students can and likely do neglect the social and economic pillars and serve to further the narrow views students currently hold of sustainability. As they advance through their programs, learning only about the environment, they enter the workforce knowing and understanding the environmental challenges in engineering, without an understanding of the economic and social issues. Thus, it is evident from this study that a greater and more frequent emphasis on social and economic aspects of sustainability is necessary in engineering curricula to complement student's existing views of environmental sustainability and to balance the three pillars as students graduate into the workforce.

B. Research Question #2:

How do engineering students view their role as an engineer in supporting sustainable practice in terms of the common language of the D4S (design for sustainability) initiative?

Even when all three pillars of sustainability are strictly defined in ABET, IEEE, and related professional outcomes and expectations, students still rely on the environmental pillar. Previous research has shown that students do not think sustainability is important, yet their definitions and understanding of the world show they do not understand the concept nor how they will impact it as engineers. In considering where students feel they will have the most impact on sustainability as engineers, they represent Planet in six of the ten principles discussed in their responses. Design for People was represented three times, and only one principle in design for Profit was mentioned. Similarly, when asked to think about principles where they would have least impact as an engineer, students preferred principles within Planet. Design for People was represented four times and only two principles in design for Profit were mentioned across the entire range of student responses. In part, these patterns are a result of a limited view of sustainability, as is illustrated with the previous question; however, some part of the student perspective may also relate to how little power engineers have on People and Profit aspects of sustainable design.

Specifically, students felt they would most be able to impact waste management improvements, use of renewable resources, and increase energy efficiency. As with students' fundamental definitions of sustainability, this pattern is consistent with the regional and university culture which is likely to play a major role in shaping how engineers view sustainability. In the city where this university is located, 89% of the power comes from hydroelectric dams with the other 11% a mix of wind, nuclear, and a small percent by coal. This large environmentally sustainable power infrastructure permeates the culture and also serves as a readily available education tool and career path for many engineers. The city in which this study was conducted has also formulated a goal to have zero net emissions by 2050 and has placed responsibility on the shoulders of citizens to recycle and compost more in achieving this goal. This focus has become a source of pride for the citizens as 'Reduce, Reuse, and Recycle' has become a way of life in the region. In summary, students are exposed not only to environmental concerns for sustainability in their local communities, but also engineering designs that address and resolve some of these concerns in the classroom. Thus, without additional and explicit intervention, it seems only natural that students would carry this local culture into their perceptions of what sustainable practice should be.

When teaching engineering students to engage in sustainable practice and to do so as part of their professional and ethical responsibility, it is important to balance the heavy emphasis on environmental principles in sustainable design with a substantial number of courses to understand the social and economic aspects. Yet we see the exact opposite. A green culture breeds a green curriculum, and People and Profit tend to fall by the wayside of design for sustainability. This is a common problem in many engineering curricula in a country that, by its developed and affluent status, tends to focus on ecosystem, nature, and other environmental facets of sustainability.

Graduating students who mainly believe they can impact only a small part of one of the three pillars of sustainability, or one of the three principles of design outlined by D4S, leads to two

problems as they enter the work force. At best, students will be unaware of the other aspects of sustainability in their work and simply ignore them or have a neutral impact. At worst, these students will so aggressively support environmental sustainability that their actions will harm the other pillars of sustainability in the design process. Further, a neglect of social and economic pillars of sustainability may indicate: (a) students do not care about the policy aspect of sustainability or (b) they do not know how to impact it or (c) they are not aware that it exists at all. This mindset reflects traditional ideals of engineering: solve a problem, optimize a design and assume this design will go forth and help the world. While the traditional ideals of engineering are important, in an interconnected global society, they are no longer sufficient or realistic. Engineers often advance into managerial roles[23, 24, 25] and in these positions of power, they need to be aware of all aspects of sustainability to guarantee the team they manage will have a positive and balanced impact on social, economic and environmental impacts of products and technologies.

Limitations

We recognize that in drawing data from a single institution, the generalizability of our findings may be limited. However, the inclusion of a broad range of engineering undergraduates from multiple levels in school does allow for the representation of a wider range of student experiences compared to previous studies and provides support for the generalizability of our conclusions.

Concluding Remarks

This study has offered insights into student's definitions of sustainability as well as their believed impact on sustainability as they become professional engineers. From this study, three problems have emerged as issues that need addressing in the engineering communities. First, there is a large skew in sustainability education that is giving students the belief that sustainability is primarily defined in terms of the environment. Within this environmental definition, there are only a few principles, those associated with waste and energy management, that seem important to engineering students. Secondly, this problem is being amplified by a strong tendency for engineering programs to teach integrated, rather than stand alone, courses on environmental sustainability. While teaching integrated rather than stand alone courses is not by itself a problem, the preference to only integrate environmental sustainability into these classes is teaching students only part of the sustainability puzzle. Lastly, historically professional engineers are promoted into managers rather than staying in mainstream engineering ranks. This move through corporate hierarchy requires engineers who are more aware of sustainable problems at all levels. Being unaware of the problems facing sustainability and the lack of common language among engineering graduates regarding sustainability has significant and problematic implications for engineers who are increasingly involved in a global discourse.

ACKNOWLEDGMENTS

The authors would like to gratefully acknowledge the National Science Foundation for their support of this work under the TUES program (grant number DUE-1245464). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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