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A Sustainability Toolbox for Engineers: Exploring how Students are likely to Engage in Sustainability Education

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Abstract

We report on preliminary results regarding the views that engineering undergraduates report concerning technology and sustainability. Specifically, we look at what engineering students believe sustainable technology means and whether they believe sustainability is a realistic possibility for technology development. Results from nine interviews and three focus groups with juniors and seniors in multiple engineering majors are analyzed from the lens of what sustainability means and how readily it may be achievable in the context of technology and technology development. Consistent with results from other studies, we find that students often discuss product lifetime and recycling when considering sustainability through the lens of engineering and technology. However, in the interview setting, students also add dimensions of decreased materials usage, reduced energy consumption, and diminished toxicity of materials as essential to enabling technology and its future development to be sustainable. While most student input regarding sustainability is specific to the engineering attributes of technology, some student remarks do touch on more generalized definitions of sustainability that extend beyond the boundaries of the physical technology itself. Regardless of what sustainability in technology means to students, most interview participants reported creative solutions for gaining ground against profit motives in high tech corporate culture and practice. These results help to lay groundwork for understanding, as teachers of sustainability, how to better connect to the student experience and engage students in meaningful and lasting considerations of sustainability in their coursework.

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.[2] 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 continue 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. At the University of Washington, engineering students are exposed to sustainability from a number of different angles throughout their undergraduate years. First, the missions of home departments or major units include an integration of sustainability challenges into research and teaching goals. For example, the Department of Electrical Engineering emphasizes:

> "… formulating engineering solutions to aspects of the largest challenges facing humanity in health, energy, the environment, and in people-centric systems."[3]

Here the sustainable development of technology falls well within the umbrella of grand challenges facing humanity. The Accreditation Board for Engineering and Technology (ABET) also requires engineering students to be exposed to sustainability in the context of technology design and development through 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." [4]

The National Academy of Engineering echoes this emphasis on sustainability in engineering programs in its description of the Engineer of 2020, calling engineering students to:

> "… be leaders in the movement toward use of wise, informed, and economical sustainable development. This should begin in our educational institutions and be founded in the basic tenets of the engineering profession and its actions."[5]

Beyond their immediate academic programs and accreditation umbrella, engineering students at the UW are a part of a campus community supported by an environmental stewardship and sustainability program that has been recognized internationally for its success in developing sustainable campus projects that integrate sustainability into culture, community, and operations.[6]

Thus, we would expect that the students we interview in this study to be speaking from a culture permeated by concerns for a more sustainable world. Familiarity with sustainability is likely to emerge from not only direct academic influence (through the missions of ABET and the home major) but also indirectly from national priorities (e.g. The Engineer of 2020) that trickle down into academic and educational programs. Campus culture, especially environmental stewardship and sustainability initiatives, also influence students' views and dispositions regarding sustainability. While multiple routes for exposure to sustainability challenges will certainly increase student familiarity with those ideas, we do not understand much about how the influence takes root in student preconceptions and potentially, misconceptions. Armed with a better understanding of both, educators can be better equipped to effectively motivate and engage students in deeper and more lasting examinations of how sustainable technology development can one day be achieved.

Background

Confusion regarding the breadth and depth of the term sustainability has mounted over the years. Two decades ago, the term sustainability was almost exclusively used to describe the goal of constraining human activity to that which does not surpass the capacity of the planet, including renewing, resource, and sink capacities.[7] In today's society, however, the term sustainability is heavily overused and can mean anything from the original, narrow and unambiguous goal of effectively managing the ecological footprint of human activity to a generic description of all things that are simply good, "a synonym for everything that is positive."[7] In between these two extremes, lies the extension of sustainability from a single focus on environmental capacity to the two additional dimensions of the social and economic pillars of sustainability tacked on to the original environmental focus by the Earth Summits of 1992 in Rio and 2002 in Johannesburg.

The end result is that "…spreading to include society and the economy creates confusion, and, instead of supporting a noble cause, it has negative consequences."[7] One of these negative consequences may indeed be that our engineering students come to the table with such confused and varied notions of sustainability that they are uncertain and perhaps even unwilling to embrace sustainability (at least, the environmental pillar) as a valid and valuable part of their engineering curriculum. Combined with the relatively weak power of ethics (including sustainability) over personal and business interests,[8] students may see sustainability as a noble but vague and entirely unreachable state of affairs.

Previous research studies in engineering education have highlighted the fact that students often bring into the classroom views of sustainability that reflect both the broad and confusing definitions of sustainability in national and global circles and a narrow view of what engineers are capable of impacting and desiring to contribute to improved sustainability practices. 'Typical' engineering-oriented definitions tend to focus on the physical attributes of technology and their contributions towards sustainability. [9,10] In a study of graduate-level mechanical engineering students, Bernstein, et al.[9] revealed students' limited interpretations of the applicability of sustainability to product design. Responses to an open-ended questionnaire from eight groups, each with 4-5 students, relied heavily on modularity, using renewable materials, and extending product lifetime as solutions to improving sustainability and often neglected consideration of environmental impacts of manufacturing processes and end-of-life logistics. Students had narrow conceptions of inputs and externalities of a product's entire lifecycle, with one group defining energy as the only input that impacts the environment during a product's use and another group failing to consider environmental impacts from the supply chain process. These students frequently portrayed sustainable design as a separate and secondary process from the generic product design approach rather than an integral part of the engineering design cycle.

Similarly, a study of sophomore, senior, and graduate civil engineering students showed a tendency to relate sustainability to the technical aspects of design.[10] Of the 28 sophomore students surveyed by Burian,[10] most could provide relatively narrow definitions of sustainability, including building structures with long lifespans or using materials with minimally damaging extraction processes. The few sophomores and three out of 22 (13.6%) seniors that could identify specific cases of sustainable design could only describe the use of recycled materials as examples. Clearly, engineering students in these studies tended to favor specific definitions of sustainability within the context of product design and manufacturing over more far-reaching philosophical conceptualizations. When pressed for generalized definitions for sustainability in Burian's study,[10] very few sophomores (14.3%) and almost half (47.6%) of seniors could recognize that the term refers to meeting the needs of the present generation without compromising the needs of future generations.[1]

An overwhelming majority of engineering students expressed concepts of sustainability, whether general or more specific, in terms of ecological impacts. Socially-oriented definitions of sustainability were few and far between. Few of Burian's[10] civil engineering seniors (19%) and graduate students (50%) could identify the Triple Bottom line, defined by John Elkington[11] as an accounting framework to consider social, environmental, and economic "pillars" of sustainability for project planning. The Brundtland Report similarly bases true sustainability on three dimensions; eco-, techno- and socio-centric dimensions.[1] Other studies show that engineering students struggle to consider ethics at a society-level. Referencing the frequent use of case studies to discuss ethics in engineering education, Seager and Selinger[13] suggest that most students think of ethics in a personal and individual professional context, but are unable to handle socially complex issues like sustainability.

Studies of both undergraduates[14,15] and graduate engineering students[13] describe resistance from engineering students to the introduction of sustainability topics in the curriculum. This hostility seems to emerge from perceptions of sustainability as being unrelated to technical concepts or not within the scope of students' professional interests. Students even misconceive sustainability as a burden to efficient product design.[9] Many studies show that students perceive significant barriers to their ability to implement sustainability. Students surveyed by Bernstein, et al.[9] were skeptical about their ability to design green products, the receptiveness of industries to incorporate greener materials or manufacturing techniques, and the ability for start-up companies to afford to spend time on sustainability without government funding. Burian[10] also points to another barrier perceived by students, noting that civil engineering students in a design course that had failed to incorporate sustainability into their projects did so because the companies or agencies they interned with did not incorporate sustainability.[10] Even in a study of students taking an energy and fuel class at the high school level, students lacked the knowledge or confidence that they as individuals could have an impact in taking actions towards energy solutions.[16]

This Study: This study complements the existing research by examining the preconceptions, misconceptions, and attitudes that electrical and other engineering students hold regarding sustainability and sustainable technology that are likely to affect how educators choose to integrate these issues into electrical engineering courses and curriculum. We begin our analysis with an exploratory series of interviews and focus groups designed to elicit a broad range of student ideas and attitudes regarding how sustainability intersects with engineering. Coded data and results from this qualitative analysis are expected to inform a larger quantitative study to understand how prevalent certain ideas and attitudes are and subsequently, interventions that capitalize on this knowledge as a point of departure for infusing sustainability into engineering curricula.

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 begin 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 (Figure 1).

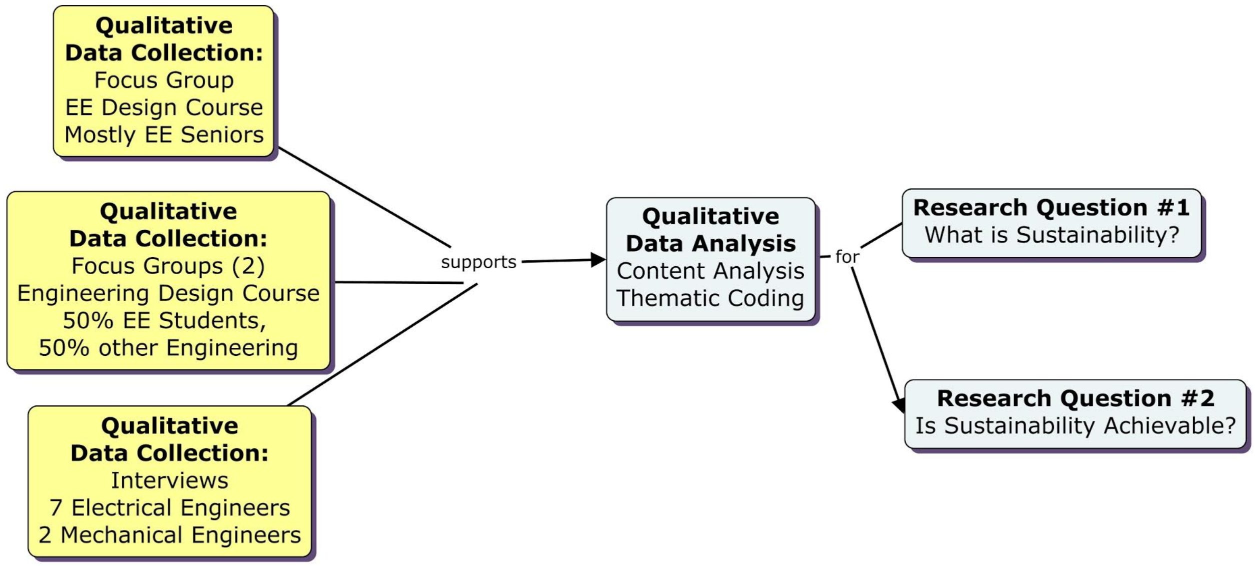

Figure 1: Research Design

A. Research Questions

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

Research Question #1:
What does it mean for technology itself to be sustainable?
This research question is important because it provides information regarding the preconceptions and misconceptions engineering students (primarily electrical engineers) bring to the classroom with regard to sustainability and sustainable technology development. Answers to this research question can potentially allow educators to understand how to initially engage students in sustainability education in electrical engineering by constructing real-world examples of sustainable practice, analysis, and design around concepts that are both familiar and interesting to students. Exposing any misconceptions students may have regarding issues of sustainability in technology also helps instructors spend explicit classroom and curricular time on these misconceptions to redirect them to more accurate baseline knowledge. This study allows for a comparison of attitudes and perceptions voiced by electrical engineers and those expressed by closely related engineering majors, both in this study and other related studies.

Research Question #2:
Is sustainable technology achievable?
The answer to this question speaks to the challenge of motivating electrical engineering students to take on the complex and knotty problems that are often embedded in considerations of sustainability. If students do not believe that sustainable technology is a realistic goal, they are unlikely to deeply or broadly engage in discussions and learning around challenges of sustainability. This question has also been addressed in other engineering fields and other studies and the results of this study will give us more insight into how generalizable convictions of powerlessness with respect to sustainability are among our engineering students.

B. Subjects and Procedures

Three groups of engineering students were involved in this study. The first group consisted almost entirely of electrical engineering students in a senior capstone design class: Sensors and Sensor Systems (hereafter referred to as Sensor Systems). Students in this class were organized into an in-class focus group after a short, initial introduction to sustainability was provided by the course instructor in the context of the sensor systems and design focus of the course. All but one student in this focus group was an electrical engineer; the remaining student was majoring in mechanical engineering. The second group consisted of students in a multi-level (sophomore, junior, senior) overview course: Sustainable Design for the Developing World (hereafter referred to as Sustainable Design). These students were organized into two in-class focus groups consisting of more than half electrical engineers but also including mechanical engineers, and pre-engineering majors. The third group of students was interviewed and selected from three courses (Sensors and Sensor Systems, Sustainable Design for the Developing World, and Advanced Technical Writing) for their sophistication and maturity regarding technology issues, as expressed through assignments in the three courses. Students were recruited by e-mail using approved IRB recruitment protocols. Six of these students were electrical engineers and two were mechanical engineers. No students participated both in an interview and a focus group. Demographics by major and population for each interview and focus group are summarized in Table 1.

Table 1: Demographics of Student Participants in Interviews and Focus Groups

Participant Pool	Major(s)	*N*	Ethnicity	Gender
Focus Group Sensor Systems	Applied Math (1) BioEngineering (1) Electrical Engineering (4)	6	Asian (3) Caucasian (3)	Male (5) Female (1)
Focus Group Sustainable Design 1	Business (1) Electrical Engineering (9) Materials Sci & Eng (1) Mechanical Engineering (2) Physics (1) Pre-Engineering (6)	20	Asian (13) Caucasian (7)	Male (18) Female (2)
Focus Group Sustainable Design 2				
Interview: John	Mechanical Engineering	1	Caucasian	Male
Interview: James		1	Unknown	Male
Interview: Matt	Electrical Engineering	1	Caucasian	Male
Interview: Todd		1	Asian	Male
Interview: Susan		1	Asian	Female
Interview: Karen		1	Asian	Female
Interview: Mary		1	Asian	Female
Interview: Amy		1	Asian	Female
Interview: Steven		1	Caucasian	Male

C. Instruments

Focus Groups and Interviews: The purpose of the focus groups and interviews as relevant to this study was to understand more fully how students view sustainability, what interests them about it, and what they think is possible with regard to contributing to sustainable technology development as an engineer. To engage the student(s) in the focus group or interview, the researcher first asked some icebreaking questions:

- In your <specify> class, identify a technology that is most interesting to you around which you have structured your <design, writing, or similar assignment>.

From here the researcher asked follow-up questions focusing on the sustainability of the technology introduced by the student(s) in the first question:

1. If you were working as an engineer in the field of this technology (including design, managing, manufacturing, etc.), what role would you take to promote sustainability?
2. If you were working as an engineer but NOT in this field, what would your role be in terms of <this technology's> sustainability?
3. What does it mean for technology, in general, to be sustainable?
4. How do you believe technology can be most used or applied to support sustainability?
5. What do you believe are the most critical barriers to sustainability in the world today?
6. What do you believe are the most underestimated sustainability issues in the world today?
7. Now let's think about an ideal world – if you were the CEO of the biggest company producing <this technology>, how would you address the issue of sustainability?

Student responses from question #3 were coded to answer Research Question #1 although sometimes student remarks made during other types of the interview/focus group also informed this question. Research Question #2 was primarily addressed by coding the last question in the list above although students sometimes commented on their attitudes regarding how realistic sustainability is for engineers to achieve in technology development in their responses to other questions.

Each focus group lasted approximately 45 minutes and involved between six and ten students in each group. Focus groups were facilitated by one to two researchers, who followed a semi-structured protocol that included the above questions. Interviews lasted less time, from 15 to 45 minutes and were facilitated by a single researcher. A total of nine interviews were conducted. Audio recordings were made, with consent from students, for all focus groups and interviews and were subsequently transcribed for analysis.

D. Data Analysis

All interview and focus group transcripts and field notes were analyzed qualitatively in order to answer the two research questions. A preliminary coding scheme was developed based on the research questions, was piloted with 3 sets of field notes and 2 transcripts, and refined in order to more fully capture data relevant to the research questions. Full coding and content analysis of all qualitative data were then conducted, in order to identify relevant concepts within the data, as well as emerging trends and themes.[17,18,19] Thematic coding was then done in order to more fully understand the identified themes, first using a lens focusing on addressing Research Question 1, then a second pass focusing on Research Question 2.

Results and Discussion

In talking about sustainability with regard to technology and technology development, most students chose most often to be talk specifically about product attributes that could lead to more sustainable product design and use practices. Some students drew on more generalized views of sustainability that extended beyond technology and were similar to the broader more established definitions offered by the Brundtland commission and the Triple Bottom Line. When considering what was achievable, some students echoed the skepticism and resistance revealed in previous studies. Yet, a surprising majority of students came up with creative solutions to supporting sustainability in high tech corporate environments, expressing a can-do attitude to supporting sustainable technology over the long haul.

A. Research Question #1:

What does it mean for technology itself to be sustainable?

In order to understand how students defined sustainability, we analyzed their references throughout the interviews and focus groups for comments that demonstrated what participants thought could be done in order to improve sustainability of technology. We also focused on responses to the following question:

"What does it mean for technology, in general, to be sustainable?"

Student definitions that incorporated a global view of sustainability varied widely from informal to more formal, but were far less frequent than operationalized definitions related to a limited number of product attributes. Details regarding each type of response are discussed next.

Global Definitions

To assess students' global views of sustainability, responses were analyzed for references to the three dimensions of sustainability – the economic, social, and environmental.[1,11] Student descriptions of a broad definition for sustainability varied from formal to informal, and tended to focus more on environmental aspects of sustainability. Two electrical engineers gave more formal definitions that closely mirrored the Brundtland Commission[1] definition:

> "<There> is the currently accepted definition for sustainability, as in not jeopardizing the needs of generations after us…I would say to be sustainable it needs to use a certain amount of resources and these resources that it uses…should produce something that will have a long term effect on the generations after" -- *Todd, Electrical Engineering*

> "I think the best definition that we talked about was that when a sustainable product or sustainable system…is one <where> the needs of…the current generation are fulfilled without compromising the needs of the next generation." -- *Matt, Electrical Engineering*

Other students used more informal descriptions of global sustainability. Many students focused on environmental impacts with informal definitions, with one student even suggesting that the term was empty of meaning because it implied a level of perfection that was simply unattainable:

> <Sustainability> means to keep using things without causing anything horrible. -- *Field Notes, Sensor Systems Focus Group*

> "<Sustainability> means it's sustainable for the environment, so it's not harming the environment..." -- *John, Mechanical Engineering*

> "Even if it says <it's sustainable>, somehow, it is not sustainable. Nothing could be perfect.

> You can at least try to minimize the bad impacts, but nothing is perfect." -- *Susan, Electrical Engineering*

Two students admitted that differences in the definition of sustainability are common, and that these definitions create confusion in using the term in a meaningful or consistent manner:

> "In all <my> classes I always end up forgetting what that professor defined at the definition of sustainability…there's a lot of ways to define it. And one of the classes was in the Forest Resources Department. And so the definitions we were using in that class were very different from the definitions <used> in this <electrical engineering> class." -- *James, Mechanical Engineering*

> "I have a pretty okay idea of sustainability after interning at certain places and maybe taking a few classes but maybe that was in high school. I feel like the first day of class in <my electrical engineering class>, <the professor> asked the class if anyone knew what sustainability is and nobody raised their hand. I mean I knew and I didn't raise my hand, but at the same time I feel like there's a lot of people who love to talk in that class so someone probably should've said something like, 'Yeah, this is how it works.'" – *Karen, Electrical Engineer*

From the wide variety of responses and views of what sustainability means in general as well as the tendency to emphasize specific product attributes (described next), we can identify a need as educators to define sustainability in a single, reliable, and consistent way that is repeated throughout the course of an engineering curriculum. Such consistency in terminology appears to be a first and necessary step to making sustainability an approachable and manageable goal both during the undergraduate years and beyond.

Operationalized Definitions

All students referenced sustainability in more focused, operationalized terms, reporting five components of sustainable technology: longer product lifetime, reduced product energy usage, decreased use of materials, minimal toxicity of materials, and improved recycling and disposal (Table 2). These definitions of sustainability centered around the physical aspects of a product and tended to relate more to environmental impacts rather than economic or social impacts.

Table 2: Operationalized Definitions of Sustainability

Theme	Extended Product Lifetime	Reduced Energy Usage	Reduced Use of Materials	Reduced Toxicity of Materials	Improved Recycling & Disposal
Focus Groups					
Sensors	X	X	X	X	
Sustainable Design 1	X				X
Sustainable Design 2	X				X
Interviews					
John, Mechanical Engineer	X	X	X		X
James, Mechanical Engineer	X				X
Matt, Electrical Engineer	X		X	X	
Todd, Electrical Engineer	X	X	X		

Susan, Electrical Engineer	X	X		X	X
Karen, Electrical Engineer	X				
Steven, Electrical Engineer	X	X	X		X
Mary, Electrical Engineer	X		X	X	X
Amy, Electrical Engineer	X	X	X	X	X

Extended Product Lifetime

In all individual interviews and focus groups, engineering students discussed the role of extended product lifetime in supporting the sustainability of technology. Some felt products should be designed for longer lifetime with a reduced need for replacement, or as some viewed it, reduced temptation to replace an aging device. For example, a student in the Sustainable Design class thought the following solution to be a sustainable one:

> If there's a way to make them <technology> more personalized… for example, if you could have ways to put some parts of the product in the way that you would like it to be, you might be more personally attached to the device and keep it longer." -- *Field Notes, Sustainable Design Focus Group*

Others were more general in their emphasis on extending product lifetime through better design. For example, another student in the Sustainable Design focus group mentioned the need to make products with a better design at the outset, so it would become impossible to launch a design twice as good twelve months from now. James, a student interviewed from mechanical engineering, reinforced this emphasis on making phones that last longer and the important link that product lifetime has to sustainability:

> "Make products that are intended to last a long time. A new iPhone comes out every three weeks. That's not sustainable…Apple is very happy in the materials they are using for their iPhones, but if you are going to buy a new one in three years, that's not very sustainable." -- *James, Mechanical Engineering*

John, a student interviewed in electrical engineering, echoed this same concern:

> "Designing phones to be used for more than a year and a half is probably the best way to do it <make sustainable products>" -- *John, Mechanical Engineering*

Still other students spoke to specific subsystem improvements that could extend product lifetime in the interests of sustainability. The *Sensors* focus group emphasized this theme throughout the focus group by suggesting the pursuit of modular phone designs and the development of lasting and durable batteries.

Others thought it was the consumer's responsibility to support the sustainability of technology by holding onto products longer before disposing of them for a newer design. For example, an engineering student in the *Sensors* focus group stated:

> …the fact that some people buy every phone every two years but most probably can't afford that so they stick to the same phone for 5 to 10 years -- *Field Notes, Sensor Systems Focus Group*

And Amy, an electrical engineering student, emphasized this same theme:

> *"*When you think of old devices and you want to get a new one, I would like the idea that, okay, can you take it some place and replace the damaged part, but nowadays they make it so expensive, you don't think it's worth fixing it, it's cheaper to buy a new one." -- *Amy, Electrical Engineering*

Overall, students in all interviews and all three focus groups mentioned the importance of product lifetime in being a part of sustainable technology. Many returned to this theme multiple times during the interview and focus group. This emphasis might be a direct result of the design emphasis of the classes in which students were recruited (e.g. Sustainable Design, Sensor and Sensor systems design) or the age (senior) of students where the curriculum is more invested in design than analysis or theory. Regardless, students' comments in this area related more to the engineer's responsibility and the corporate role in extending product design rather than the role of other stakeholders, including the end consumer.

Reduced Energy Usage

Despite the fact that many students in the focus groups and interviews were enrolled in an electrical engineering department which has a nationally recognized program in power and renewable energy systems, only one student spoke of sustainability in terms of renewable energy technologies. This lone student stated:

> "The main sustainability I'm interested in is hydro-power and wind, renewable resources. Looking at how much energy they save, looking at fossil fuels and how much pollution they produce." -- *Steven, Electrical Engineering*

Other students vaguely mentioned using less power as a goal of sustainability, but didn't develop this idea with much depth. Comments such as the following were common:

> "I would try to make more devices that … can do more with less power." -- *Susan, Electrical Engineering*

> "…something that uses less power. If something can charge up quickly, it takes up less energy." -- *Amy, Electrical Engineering*

One student clearly made reduced energy usage a second priority in the design process:

> "The engineers that are developing, the first step is just to make it work first, but after it works, you see all these major power consumptions or other negative effects, you should try to minimize those the best you can and if you can't, maybe move on to a different solution." -- *Todd, Electrical Engineering*

Thus, although students realized that energy consumption was a part of the sustainability puzzle, most did not pursue the idea much further than generalized statements regarding its importance.

Reduced Use of Materials

While students see the need to extend the lifetime of products in order to reduce the number of devices produced and consumed, they are less consistent in addressing reductions in components (e.g. materials, energy, etc) as a parallel strategy to improving the sustainability of technology. Student comments on the reduced use of materials were highly generalized and infrequent. For example, a student in the Sensors focus group stated:

> If, in the process of making it…it uses less materials that can be replenished to make it -- *Field Notes, Sensor Systems*

John, an electrical engineering student was more specific, advocating for reducing the use of freshly mined materials (and moving instead to greater use of recycled materials). However, the majority of students who advocated for reduced use of materials did so through the process of making products ever smaller:

> "They're trying to make <chips> faster and smaller, and to me, smaller means using less material…that's much more efficient, using less material instead of a big factory and later it would be a smaller piece of junk." -- *Amy, Electrical Engineering*

While Amy recognizes that using fewer materials is a good thing to do, she does not connect it to how a smaller device will become a sustainable device once it becomes junk. Steven also comments on reduction in device size but does not connect it to a more sustainable world:

> "We can use technology to reuse a lot of those components or use technology to use less…we use less and less and smaller and smaller things…we're actually improving a lot." -- *Steven, Electrical Engineering*

Implicit in these students' comments seems to be a generalized view that ecological sustainability can be realized with smaller products. However, this viewpoint did not take into account increased global consumption or the waste stream of these devices as barriers to sustainability.

Overall, students in 5 of 9 interviews (55.6%) and one focus group mentioned the importance of reducing materials in high tech products as being a part of sustainable technology development strategy. This may be a result of the absence of materials engineering majors in the study pool or it may reinforce the theme that students tend to view sustainability from the end-of-life perspective of technology (e.g. the grave) rather than the cradle phase.

Reduced Toxicity of Materials

While most students among those who participated in focus groups and interviews had been exposed to the toxic effects of electronic and related waste on both human and ecosystem health, reduced toxicity in electronic devices was discussed only rarely. However, students that did mention this issue were able to move beyond environmental impacts of toxicity and could easily connect it to social and economic aspects of sustainability. A few students also touched on the full spectrum of global injustice (environmental economic, and social) of electronic waste recycling and disposal:

> “With poor countries, the recycling technology is not developed, so they do it poorly. They recycle in their backyard without any protection or equipment to keep them safe. It’s so much more expensive here, so that why we go and donate it. It <will> hurt their health, public health, environment….For example when they try to extract gold…they burn with chemicals and you’re left with the residue that goes into water and air and soil. Everything got polluted. And later they grow their crops and it gets into the food chain and its stays there.” – *Amy, Electrical Engineer*

> “<the U.S.> is number one in producing e-waste and number two is <the> United Kingdom and we are all just discarding the electronic waste and throwing them as dumps in developing countries. And that’s where you can see as…in Southern China where all you can see is e-waste from developing countries and the children are going through many diseases just because it’s not being handled properly but here we don’t know about it…They burn it and the smoke is harmful to breathe. The waste is going into water and they are consuming that water and they’re using the same water to grow vegetables. So in return they’re getting those harmful chemicals like silicon lead in their food and they’re having brain cancers, all kinds of diseases. What really hurts is we don’t know… in the U.S. we don’t know anything about it because we don’t see it anywhere so we’re totally unaware of what’s going on although it’s one of the major problems in the world.” – *Mary, Electrical Engineer*

Overall, students in 4 of 9 interviews (44.4%) and only one focus group mentioned the importance of reduced toxicity of materials in high tech products as being a part of sustainable technology strategy.   This result was surprising considering most students’ exposure to electronic waste in their programs.

Improved Recycling and Disposal

Improving recycling and disposal of technology was commonly mentioned in relation to other issues of sustainability, including longer product lifespans and reducing toxicity of materials, under the theme of electronic waste. Most students had been previously exposed to the topic of electronic waste in classes, so it is understandable that it was the most popular example of this definition. When students were asked how they as engineers or CEOs could potentially improve the recycling or disposal of a product, students frequently suggested using increased modularity to allow for product components to be used longer, thereby generating less waste:

> “When you think of the old devices and you want to get a new one. To me, if my laptop gets really old, I like the idea that…you take it someplace and just replace the damaged part. But nowadays, they make it so expensive that you don’t think it’s worth fixing it. It’s cheaper to buy a new one.” -- *Amy, Electrical Engineering*

> “I would make sure that my company…whenever something breaks, people break it <and> we’ll take it back. Use the <old> one or try to fix it. If not, try to use the useful components of that try to build a new one. And the components that <get> disposed should be ecofriendly...we’re not going to throw them away or just trash them.” -- *Mary, Electrical Engineering*

> “We can also talk about electronic waste, where as we can try to reuse a lot of components instead of throwing it away” – *Steven, Electrical Engineering*

> Better plan for disposal rather than just thinking of a new one. More holistic approach to recycling and disposal. -- *Field Notes, Sustainable Design Focus Group*

A few students were skeptical that companies would be the ones to take the first step towards encouraging recycling. James, a mechanical engineering student, expressed the concern that the demand for recycling would have to come from consumers first:

> "A lot of people don't care and don't use it (recycling), so they (the companies) haven't developed it further." – *James, Mechanical Engineering*

Some participants were more positive and had creative ideas on how to encourage both consumers and companies to recycle products:

> "There should be booths in every street or every area where you can go to dispose or recycle their products, take <them> back. Not that people have to go or pay for shipping…Some companies want you to recycle their products and they can reproduce them and make them better, but not every company is doing it… I have seen some companies that are taking your old equipment back and then giving you a new one. It's not everywhere (in the US)." -- *Mary, Electrical Engineering*

Overall, students in 6 of 9 interviews (66.67%) and two focus groups mentioned the importance of improved recycling and disposal practices for high tech products as being a part of sustainable technology strategy. While students could only give examples of recycling and disposal improvements in reference to electronic waste, this may be in part due to students having been introduced to it in previous classes. However, when pressed for other examples of improving recycling of other technologies students offered limited suggestions of using more eco-friendly products to prepare technology for being disposed of in landfills.

In summary, the engineering students interviewed could more readily offer operationalized definitions of sustainability than they could broad, global definitions. Global views of sustainability tended to be rather informal, and students acknowledged that an over-arching definition wasn't something they were comfortable with. It is possible that a definition that could reconcile both the global and more technical aspects of sustainability would be readily accepted by engineering students. Operationalized definitions encompassed a broad scope of a product's lifecycle. Occasionally, some definitions, such as using less energy, were not developed in-depth and were merely stated as a component of environmental sustainability. However, other topics, like reducing the toxicity of materials, did manage to pull descriptions from students that highlighted an understanding of sustainability to incorporate social and economic impacts of technology. Using global topics such as electronic waste and its disposal might be ones that can help engineering students to think about economic and social impacts at a grander scale than using case studies that focus on specific types of technologies.

Research Question #2:
Is sustainable technology achievable?
In order to draw out students' views on whether or not sustainability in our global society is

achievable, and if so, to what degree, we focused on interview and focus group responses to the following interview/focus group question:

Now let's think about an ideal world – if you were the CEO of the biggest company producing <this technology>, how would you address the issue of sustainability?

While data was also drawn from throughout the interview/focus group transcripts when relevant, the question above served as a springboard for coding date addressing this research question. This coding and analysis resulted in four categories into which students' views on the viability of sustainability fell: 1) Skeptical, 2) Resistant, 3) Cautiously Optimistic, and 4) Can Do (see Table 3).

Table 3: Views on Sustainability -- Frequency of Participant Responses by Category

	Skeptical	**Resistant**	**Cautiously Optimistic**	**Can Do Approach**
Interview Responses	3	1	3	8
Focus Group Responses	2	1	3	9

These four categories are further explained and illustrated with interview and focus group data below.

Skeptical: Responses in this category were consistent with other studies[13,14,15] in which students generally believed sustainability and sustainable technology to be worthwhile goals, but questioned the ability of these goals to compete with more profit-oriented motives in the corporate world. For example:

> "When you're the CEO, there's a board that says, 'No. You can't do that, because we won't make as much money,' you know. … That's the problem." -- *Matt, Electrical Engineering*
>
> One students says that if he were the CEO, he thinks that generating as much profit as possible is the primary role of the CEO. -- *Field Notes, Sensor Systems Focus Group*
>
> One student thinks that a person cannot be a CEO if one is a "tree hugger." The CEO needs to generate profit, not invest in something that won't make money. Of course many companies have ideas about sustainability in their mission statements, but who really does that? The student had doubts. -- *Field Notes, Sustainable Design Focus Group*
>
> "[The company] would go out of business [if it made sustainable products]. So you [the consumer] buy this [product] and you fall in love with it, but it's designed to be thrown away every year. And then you get the exact same one, and you're still as attached to it." -- *James, Mechanical Engineering*

Resistant: Responses in this category were also consistent with previous studies in that students had doubts about the feasibility of sustainability, similar to the "skeptical" responses described above. However, the responses coded as "resistant" were of a more personal nature, hinting at the students' own resistance to focusing on topics of sustainability. For example:

> "[For example], saving trees. I know it's a good thing, but I think that's…too much, yeah. I mean, that's everywhere. 'Go green, do this.' I mean, no, I totally understand. … We should try saving those things, but…." -- *Susan, Electrical Engineering*

Cautiously Optimistic: Although, as described above, a number of students' responses were consistent with previous studies, even more students added a "cautious optimism" to their recognition of the barriers to sustainability. Students whose responses fell into this category understood the limitations of traditional corporate economic models in being able to support a meaningful push toward sustainable technology, yet were optimistic that steps can and should be taken in the direction of producing more sustainable products. Some students, in imagining themselves in positions of power, considered ways in which they could use that power to make progress toward sustainability:

> "I think as CEO you might have more power to make, to market, the product in a certain way, to make your phone a sustainable phone maybe. I think you just have more power to sort of do the things that as a design engineer you might have wanted to do. … Like, you want to use the materials that cost little more. Now you have the executive authority to sort of do it." -- *Matt, Electrical Engineering*

> "I would try to [make products sustainable]. I'm not sure if it's possible or not, but I would try." -- *Mary, Electrical Engineering*

> "Instead of being motivated by something else, maybe I can be motivated by, as I'm designing a product think about, 'Will this be sustainable for the future generations?' and things like that. I think lots of people that are concerned about cutting profits make enough money already. And they could take a pay cut and still be living comfortably." -- *John, Mechanical Engineering*

Other students offered examples of companies that already do consider sustainability, and are successful. For example:

> You have to make a profit. But still think about how you can reduce damage to the environment. For example, Tesla pushed through their electric car, and the company is doing well. Now they're putting money into space projects and solar power. -- *Field Notes, Sustainable Design Focus Group*

Can Do: Moving a step beyond the "cautiously optimistic" category, several other students jumped immediately to creative solutions, often expressing little concern about potential barriers. These responses were coded as reflecting a "can do" approach.

For some students in this category, the impacts of sustainability (e.g., protecting people's health or the environment) were immediately prioritized, without getting into great detail about how the company might achieve that sustainability:

“[The product] shouldn’t be harming people’s health. That’s my main priority, even before the environment. It shouldn’t be affecting people’s health at all. So I think that’s it. … So I’ll just make sure all the products my company makes, those are all eco-friendly.” -- *Susan, Electrical Engineering*

“I would definitely make [my company’s product] reusable. Also…the first thing is, so the disposables, I’m not going to transfer or dump them to another country. That’s not what’s going to happen. Because if something is happening, it should be happening in my country, in my area so our people can face the consequences. … We don’t know what’s going on, but there, whole generations have been getting affected. … People will be more aware of it and we can take care of it. … For my product I would…take care of how it’s being made, its production. And make sure we are not using the nonrenewable components in it. Second of all, I would make sure that my company is not producing a new product every year. We’ll make sure that its life expectancy is a little longer, but not every year. And also…whenever something breaks, we’ll take it back. Use the [same] one or try to fix it. If not, try to use the useful components to try to build a new one. And the components that get disposed should be eco-friendly. We’re not going to throw them away or just trash them. We’ll make sure of that.” -- *Mary, Electrical Engineering*

Other students offered more concrete ideas for corporate leaders to maintain profitability while investing in sustainable corporate models. For example:

“I would want business analysts or statisticians to come up with a way to measure [the company’s] sustainability or the sustainability of the products that we produce. And also the cost effectiveness, and know if there’s a way to satisfy both to a good extent, then we should try to aim for that. … You have to do whatever you need to make it work first without harming people or others or doing anything illegal. But once you have it working then definitely for sure try to minimize it, and not just for the profit but minimize it for the sustainability portion of it too.” -- *Todd, Electrical Engineering*

“It’s hard enough thinking about the products already, so it would probably take like another month to make it completely sustainable.’ So I’m just thinking that it would be easier if there was another department that only focused on how to make [products] sustainable or certain requirements they’d have to fill, and I would just expect that to be put across the company.” -- *Karen, Electrical Engineering*

“When you have something for a long time then you feel attached to it. If you can somehow create a product, or multiple products, that everyone who buys your products will have one product that is specifically designed for them, and it works the very best for them, then they'll keep it for a long time. And that's really idealized because that means…if somebody wants a phone that's going to last for five days without charging, then the batteries in it are not going to have any toxic chemicals and stuff. And when it gets thrown away then it gets disposed of in an environmentally conscious way and sustainable way.” -- *James, Mechanical Engineering*

More money from the company would go toward recycling the product.

> Marketing needs to make sustainability look cool. -- *Field Notes, Sustainable Design Focus Group*

> The student would form a specific research team filled with research folks and have them care about sustainability, and she would focus on making the bucks since she is the CEO and that's what CEOs do. She said she would act on sustainability as long as it is not extremely unprofitable. -- *Field Notes, Sensor Systems Focus Group*

> From one student's perspective, sustainability is not the issue, especially living in the U.S. It is an issue in developing countries, but here he could find a way to make more money. For example, he would buy the old iPads and utilize the materials used in the old iPad to make more money. He would be able to work for sustainability and earn money at the same time. -- *Field Notes, Sustainable Design Focus Group*

Still other students in this category thought more broadly, imagining ways in which companies could reach out further in order to make their overall impact more sustainable:

> "I would probably try to invest more into hydroelectric [energy], actually. … Wind energy maybe, too, but maybe not as much just because it's not as great as hydroelectric energy can be." -- *Steven, Electrical Engineering*

> One student would partner up with other NGOs or groups that work for sustainability and come up with better approach. -- *Field Notes, Sustainable Design Focus Group*

> One suggested he would build schools and churches and teach people about their products and sustainability so all they want is to buy his stuffs and live a sustainable life style. -- *Field Notes, Sustainable Design Focus Group*

In summary, the majority of the students in this study were more optimistic about the feasibility of sustainability than had been anticipated based on previous studies. Although some were clearly skeptical about the possibilities or resistant to the topic in general, most expressed at least some hope that the tension between profitability and sustainability could be resolved. The balance between enthusiasm for sustainable practices and recognition of practical, corporate constraints varied widely. However, it is encouraging to find that so many of the students offered creative ideas for overcoming perceived constraints, rather than simply dismissing sustainability as impractical or impossible. It should be noted that many of the responses coded as "cautiously optimistic" or "can do" came out of the Sustainable Design focus groups. These students were already immersed in a course focusing on sustainability, which may have influenced their thinking on such topics. This suggests that targeting sustainability issues within the engineering curriculum may be an effective way to impact students' understandings and beliefs about sustainability.

Limitations

We recognize that in drawing data from a single institution, the generalizability of our findings may be limited. However, the inclusion of engineering students from multiple levels in school and multiple majors in the study does allow for the representation of a wider range of student experiences. Despite the relatively small size of the data set, we feel that our findings are valuable, as they provide insight into how students define sustainability as well as their perceptions of how feasible it is to implement sustainability for technology.

Concluding Remarks

This study has offered insight into students' perceptions of sustainability for technology. Specifically, students tended to rely on informal or operationalized terms to define sustainability, with some students acknowledging that they and other engineering students lacked confidence in using a more formal or uniform definition. Students also expressed some general skepticism, but generally offered creative solutions and positive "can do" attitudes towards sustainability. However, interpretation of these results should take into consideration that many of these students had taken a sustainable design course or had discussed sustainability in other classes.

In summary, engineering students appear to be more comfortable with informal generalized views and focused definitions of sustainability that relates to their field of interest. Helping students to become more familiar with a consistent and more formal global definitions may help them to develop deeper thinking about its relationship to various technologies and their lifecycle stages. While most definitions of sustainability given by students focused on environmental dimensions, consideration of global issues such as electronic waste allowed for students to also connect technologies to the economic and social dimensions as well. Thus, once a consistent and familiar definition of sustainability is established, educators may be able to present students with global topics relevant to the student's chosen interests in order to demonstrate and solidify a more balanced definition of sustainability.

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