International Journal of Engineering Education Vol. 34, No. 6, pp. 1976–1986, 2018
Printed in Great Britain
0949-149X/91 $3.00+0.00

Do Engineering Students View Sustainability Differently from Students in Other Majors?*

DENISE M. WILSON[1] and MEE JOO KIM[2]
[1] University of Washington, Department of Electrical and Computer Engineering, Seattle, Washington 98195-2500, USA.
E-mail: denisew@uw.edu
[2] University of Washington, College of Education, Seattle, Washington 98195, USA. E-mail: mjk5ad@uw.edu

Despite emphasis on sustainable development by a variety of international organizations including the accreditation organization ABET, many undergraduates conceptualize sustainability in more narrow terms than internationally accepted definitions of sustainability and sustainable practice. This study examines the breadth and depth of student perceptions of what sustainability is, their beliefs regarding sustainability, and how they can and will contribute to a more sustainable future. Differences and similarities between engineering students and those outside of engineering in business, education and environmental majors are highlighted. Responses to three short answer questions from a survey administered to 228 engineering undergraduates and 186 undergraduates in other majors are thematically coded and analyzed qualitatively. Consistent with previous studies, many engineering students (almost 50%) and a majority of students outside of engineering (over 60%) operationalize sustainability as an environmental issue, neglecting aspects of social and economic equality that are widely recognized as being essential pillars of sustainable development. As professionals in their chosen profession, students see their most likely contributions to sustainability as reducing waste through recycling and reuse, making more efficient use of resources, and using renewable energy. When asked to identify what they are least likely to contribute to in terms of sustainability over their professional lives, students again point to reducing waste and making efficient use of resources. However, many also see contributing to public advocacy and policy change as well as creating sustainable products and structures as areas where they are unlikely to contribute during their careers. These results suggest that many students may misperceive sustainability as a vague concept that does not lend itself to action or that sustainable development is only an issue of environmental protection without regard to the promotion of social and economic equality.

Keywords: engineering education; environmental impact; sustainability; sustainable development; student beliefs

1. Introduction

According to the Brundtland Commission, "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1, p. 1]. International summits that followed the Brundtland Commission (the 1992 Earth Summit [2] and the 2002 Johannesburg World Summit [3]) formalized a broad conceptualization of sustainable development that extended well beyond protecting the natural environment to include economic and social facets of sustainable development. This formalized conceptualization of sustainability is complemented by the implementation-focused, globally recognized Design for Sustainability (D4S) framework developed by the United Nations Environment Program (UNEP) that specifically identifies challenges involved in creating a more sustainable future for all nations in terms of not only design for the planet but also for people (i.e., social concerns) and for profit (i.e., economic concerns). D4S extends beyond addressing traditional ecological concerns in product design to embrace meeting consumer needs in a more holistic sustainable way over the long haul. D4S strategies are invested in reducing negative social, economic, and environmental impacts of products throughout the supply chain as well as at the end of the life cycle and take a practical step-by-step approach to both incremental and drastic product redesign and innovation. The overarching goal for D4S is to enable companies to embrace all three major pillars of sustainability: environmental, economic, and social [4].

Particularly important for this study, D4S provides specific sustainability challenges across all three of these pillars [4, p. 24] that provide a framework by which the students' beliefs about how they will contribute to sustainability can be coded and analyzed. This study also uses the three foundational pillars of sustainable development (economic, social, environmental) as a lens with which to examine how students view or operationalize sustainability. This study emphasizes understanding how engineering students may differ in their views of sustainability compared to students in other majors.

2. Background

The Accreditation Board for Engineering and Technology (ABET) requires that accredited engineering undergraduate programs assess and evaluate how

* Accepted 16 July 2018.

well certain student outcomes are achieved. Among these outcomes is 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" [5]. While this outcome includes considerations of sustainability in the engineering design process, it does not provide specific guidance as to how these considerations should be integrated into the curriculum nor does it define sustainability for such purposes. Like the Education for Sustainable Development (ESD) initiative of the United Nations [6], this ambiguity may be intentional to allow for principles of sustainability to be tailored to specific disciplines. Such ambiguity has culminated not only in a lack of support for ESD and teaching sustainability, but also a lack of understanding of how to achieve the learning outcomes that have emerged in depth, breadth, and great numbers from the ESD [7]. As a result, while many university and college campuses in the U.S. have successfully adopted greening initiatives and pursued research in sustainability and sustainable development, pedagogical strategy to integrate sustainability topics into the curriculum at a deep enough level to achieve the objectives of the ESD has lagged far behind [8]. Despite the critical role that engineering plays in sustainability, much that is engineered remains unsustainable [9]. Such a phenomenon is not surprising considering that engineering students' understanding of sustainability is largely unsatisfactory [10]. As a result, the prospects for graduating engineers who can become effective change agents for social and environmental responsibility look grim. As with any shift in education and curriculum, developing effective teaching pedagogy requires first diagnosing and understanding the preconceptions, misconceptions, and missing conceptions students bring into the classroom [11].

Previous research studies in engineering education have predominantly focused on implementing sustainability curriculum and evaluating its effectiveness in changing students' cognitive knowledge and abilities. For example, recognizing that the crowded curriculum was a major barrier to implementing sustainability instruction in engineering, Bernstein et al. [12] chose to overlay a critique of the environmental sustainability of existing designs into a product design course. This problem-based learning approach was successful in teaching students to consider some environmental considerations of engineering design but the study also revealed that students viewed sustainable design as a secondary process in product design rather than an integral part of the engineering design cycle. In civil engineering, interventions designed to integrate sustainability into undergraduate courses improved students' definitions of sustainability, but these definitions remained rather narrow, including building structures with long lifespans or using materials with minimally damaging extraction processes [13]. In these studies, engineering students tended toward beliefs about sustainability that were restricted to contexts of product design and manufacturing rather than more far-reaching philosophical conceptualizations. Furthermore, engineering students' understanding of sustainability was largely restricted to ecological impacts and neglected social and economic pillars [13]. These limited views of sustainability have been compounded by individual student resistance, at both undergraduate and graduate level, to the integration of sustainability topics into engineering courses, which seems to be related to beliefs that sustainability is unrelated to the technical content in engineering curricula and is outside the scope of engineering education [14–16]. Such resistance supports the need to attend to not only cognitive outcomes from sustainability instruction but also to address affective learning outcomes [17] and to use hands-on learning to supplement abstract or conceptual instruction [18].

This study complements previous studies in engineering education on sustainability which have been largely quantitative and focused on cognitive outcomes with a qualitative study that casts a wide net across both student knowledge and student beliefs to not only assess whether their understanding of sustainability and sustainable development is satisfactory but also where exactly the holes are in that understanding. The open-ended short answer questions used in this study may avoid the potential roadblock that terminology associated with ESD, the Brundtland commission, and other initiatives and declarations pose by allowing students to express in their own words how they view sustainability and ultimately value it in their profession. This study also analyzes responses from both engineers and non-engineers in an effort to understand similarities and differences among disciplines. Such insight can support strategy for which elements of sustainable development should be implemented at the general education level and which are better suited for implementation within a specific discipline.

3. Methods

The goal of this research is to support the development of various tools for teaching sustainability to undergraduate engineering students by first taking a comprehensive look at how students view sustainability as future engineers. The intervention-based component of this research produced educational tools [19, 20] to support teaching sustainability in the traditional pedagogical culture of many engineering programs. The basic research component included a student survey with demographic, Likert-scale, and short answer items that assess student misconceptions, preconceptions, and missing conceptions about sustainability. While a previously published article from our group [21] focused on how engineering students define and operationalize sustainability and how these students anticipated contributing to a more sustainable future, this analysis looks at how those definitions of sustainability and beliefs about professional contributions are different between engineering students and students in other majors.

3.1 Research question

This study focuses on one basic research question: How do engineering undergraduates differ from undergraduates in other fields in their operationalization of sustainability and their anticipated contribution to sustainable practice? To answer this question, we evaluate three short answer questions from a survey administered to a broad population of undergraduates in engineering, business, environment, and education. The answer to this research question not only provides insight into how engineering students view sustainability differently from their peers but also how limited curricular resources might be best invested in introducing and exploring options for teaching sustainable practice in engineering programs.

3.2 Subjects and procedures

Convenience sampling was used to recruit 228 engineering undergraduates and 186 undergraduates outside of engineering at a single doctoral granting, high research activity, public university in the Pacific Northwest. In engineering, subjects were recruited in required and technical elective courses by offering extra credit for completing the survey. Outside of engineering, subjects were recruited by e-mail and offered a $10 incentive to complete the survey. Procedures were approved by the Institutional Review Board (IRB) prior to the start of the study. The study population was diverse and represented multiple engineering majors, ethnicities, and both genders. Characteristics of the study population are detailed in Table 1.

3.3 Instruments

The questions used in this study were part of a survey containing (a) basic demographics; (b) self-reports of self-efficacy, task value, belonging, job values, and professional identity; and (c) self-assessments of external social indicators including various facets of global citizenship and perceptions of professional and consumer responsibility for sustainable practice and development. Details regarding these self-assessments are published elsewhere [22]. These Likert-scale and multiple choice items were complemented by several short answer questions that sought to identify how students conceptualized sustainability and how they transformed their understanding of sustainability into action through contributions as a future engineer and consumer. In total, the survey contained more than a dozen demographic items, over 150 Likert-scale questions, and five short answer questions. Three of the short answer questions were analyzed in this study:

- How do you define sustainability?
- What do you believe your most important contribution to sustainability will be as a professional in your chosen field?
- What part of sustainability do you believe you

Table 1. Demographics of Study Population

		Engineering		Other	
		n	%	***n***	%
Total Participants		228	55.1	186	44.9
Gender	Female	40	17.5	56	30.1
	Male	188	82.5	130	69.9
Ethnicity	Asian American	111	48.7	69	37.1
	Black	3	1.3	4	2.2
	Caucasian	86	37.7	93	50.0
	Latina/o	11	4.8	9	4.8
	Middle Eastern/Arab	6	2.6	1	0.5
Year in School	Freshman	4	1.8	5	2.7
	Sophomore	13	5.7	21	11.3
	Junior	135	59.2	42	22.6
	Senior/5th Year Senior	70	30.7	100	53.8
Student Status	U.S. Citizen or Permanent Resident	174	76.3	165	88.7
	International	52	22.8	20	10.8

will be least likely to impact as a professional in your chosen field?

3.4 *Data analysis*

Responses to short answer questions were analyzed using qualitative methods involving a multi-step phase analysis consistent with that described in [23–25]. Short answer data were cleaned, de-identified, and aggregated into a single MS Excel spreadsheet before analysis. Four individual researchers analyzed the resulting data and inconsistencies were discussed and resolved prior to final coding and theme identification. Analysis of the first research survey question provided insight into how students operationalized sustainability and used the three pillars of sustainability (environmental, social, economic) as themes by which to deductively code the data (Fig. 1).

For the second and third survey questions, the sustainability challenges identified in the D4S framework were used as themes by which to deductively code the data (Fig. 2). Multiple passes at the data were used in all cases to deductively code the data into these established frameworks (the three pillars model of sustainability and the D4S sustainability challenges) and then inductively (bottom-up) code data that did not fit into the chosen frameworks.

For the first short answer question "How do you define sustainability?", the data were initially coded descriptively by the approach the student took to sustainability (e.g., self-sufficiency, recycle/reuse, conservation, efficiency) and the stakeholders affected by the approach (e.g., planet, people, economics). From this initial pass, coded data were then organized into three themes (social, environmental, economic) and interpreted within the global view that sustainability and sustainable development should extend well beyond environmental protection [1–6]. A third pass at the data further coded responses that could not be identified specifically by one of these themes, but spoke to a more generalized operationalization of sustainability such as self-sufficiency or maintaining the status quo. A final pass looked specifically for definitions that included concerns for both the current generation and the future generation, consistent with the definition of sustainable development put forth by the Brundtland commission and subsequent summits on the topic [1–3]. Responses that could not be coded after this fourth pass were placed in a separate category. For purposes of interpretation, the three pillars model of sustainability (Fig. 1) was used as

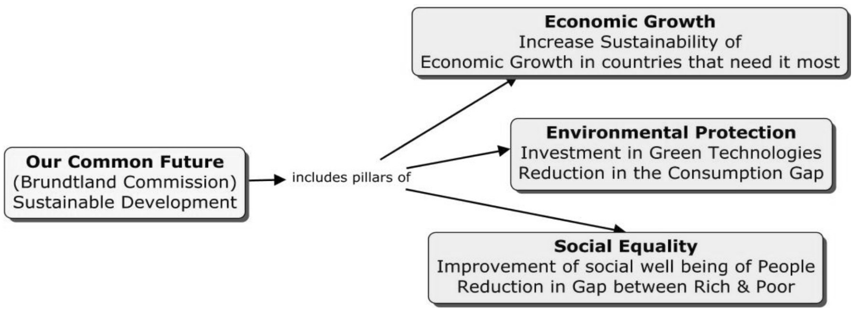


Fig. 1. Conceptual Framework for Interpreting how Students Operationalize Sustainability.

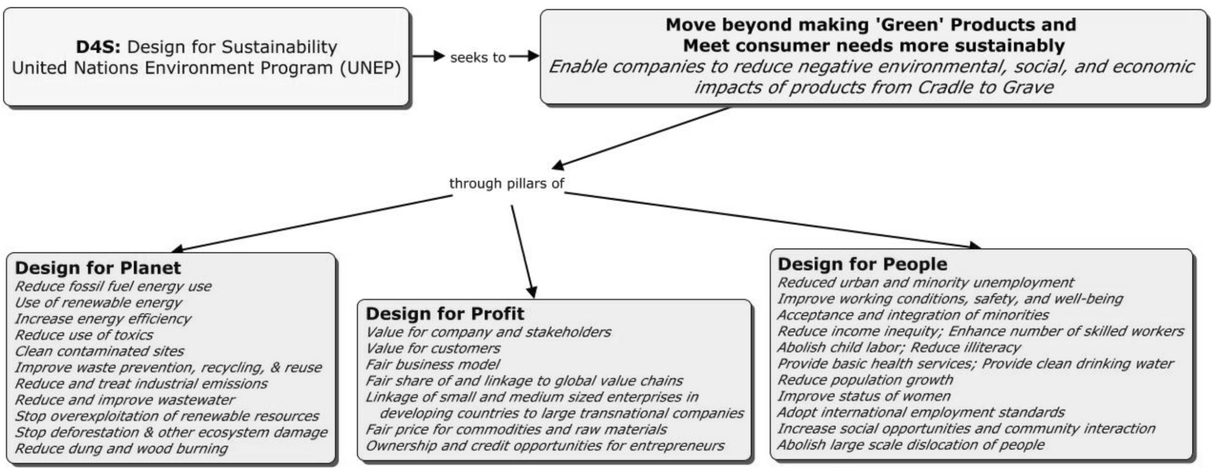


Fig. 2. Conceptual Framework for Interpreting Student Beliefs about Contributing to Sustainability.

the grounding framework by which the data were analyzed. A correct and complete operationalization of sustainability would include mention of social, economic, and environmental considerations, while a correct and incomplete response would include mention of only one or two pillars. Failure to mention any of the three pillars in a generalized or vague response is considered a misconception.

For the second and third short answer questions (most and least likely contributions to sustainability), responses were coded using the D4S framework outlined by the UNEP [4, p. 24] which outlines specific challenges to sustainable development in Design for Planet, People, and Profit. These data were coded by the type of contribution identified by the student in each response and then mapped thematically to the sustainability challenges identified in D4S. As with the first short answer question, responses that were too generalized to fit within a specific D4S theme were analyzed and grouped together according to commonality. Responses that clearly mapped to a specific challenge or challenges were considered accurate conceptions while those that were too generalized or far afield from these challenges were considered misconceptions.

3.5 Data quality

Multiple strategies were used to maintain the quality of data collection and handling consistent with the quality framework of Walther, Sochaka, & Kellam [26]. To optimize the validity of the analysis results, the data collected for all three short answer questions were coded according to globally accepted contexts for sustainability both through the three pillars of sustainability defined in Our Common Future (Fig. 1) and the planet, people, and profit challenges defined within the D4S framework for sustainable development (Fig. 2). Data collected from the three short answer questions were also triangulated to validate the conclusions. For example, all three short answer questions were analyzed in terms of which pillar of sustainability students tended to emphasize: social, environmental, or economic to ensure that emphasis on a particular pillar was not a consequence of the way a single question was posed. Data from the last two short answer questions addressing students' least and most anticipated contributions to sustainability allowed the research team to distinguish potential contributions to sustainable development to which students were unaware from those that students simply felt were outside the purview of their careers or professional interests.

Care was also taken during data collection and handling to ensure reliability of the results. Unlike focus groups and interviews where the prompts of researchers may expose researcher bias and thus influence student responses, the three questions analyzed in this effort were embedded in a survey which students took remotely, thus minimizing the impact of bias in the research and by the researchers. Reliability in data handling and interpretation was improved by having three different researchers code several subsets of data and using inconsistencies to refine the coding scheme and to enable convergence of results.

4. Results and discussion

Our analysis shows many similarities between undergraduate engineering students and undergraduate students in other majors with few differences. In particular, two themes emerge repeatedly from our analyses. First, many student responses are so generalized that they may be unable to define or take effective and significant action in their careers to support a more sustainable future. Second, among responses which are specific rather than generalized, concern for the environment overwhelms any mention of social or economic facets of sustainability. And, within responses indicative of protecting the environment, only a small number of sustainability challenges emerge.

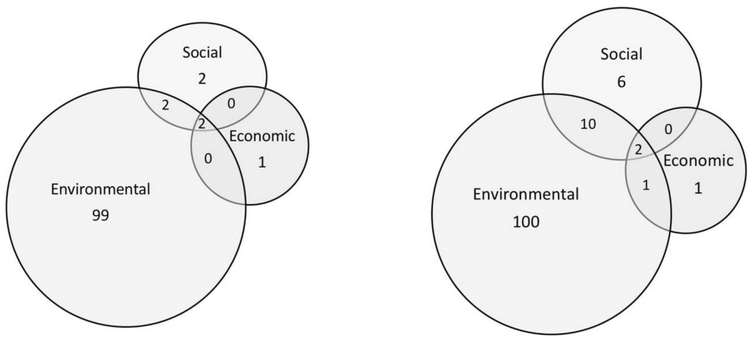
4.1 Operationalizing sustainability

When asked to define sustainability, most undergraduates (over 85%) did not contextualize it in terms of the Brundltand concepts of serving the needs of the present generation while not compromising the needs of future generations. Despite this missing conception, many students did operationalize sustainability in terms of protecting the environment. Complete results for this phase of the analysis are summarized in Table 2 and in Fig. 3.

Of those students who defined sustainability in terms of the environment, a majority viewed sustainability as an issue of conserving natural resources. For example, a male student in engineering stated that "Sustainability is . . . the preservation and careful use of resources to ensure that future generations will live to see those resources as well." In contrast, a female outside of engineering, in business, viewed sustainability as an issue of both conservation and environmental impact: "Sustainability: the practice of building, designing, and using things/processes in a way that allow for indefinite continued use with minimized impact on the environment." Another female in a business major saw sustainability as an issue of reducing environmental impact alone: "Taking care of the environment by reducing emissions." Similarly, a female in education viewed sustainability as reusing or

Table 2. Operationalization of Sustainability

Nature of Response	**Engineering**		**Other**	
	n	**%**	***n***	**%**
Sustainability is defined consistent with Brundtland Commission	23	9.8	36	19.4
Pillars of Sustainability				
Environmental Only	99	43.4	100	53.7
Social Only	2	0.9	6	3.2
Economic Only	1	0.4	1	0.5
Environmental and Social	2	0.9	10	5.4
Environmental and Economic	0	0	1	0.5
Environmental, Social, and Economic	2	0.9	2	1.1
Focus of Environmental Responses				
Conserve Resources	40	17.5	76	40.9
Reduce Environmental Impact	22	9.6	21	11.3
Renew, Reuse, Recycle	30	13.2	18	9.7
Other	16	7.0	9	4.8
Type of Generalized Responses				
Maintaining the Status Quo	23	10.1	16	8.6
Self-Sufficient Products/Processes	17	7.5	10	5.4
Long-Lasting Products/Processes	22	9.6	13	7.0
Needs of Present & Future Generation	1	0.4	10	5.4
Efficient Products/Processes	3	1.3	4	2.2
Other	49	21.5	24	12.9
Do not know	16	7.0	5	2.7



(a) Engineering Student Responses (b) Other Student Responses

Fig. 3. Operationalization of Sustainability in Student Responses.

recycling waste: "Being able to re-use something through recycling and composting."

While preservation or protection of the environment was a common theme among students' responses, certain more generalized responses were also quite common. For example, some students identified sustainability as an issue of self-sufficiency: "The ability to maintain something without additional assistance" (Female, Education) or of long-lasting products, systems, or processes: "Sustainability is something that you know will last for a significant amount of time and be dependable." (Female, Education) Several students kept their responses restricted to generalized dictionary definition of sustainability or variants thereof as in "The ability to maintain or endure." (Male, Engineering)

In many cases, the responses of engineering students and those in other fields were similar. Students tended to focus their responses solely on protection of the environment, although more so with students outside of engineering (53.7%) than within engineering (43.4%). Similar numbers of students both within and outside of engineering operationalized sustainability in general terms of self-sufficiency, long lasting products and processes, and maintaining the status quo. Many more students outside of engineering (40.9%) than students in engineering (17.5%) spoke to the conservation of resources as an essential element of sustainability, but similar numbers of student responses represented renewing and recycling resources as well as reducing environmental impact. A tendency to focus on protection of the environment is consistent with previous studies of engineering students' views of sustainability [12, 13, 15, 16, 21] as well as the emphasis on greening over social and economic issues among sustainability efforts on university campuses [27]. Many of the generalized responses

Table 3. Most Likely Contributions to Sustainability

Challenge/Issue	Engineering		Other	
	n	%	*n*	%
Planet				
Efficient use of Resources	33	14.5	23	13.9
Increase Energy Efficiency	32	14.0	3	1.6
Reduce Waste, Recycle/Reuse	25	11.0	37	19.9
Use of Renewable Energy	16	7.0	5	2.7
Reduce Fossil Fuel Use	3	1.3	3	1.6
Reduce use of Toxics	2	0.9	2	1.1
Stop overexploitation of Resources	0	0	3	1.6
Stop Ecosystem Damage	1	0.4	6	3.2
Other	29	12.7	19	10.2
People				
Increase Literacy	0	0	3	1.6
Improve Working Conditions	0	0	2	1.1
Reduce Population Growth	1	0.4	2	1.1
Other	2	0.9	7	3.8
Profit				
Value for Customers	0	0	3	1.6
Value for Company/Stakeholders	1	0.4	2	1.1
Other	2	0.9	4	2.2
Generalized				
Working in Chosen Profession	32	14.0	14	7.5
Influencing Local Community	32	14.0	12	6.5
Maintaining/Increasing Awareness	10	4.4	7	3.8
Teaching or Volunteering	4	1.8	22	11.8
Choosing a Company/Organization	1	0.4	6	3.2
Other	23	10.1	12	6.5
Do not know	11	4.8	13	7.0

among students reflect a tendency to poorly or inaccurately operationalize sustainability that is consistent with a previous multi-institution study of engineers conducted over a decade ago [10]. However, it is possible that the abundance of generalized responses to this question may be a result of the abstract nature in which it was posed. If this were true, we would expect to see more specific responses when asking a less abstract (more applied) question, as is the case with the remaining two short-answer questions in this study, discussed next.

4.2 Most likely contributions to sustainability

Not surprisingly, when asked about their anticipated contributions to sustainability as a professional in their chosen fields (Table 3), a large number of students again voted for the environment and even more so than when asked to define sustainability.

Within environmental concerns (design for the planet), similar numbers of students within engineering (14.5%) and outside of engineering (13.9%) spoke to the efficient use of resources while a larger number of students outside of engineering spoke to recycling and reducing waste (19.9%) as a means to contribute to sustainability in their chosen professions. For example, students sought to contribute to sustainability by "Implementing recycling & compost systems in my workplace." (Female, Business) or by "Finding ways to minimize waste in all forms." (Male, Engineering). Many also desired to contribute by making more efficient use of resources: "Making sure I utilize resources in a smart fashion. Whether it be technological, human, or natural resources." (Male, Business) or "Everything I design will be as efficient as possible, consuming the least amount of resources necessary, and the most sustainable resources reasonable." (Male, Engineering).

Only 1.3% of engineering students and 7.6% of other students envisioned contributing to design challenges associated with people. An equal number of engineering students (1.3%) and somewhat larger number of other students (4.9%) articulated contributions to sustainability through profit (economics).

For responses that could not be coded into Planet, Profit, or People themes, the most often cited contribution was working in the chosen profession. In other words, many students (14% of engineering students and 7.5% of other students) thought that their most likely contribution to sustainability would come about as a natural part of what was required in their jobs. Furthermore, many engineering students (14.0%) also expressed that influencing their local community would be a likely contribution to sustainability in their careers.

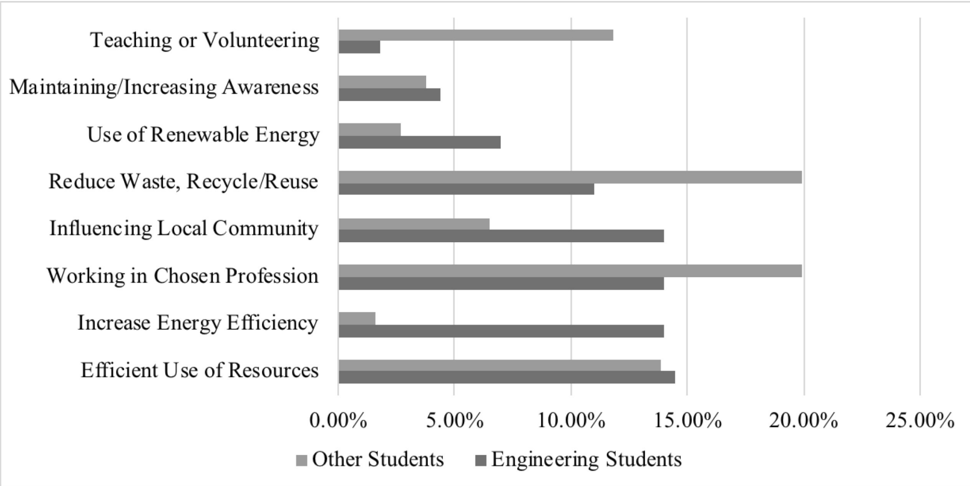


Fig. 4. Most Anticipated Contributions to Sustainability.

Interestingly, more engineering students than students in other fields saw influencing their local community or working in the chosen profession as a contribution to sustainability while more students in other fields outside of engineering (11.8% vs. 1.8%) saw teaching or volunteering as a pathway to contributing to sustainable practice.

Overall (Fig. 4), engineering students were most likely to view their contribution to sustainability applied via the efficient use of resources, increasing energy efficiency, working in their chosen profession, or influencing local community on issues relevant to sustainable development and design.

Similar to the results in Table 2, many students failed to provide detailed explanation as to what kinds of contributions they can make to make more sustainable future. However, the good news is that when the question posed to students was shifted from the abstract to the applied, as is the case from the first short answer question to the second short answer question in this study, more students were specific in their responses. Such improvement suggests that how students are asked about their attitudes, knowledge, and beliefs with regard to sustainability may affect their responses. Furthermore, the fact that conserving resources and recycling and reuse of resources dominate student responses in the environmental category, regardless of how the question about sustainability is posed, suggests that these two activities are central to students' understanding of sustainability. The results in Table 3 also suggest that students, engineering and otherwise, have narrow views of sustainability not only in their propensity to define it in terms of the environment, but also within their views on how to protect the environment. Of twelve sustainability challenges within design for the planet identified within D4S [4], most students collectively envision contributions in only four of these challenge areas. Whether such a result is due to being unaware of or not feeling competent to contribute in these challenge areas can be examined in part by looking at student responses to the last question in this study, discussed next.

4.3 Least likely contributions to sustainability

When asked to identify areas in which they were least likely to contribute to sustainability (Table 4), responses related to protection of the environment were remarkably similar to students' perceptions of their most likely contributions, as summarized in Table 3.

Reducing waste, recycling, reusing, and efficiently using resources were popular responses in both cases (Fig. 5) suggesting that many students view protecting the planet to be largely contained within these two D4S challenges. While responses associated with design for the planet tended to be consistent with previous questions, additional insight can be gained from more generalized responses provided by students. Among these generalized responses, 7.5% of engineering students and 5.9% of students in other fields saw creating sustainable products or structures as something they were least likely to be able to do in their careers. While outside of engineering, such low percentages might be expected because the chosen profession would not involve the design and construction of actual products, in engineering, such low response rates are somewhat concerning. This result suggests that some engineering students believe that, despite having the ability to do so, they will be unlikely to influence the sustainability of the very products they are charged with designing.

These results also suggest that engineering stu-

Table 4. Least Likely Contributions to Sustainability

Challenge/Issue	Engineering		Other	
	n	%	*n*	%
Planet				
Reduce Waste, Recycle/Reuse	16	7.0	9	4.8
Efficient use of Resources	12	5.3	6	3.2
Use of Renewable Energy	10	4.4	5	2.7
Stop Ecosystem Damage	6	2.6	8	4.3
Reduce Fossil Fuel Use	6	2.6	6	3.2
Stop Ecosystem Damage	6	2.6	8	4.3
Reduce Industrial Emissions	2	0.9	5	2.7
Stop Overexploitation of Resources	2	0.9	5	2.7
Other Response	28	12.3	24	12.9
People				
Increase Literacy, Abolish Child Labor	2	0.9	6	3.2
Reduce Population Growth	1	0.4	4	2.2
Improve Working Conditions	0	0	1	0.6
Other Response	13	5.7	7	3.8
Profit				
Fair Business Model	2	0.9	4	2.2
Value for Company/Stakeholders	8	3.5	1	0.5
Other Response	6	2.5	4	2.2
Generalized				
Creating Products/Structures	17	7.5	11	5.9
Public Advocacy/Policy Change	19	8.3	11	5.9
Nothing	6	2.6	9	4.8
Influencing Local Community	5	2.2	11	5.9
Maintaining/Increasing Awareness	0	0	1	0.6
Other	15	6.4	13	7.0
Do not know	56	24.6	33	20.0

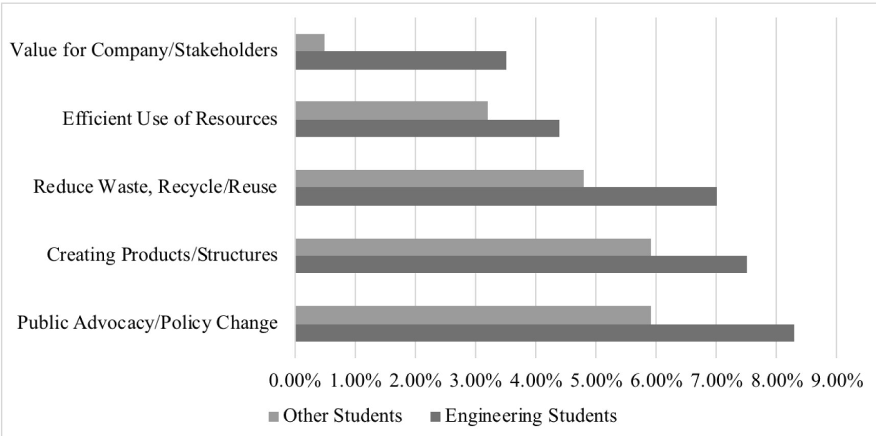


Fig. 5. Least Anticipated Contributions to Sustainability.

dents feel ill-prepared to advocate for more sustainable development at a public policy and political level. For instance, 8.3% of engineers said in their responses that they felt least likely to contribute to sustainability through such policy and advocacy actions, compared to 5.9% of responses among students in other fields. Finally, 89 students did not know how they would be least likely to contribute to sustainability during the course of their careers. Such results strongly suggest a lack of awareness of the breadth of sustainability challenges that face our world today.

5. Implications

Similarities rather than differences predominate in the comparison of engineers versus students in other fields, implying that from a higher education perspective, sustainability is a topic best introduced with common language in general education rather than discipline-specific courses. In addition to instilling a common language among students, incorporating sustainability into general education can also go a long way in reducing the gap among disciplines in coverage of and competence with the complex web of sustainable practice [27]. Also, in addition to developing a common language and framework for global sustainability in general education courses, the capstone design courses provide a valuable opportunity for engineering students to apply concepts of sustainability learned in general education. For example, engineering design students can apply environmental concepts of sustainability through using ROHS compliant electronics, reducing parts counts, using recycled materials, and capitalizing on renewable energy when applicable and available. Moving beyond the environmental pillar of sustainability, students can also explore options for outsourcing manufacturing and assembly for product designs to countries with significant opportunities for social progress [28] or fair wages while also contextualizing design costs within a fair value model for potential products [29].

This study has also suggested a need to pose questions regarding sustainability in multiple ways to students and to develop additional instruments to assess social and economic facets of sustainability in addition to looking at environmental issues. Such findings coincide with a worldwide deficit in social and economic indicators of sustainability values, attitudes, and behaviors [30]. Overall, consistent with other studies, the results presented here support the call for more tightly integrated, balanced, and comprehensive coverage of sustainability in higher education, even in crowded curricula, to overcome the mile wide and inch deep treatment [30] of many critical challenges in sustainable development. Unfortunately, the power structures, implicit values, and other factors underlying culture among higher education institutions in the United States [27] tend to work against such change.

6. Limitations

Although sample size in this dataset is not particularly small ($n = 414$) and extends to multiple majors outside of engineering, the qualitative analysis associated with our coded data is not suited to making claims of statistical significance. Furthermore, the fact that the data are limited to a single institution introduces the possibility of bias due to institutional and local culture. However, the prevalence of vague or generalized notions of sustainability has been shown in other studies and this study serves to reinforce the pressing need to more tightly integrate sustainability into higher education across all disciplines. The qualitative nature of this study also casts a net that supports the development of additional quantitative instruments (e.g., surveys) to explore potential statistical significance in the results that emerge from this study.

7. Conclusions

This single institution, qualitative study has explored the preconceptions, misconceptions, and missing conceptions about sustainability and sustainable practice among students in multiple disparate fields including engineering, business, environment, and education. The results show more similarities than differences in the views of engineering students vs. students outside of engineering. When questions regarding sustainability are posed as abstract or conceptual, many students provide vague or misconceived notions of sustainability. When questions are posed in a more applied way looking at anticipated contributions to sustainable practice, however, students are more specific. Furthermore, all students, engineering or otherwise, tend to define specific contributions to sustainable practice in terms of protecting the environment. Consistent with previous studies, the results of this study strongly suggest the need to more tightly and more meaningfully integrate sustainability into higher education, regardless of discipline.

Acknowledgments—The authors 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.

References

1. Brundtland Commission, Our Common Future, Chapter 2, 1987. [Online]. Available: http://www.un-documents.net/our-common-future.pdf
2. United Nations Sustainable Development Agenda 21: Table of Contents. Earth Summit, 1992. [Online]. Available: https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf
3. United Nations General Assembly, World Summit Sustainable Development. The Johannesburg Declaration on Sustainable Development, 2005. [Online]. Available: https://sustainabledevelopment.un.org/milesstones/wssd
4. United Nations Environment Program, Design for Sustainability (D4S): a Step-by-Step approach, 2009 [Online]. Available: http://www.jcdiehl.nl/d4s-sbs/
5. ABET, ABET Student outcomes., 2018-2019. [Online]. Available: http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/#outcomes
6. UNESCO, Contributing to a more sustainable future: Quality education, life skills and education for sustainable development. Paris, France: United Nations Educational, Scientific, Cultural Organization, 2005. [Online]. Available: http://unesdoc.unesco.org/images/0014/001410/141019e.pdf
7. C. M. Armstrong, Implementing Education for Sustainable Development: The Potential use of Time-Honored Pedagogical Practice from the Progressive Era of Education, *Journal of Sustainability Education.*, **2**, March 2011.
8. D. Cotton, I. Bailey, M. Warren, and S. Bissell, Revolutions and second-best solutions: Education for sustainable development in higher education, *Studies in Higher Education*, **34**(7), 2009, pp. 719–733.
9. Forum for the Future, The Engineer of the 21st Century Inquiry, June 2000. [Online]. Available: https://www.

forumforthefuture.org/sites/default/files/project/downloads/e21cengineersforsustainability.pdf
10. A. Azapagic, S. Perdan and D. Shallcross, How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum, *European Journal of Engineering Education*, **30**(1), 2005, pp. 1–19.
11. S. M. Donovan, J. D. Bransford and J. W. Pellegrino (eds.), How people learn, Washington, D.C.: National Academy Press, 1999. [Online]. Available: https://www.nap.edu/catalog/9853/how-people-learn-brain-mind-experience-and-school-expanded-edition
12. W. Bernstein, R. Devarajan, M. Cox, F. Zhao, J. W. Sutherland and K. Ramani, Implementing design critique for teaching sustainable concept generation, *ICED 2011: 18th International Conference on Engineering Design*, Copenhagen, Denmark, 2011.
13. S. Burian, Teaching Sustainability and Sustainable Engineering Practice in the Civil Engineering Curriculum, *ASEE 2010: American Society of Engineering Education National Conference*, Louisville, Kentucky, 2010.
14. T. P. Seager and E. Selinger, Experiential Teaching Strategies for Ethical Reasoning Skills Relevant to Sustainability, *IEEE Intl Symposium on Sustainable Systems and Technology*, Boston, Massachusetts, 2009.
15. D. Braun, Teaching Sustainability Analysis in Engineering Lab Courses, *IEEE Transactions on Education*, **53**(2), 2010, pp. 243–247.
16. D. Braun, Teaching Sustainability in Electronics Lecture Courses. *ASEE 2011: American Society of Engineering Education National Conference*, Vancouver, British Columbia, 2011.
17. K. Shephard, Higher education for sustainability: Seeking affective learning outcomes, *International Journal of Sustainability in Higher Education*, **9**(1), 2008, pp. 87–98.
18. Y. Sipos, B. Battisti and K. Grimm, Achieving transformative sustainability learning: Engaging head, hands and heart, *International Journal of Sustainability in Higher Education*, **9**(1), 2008, pp. 68–86.
19. D. M. Wilson, Basic Engineering Design [Online]. Available: http://labs.ee.washington.edu/community/BasicEngDes/
20. D. M. Wilson, Real World Considerations in Engineering Design [Online]. Available: http://labs.ee.washington.edu/community/RWC/
21. S. Kelly-Quattrocchi, D. M. Wilson, R. Roberts and R. Yonemura, Is Protecting the Environment all there is to Sustainability?, *American Society of Engineering Education National Conference*, New Orleans, LA, 2016.
22. R. Roberts and D. Wilson, Cross-Validation of a Global Citizenship Scale: Constructs for Evaluating Undergraduate Engineering Perspectives, *American Society of Engineering Education National Conference*, New Orleans, LA, 2016.
23. V. Braun, Using thematic analysis in psychology, *Qualitative Research in Psychology*, **3**(2), 2006, pp. 77–101.
24. A. Coffey and P. Amanda, *Making Sense of Qualitative Data*, Thousand Oaks, California: Sage Publications, 1996.
25. G. Guest, *Applied Thematic Analysis*, Thousand Oaks, California: Sage Publications, 2012.
26. J. Walther, N. W. Sochacka and N. N. Kellam, Quality in interpretive engineering education research: Reflections on an example study, *Journal of Engineering Education*, **102**(4), 2013, pp. 626–659.
27. J. Everett, Sustainability in higher education: Implications for the disciplines, *Theory and Research in Education*, **6**(2), 2008, pp. 237–251.
28. 2017 Social Progress Index [Online]. Available: https://www.socialprogressindex.com/
29. D. M. Wilson, Economic Consequences that Influence Engineering Design. [Online]. Available: http://www.comingalongside.org/resources/RWC_EconomicConsequences.pdf
30. A. A. Leiserowitz, R. W. Kates and T. M. Parris, Sustainability values, attitudes, and behaviors: A review of multinational and global trends, *Annual Review of Environment and Resources*, **31**, 2006, pp. 413–444.

Denise Wilson received the BS degree in mechanical engineering from Stanford University, Stanford, CA, in 1988 and the MS and PhD degrees in electrical engineering from the Georgia Institute of Technology, Atlanta, in 1989 and 1995, respectively. She also holds an M.Ed. from the University of Washington (2008). She is currently a Professor with the Electrical and Computer Engineering Department, University of Washington, Seattle. Her research interests in engineering education focus on the role of self-efficacy, belonging, and other affective aspects of the student experience and on effective methods for teaching global issues such as those pertaining to sustainability.

Mee Joo Kim is a doctoral candidate at University of Washington, Seattle, College of Education majoring in Higher Education. She received the BA in International Relations from Ewha Womans University, South Korea and the MEd in Social Foundations from University of Virginia. Her research interests are in engineering education focusing on student autonomy and its impact on their motivation to persist in engineering programs.