Sustainability as a Route to Broadening Participation in Engineering

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Abstract

Background Sustainability is increasingly a vital consideration for engineers. Improved understanding of how attention to sustainability influences student major and career choice could inform efforts to broaden participation in engineering.

Purpose Two related questions guided our research. How do career outcome expectations related to sustainability predict the choice of an engineering career? Which broader sustainability-related outcomes do students perceive as related to engineering? To address both questions, we compared effects for engineering and nonengineering students while controlling for various confounding variables.

Design/Method We conducted a survey to collect responses about sustainability and other variables of interest from a national sample of college students in introductory English classes. Data were analyzed using descriptive statistics and correlational analysis.

Results Students who hope to address certain sustainability issues such as energy, climate change, environmental degradation, and water supply are more likely to pursue engineering. Those who hope to address other sustainability issues such as opportunities for women and minorities, poverty, and disease are less likely to do so. Students hoping to address sustainability-related outcome expectations with obvious human relevance are less likely to pursue engineering. Yet those students who perceive "improving quality of life" and "saving lives" as associated with engineering are more likely to pursue the profession.

Conclusions Our results suggest that showing students the connection between certain sustainability issues and engineering careers could help those striving to increase and diversify participation in engineering. A broader range of engineers would likely bring new ideas and ways of thinking to engineering for sustainability.

Keywords diversity; participation; sustainability

Introduction

Issues such as resource shortages, climate change, and widespread poverty and inequality highlight the need to pursue a more sustainable path – one where we meet current needs of all people without compromising the ability of future generations to do the same. Increasingly, sustainability is an overarching consideration across many fields, including engineering.

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Grand challenges posed to twenty-first century engineers largely involve macro-scale issues such as sustainability, and addressing these issues should be among the strengths of future engineers (Vest, 2008). Furthermore, Borrego and Bernhard (2011) emphasize that attracting diverse students to solve problems in sustainability is a key future opportunity in engineering education research. To help address these converging needs, our research examines the link between students' sustainability-related outcome expectations and their participation in engineering. This study draws on data from a nationally representative sample of students enrolled in college English classes (including students with both engineering and nonengineering career intentions) who were surveyed in the fall of 2011. Our results show a number of significant differences between engineering students and other students with respect to their sustainability-related outcome expectations and associated perceptions of engineering. For example, students choosing to pursue engineering are less interested in addressing disease and poverty, yet engineers are needed who are willing to engage with these issues. The current disinterest in these issues is worrisome but also reveals an opportunity: perhaps emphasizing the human impact of engineering through sustainability issues will help to attract a larger, more diverse group of students. Just as biodiversity protects ecosystems from disease, resource shortages, and climate change, we believe that a broader diversity of thought among engineers is essential if we hope to address these and other threats to human quality of life.

Addressing Sustainability through Engineering

Sustainability is most commonly defined as meeting the "needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). The United Nations considers sustainability "the framework for our efforts to achieve a higher quality of life for all people" (United Nations, 1995). The constantly evolving theoretical discourse on sustainability is not the focus of this article, however. Others have articulated broad descriptions of sustainability theory in general (e.g., Edwards & Orr, 2005) and, in particular, as applied to education (e.g., Orr, 2004; Rowe, 2007) and engineering education (e.g., Mihelcic et al., 2003).

While there are various definitions of sustainability, many have in common overlapping environmental, social, and economic dimensions (Filho, 2000). These dimensions are represented in Figure 1 as nested circles with environment surrounding society, which in turn surrounds economy. The nested relationship reflects the reality that a functioning society requires an environment that supports human life, and a functioning economy requires a stable society. Certain dimensions of sustainability may be in conflict: consider, for example, highly processed junk food that has low immediate, individualized costs but high societal health costs for treating diseases such as diabetes, which are linked to the junk food. In other cases the sustainability dimensions may be in alignment: choosing a vehicle that gets better gas mileage lowers driving costs and leads to fewer climate-changing emissions. Pursuing truly sustainable solutions requires consideration of all three dimensions. Coal mining, for example, is

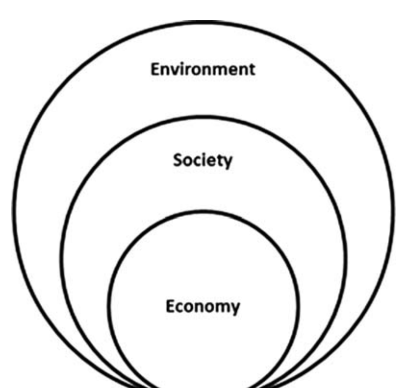

Figure 1 Three dimensions of sustainability.

unsustainable in each of these dimensions: coal is a limited resource; burning it produces climate-changing emissions; and miners are exposed to health and safety risks. Coal is cheap in the near-term only because it is sold at a cost that does not adequately account for factors such as climate change and human health. Nuclear energy produces negligible climate-changing emissions when compared with coal, but there are significant sustainability concerns about long-term risks to human health. For more renewable sources of energy, such as solar, wind, and biofuels, economic challenges are a major hurdle to the development of a truly sustainable solution. Sustainability is not solely about the environment in isolation but rather how it affects humans and vice versa (e.g., Moskell & Allred, 2012).

Sustainability theory can be better understood through some of the societal issues related to sustainability. Recognizing these issues is especially important for our research because many students are unfamiliar with the term sustainability as we have already defined it. These students may, however, be familiar with specific environmental sustainability issues such as climate change, environmental degradation, and water pollution. These students are also more likely to have heard of social sustainability issues such as disease, poverty, and distribution of resources. For our research, we used more tangible issues like these to help gauge student interest in sustainability.

Our sustainability issues reveal a widely recognized need for participation and leadership from engineers (American Society of Engineering Education [ASEE], 1999; Environmental Protection Agency [EPA], 2007; National Academy of Engineering [NAE], 2005; National Science Foundation [NSF], 2008). Engineering for sustainability requires new problem-solving competencies across the dimensions of sustainability, and this requirement is one reason for calls to broaden the engineering curriculum (NAE, 2005). Truly sustainable solutions are more likely to emerge from a model in which sustainability is a filter through which all engineering decisions are passed. For example, engineers working on water supply issues still need to know about pipes and pumps, but they also need to evaluate how their design affects other factors such as local development and health in addition to water availability and downstream pollution. Forward-looking engineering programs help their students acquire such skills. Some universities, such as James Madison University, have started entirely new programs in sustainable engineering. Others, such as the University of Florida and Arizona State University, have renamed and reorganized engineering colleges and departments with sustainability as the overarching theme. Still more are incorporating sustainability considerations as courses or themes in existing programs (Allenby, Murphy, Allen, & Davidson, 2009).

Addressing sustainability through engineering can change what it means to be an engineer. Engineers need new skill sets, and engineering educators must learn ways to teach them. But we also need to learn how to attract new participants to the field, including those who already possess these new skills or have a special interest in developing them. Women, for example, have historically provided a unique voice to sustainable development efforts around the world (Charkiewicz, Hausler, Wieringa, & Braidotti, 1994). Yet women remain seriously underrepresented in engineering in the United States, where fewer than one in five engineering bachelor's degrees are awarded to women (Aud, Hussar, Johnson, Grace, & Roth, 2012; Yoder 2012).

Diversity is lost at every educational and career transition in engineering, and the barriers to more diverse participation are numerous and complex. In the *Beyond Bias and Barriers* report, a National Academy of Engineering committee outlined some of these barriers (NAE, 2007), range from deliberate discrimination favoring white men to inadvertent prejudices – prejudices that habitually influence our evaluations of people and their work and can consequently limit diversity in engineering. Public perceptions of engineering actions and culture also disproportionately attract certain participants over others (NAE, 2008).

Our research is most closely aligned with the latter perception-related barriers, and we build on preliminary evidence suggesting that the theme of sustainability could be used to increase participation and diversity of thought in engineering. A National Academy of Engineering committee recommended emphasizing the societal impacts of what engineers do as a means to improving participation in the field (NAE, 2008). Other research found above-average representation among women in several fields: sustainability leadership positions in industry (Harrison & Klotz, 2010); the Engineers without Borders Program, which emphasizes the social aspect of sustainability (Kaminsky, Casias, Javernick-Will, & Leslie, 2012); and engineering with a focus on community service (Bauer, Moskal, Gosink, Lucena, & Munoz, 2007; Coyle, Jamieson, & Oakes, 2006). In the Civil and Environmental Engineering Department at the University of Vermont, a study of curricular reform emphasizing sustainability showed that female students were more interested in learning about sustainability than were their male counterparts (Hayden, Rizzo, Dewoolkar, Oka, & Neumann, 2010). Above-average participation of underrepresented populations was also identified in sustainability themed engineering groups at Georgia Tech and Carnegie Mellon (Zimmerman & Vanegas, 2007).

Framing Career Choices through Outcome Expectations

Our study frames career choices through outcome expectations, which are defined as "beliefs about the outcomes of various courses of action" and differ from goals, which are related to one's intentions to pursue a course of action (Lent et al., 2003). For example, a student might have a career goal (e.g., become an engineer) because she has an associated outcome expectation (e.g., help solve societal problems). Outcome expectations are a construct that has been found to be important in multiple frameworks conceptualizing career choice. For example, social cognitive career theory is one model that has proven useful when examining student career choices (Lent, Brown, & Hackett, 1994; Lent, Brown, & Hackett, 1996). In this framework, mediating factors that influence career goals include self-efficacy beliefs, outcome expectations, and contextual experiences. The importance of the outcome expectation construct has also been conceptualized in motivation frameworks that can be related to career choice. For example, in expectancy-value theory (Wigfield & Eccles, 2000), utility value can characterize the perceived future importance that is related to a particular career choice, such as making money or helping to solve societal problems (Matusovich, Streveler, & Miller, 2010). Thus, in studies of career choice, outcome expectations and utility value are similar constructs.

Prior research has found that certain outcome expectations can predict student choice of science-related careers. For example, intrinsically rewarding outcome expectations (e.g., inventing new things, making use of talents and abilities, developing new knowledge and skills, and having an exciting job) are positively related to aspiring towards a physics career (Hazari, Sonnert, Sadler, & Shanahan, 2010). In engineering, some of these outcome expectations are also important, such as inventing new things (Orr, Hazari, Sadler, & Sonnert, 2009), benefiting humanity, and making money (Matusovich, Streveler, & Miller, 2010). Outcome expectations attracting students towards a particular career are not homogeneous; some students may be more motivated by one outcome expectation while others are more motivated by a different one. As Matusovich et al. (2010) wrote, "To persist in earning an engineering degree, not every student must be motivated in the same way by the same things. . . .

There are many ways to reach students and help them connect to the personal possibilities an engineering degree could bring" (p. 300). In order to be satisfied in their career, female engineering students, for example, report at a significantly higher rate than their male counterparts that they want to help other people (Orr, Hazari, Sadler, & Sonnert, 2010). Since engineers can help people in many ways, we may be able to gain greater insight by understanding the particular ways engineering students aspire to help others.

In our study, rather than focusing on broad outcome expectations (e.g., making money) that have been considered by prior work, we investigated more specific outcome expectations related to sustainability that may help explain student choice of engineering careers. Our interest was not only in the sustainability-related outcomes that students commonly associate with engineering careers but also with those outcomes that students do *not* connect with engineering. Identifying such disconnects may help us to address them in order to enhance participation of diverse students who are motivated by outcomes that they mistakenly perceive are not available through an engineering career. Thus, we hope our findings can be applied to help stimulate the broader participation in engineering needed for more sustainable engineering solutions. Accordingly, our research was guided by two questions:

1. How do career outcome expectations related to sustainability vary between engineering students and other students? How do these outcome expectations predict the choice of an engineering career?

2. Which broader sustainability-related outcomes do engineering students and other students perceive as related to engineering? Are those who associate certain outcomes with engineering more likely to choose a career in the field?

Method

SaGE Data

Data for the present analysis came from the Sustainability and Gender in Engineering (SaGE) survey, which was administered using an approach modeled after prior national studies (Potvin, Tai, & Sadler, 2009). We developed a random sample of institutions to recruit for participation from a comprehensive list of U.S. colleges and universities provided by the National Center for Educational Statistics. The sample was stratified by institution type and the number of enrolled students: four-year large (23,051 or above), four-year medium (7,751 to 23, 050), four-year small (7,750 or less), two-year large (15,650 or above), two-year medium (6,726 to 15,650), and two-year small (6,725 or less). Institutions were recruited to participate in the study through an initial e-mail and then through follow-up phone calls and e-mails. Ultimately, all 50 institutions that agreed to participate in the research returned some student surveys (100% institutional response rate). In total we received responses from 6,772 individuals enrolled at these 50 institutions. The home zip codes of respondents are shown in Figure 2.

Between October and December of 2011, representatives at the randomly selected participating institutions distributed the paper-based SaGE survey to students as part of their normal introductory college English classes. By surveying students in English classes, we could collect a sample that includes perspectives of students interested in engineering as well as those who are not. Introductory sections were targeted because many students in these courses have relatively recently made at least an initial decision of whether or not to major in

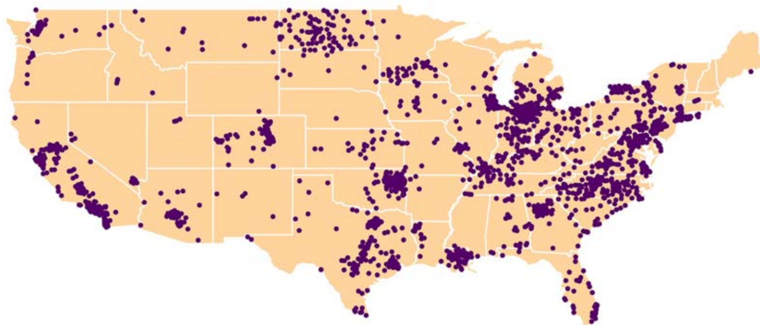

Figure 2 SaGE respondent distribution. Dots indicate home zip codes for at least one respondent (more than one respondent from a zip code appears as a single dot). Figure adapted from Wickham (2009) and Lewin-Koh & Bivan (2012).

engineering. This decision point in the educational trajectory is particularly appropriate because women who choose to major in engineering in college persist at a rate similar to that of men (Lord, Camacho, Layton, Long, Ohland, & Wasburn, 2009; National Science Board, 2012). Retention during college matters, but a greater opportunity to increase participation in engineering is in identifying methods that result in more students majoring in engineering in the first place.

The SaGE survey is designed to take 20 to 30 minutes. It includes 47 anchored, numerical, multiple-choice, and categorical questions. The survey is divided into five sections: Your Career Goals, Your High School Experiences, Sustainability and You, About You, and Demographic Questions (located at the end of the survey to avoid biasing respondents). Relevant to the questions guiding the research in this article, several questions on the SaGE survey were designed to investigate sustainability-related outcome expectations and beliefs about engineers' role in the pursuit of sustainability. The following Study Design section provides additional description of the survey questions that measure these variables.

Validity of the survey was tested in several ways. To ensure content validity, we developed a preliminary hypothesis generation survey given to first-year engineering ($n = 82$) and non-engineering ($n = 41$) students, and to high school science teachers ($n = 83$) via the National Science Teachers' Association listserv. The hypothesis generation survey was based on broad theory and literature that was described in the introduction to this article as well as question-specific theory and literature that is described in more detail later. Responses to draft questions were further examined for face and content validity on the basis of the results of pilot testing and focus groups among first-year engineering students at two four-year institutions. Face and content validity were also addressed through feedback from engineering educators, including several with expertise in sustainability. Revisions based on this feedback primarily reduced the length of the survey and eliminated or reworded unclear questions. We assessed test-retest reliability of the survey questions with results from students in first-year courses at two four-year institutions.

Our analysis was performed using the R language and environment for statistical computing (R Core Team, 2013). As expected, our dataset included some missing data. The patterns in missing values across predictor variables were used to impute values for the missing data using the Amelia II package in R (Honaker, King, & Blackwell, 2011). Imputation helped us avoid sample bias from listwise or pairwise deletion of variables that are missing at random, meaning that there are measured patterns for their missing values (Rubin, 2009). Through imputation, we also were able to avoid unnecessarily losing statistical power. Specifically, imputation allowed us to use 6,550 of the 6,772 surveys returned in the current analysis. The remaining 222 had too few responses in the variables that we consider in this paper to impute properly.

Study Design

Again, two related questions guide this research: How do career outcome expectations related to sustainability vary between engineering students and other students? Which broader sustainability-related outcomes do engineering students and other students perceive as related to engineering? Together, responses to SaGE questions about career choice, sustainability-related outcome expectations, and the extent to which various issues are associated with engineering allowed us to explore these guiding research questions and the related subquestions.

The question on the SaGE survey that allowed us to identify respondents who plan to pursue engineering asked respondents, "Please rate the current likelihood of your choosing a career in the following." Eight engineering disciplines were offered: bio-engineering, chemical engineering, materials engineering, civil engineering, industrial/systems engineering, mechanical engineering, environmental engineering, and electrical/computer engineering. Each response was supplied on a five-point anchored-scale ranging from "0 – Not at all likely" to "4 – Extremely likely." Students who selected "4 – Extremely likely" for one or more of these eight engineering disciplines were identified as likely engineering students in this article.

Of the 6,550 analyzed respondents to the SaGE survey, 13% (n = 866) were likely to pursue a career in at least one of the engineering disciplines. As expected, this percentage was lower for female students (6.5%, n = 231) than it was for male students (21%, n = 635). The proportions of engineering students in our data are slightly higher than those from an annual survey of first-year college students, which reported that 11% of all students, including 18% of males and 4% of females, intended to major in engineering (Pryor et al., 2013). One reason we recruited from a random sample was to ensure a representative sample of female students for any evaluation of gender themes. Studies relying on volunteer survey responses are prone to overrepresentation of women. The 2007 National Survey of Student Engagement (NSSE), for example, received 65% of responses from female students (NSSE, 2007), even though this group made up 56% of the sample population at participating institutions. Our sample population is 54% (n = 3,552) female students.

The question on the SaGE survey that is the most direct measure of students' sustainability-related outcome expectations asks, "Which of these topics, if any, do you hope to directly address in your career? (Mark ALL that apply)." There are binary response options: energy (supply or demand), disease, poverty and distribution of wealth and resources, climate change, terrorism and war, water supply (e.g., shortages, pollution), food availability, opportunities for future generations, opportunities for women and/or minorities, and environmental degradation. The mean test-retest reliability for responses to this question was 0.63, which we calculated using nonparametric correlation, the phi-coefficient. These response options are drawn from Nobel Prize winner Richard Smalley's list of the 10 most pressing challenges facing humanity (Smalley, 2003). While any list like this is necessarily limited, Smalley's challenges provide response options with which students are more likely to be familiar and which span environmental, social, and economic dimensions of sustainability. Students were asked which topics they hope to address and to indicate whether or not they intend to apply themselves to each issue. Response options were not designed to evaluate how students intend to address these issues. We would expect, for example, that the food availability option could be selected by a student planning to develop genetically modified foods or by a student who plans to start an organic farm. As this example shows, responses are useful for identifying sustainability-related outcome expectations, as opposed to the actual level of sustainability of the students' planned actions.

The question that evaluates which sustainability issues students perceive as related to engineering asks, "In your opinion, to what extent are the following associated with the field of engineering?" The response options were: creating economic growth, preserving national security, improving quality of life, saving lives, caring for communities, protecting the environment, including women as participants in the field, including racial and ethnic minorities as participants in the field, addressing societal concerns, and feeling a moral obligation to other people. The mean test-retest reliability for responses to this question was 0.61, which we calculated using Pearson's correlation. Responses were given on a five-point anchored scale ranging from "0 – Not at all" to "4 – Very much so." As with the previously mentioned question on sustainability-related outcome expectations, the options on this question were chosen to represent a range of sustainability-related actions spanning environmental, social, and economic dimensions. Responses were also chosen to represent the needs of the current generation (e.g., including women and minorities, saving lives) as well as needs of future generations (e.g., protecting the environment, addressing societal concerns). Where possible, response options were phrased so that respondents who perceive engineering in opposite ways are not likely to be classified together. For example, "protecting the environment" is used rather than just "the environment." These response options suggest relationships between sustainability issues and engineering, not whether the options are good or bad for sustainability, which is a more nuanced consideration. For example, leading sustainability advocates make widely accepted arguments both for (Hawken, Lovins, & Lovins, 2008) and against (Meadows, Meadows, Randers & Behrens, 1972) economic growth as a strategy for sustainability.

Several analytic methods were used to answer our research questions. Before running more involved analysis, such as binary logistic regression, we calculated proportions to determine whether there were differences between groups of students by primarily focusing on engineering students and other students. We used Wilcoxon rank-sum tests to evaluate whether differences in proportion were statistically significant. This nonparametric test can be used to determine whether a particular population tends to have a greater rank (in this case, a greater proportion of affirmative responses) than another; it does not make assumptions about the normality of the distributions. After we identified statistically significant differences in this manner, we performed logistic regression analysis to develop a more comprehensive understanding of these differences. Regression analysis allowed us to determine whether and how variables predicted student career goals, specifically an engineering career choice, while simultaneously accounting for other potentially confounding factors. Because the outcome variable for this analysis was binary (0 = nonengineering career choice and 1 = engineering career choice), we used binary logistic regression. To clarify which sustainability items were influencing student career choice, we included various control variables to account for student prior performance (using an academic performance index combining reported grades and standardized test scores in science, mathematics, and English), socioeconomic status (measured through the highest level of education for female and male parent or guardian), gender, race, and family support (as seen through responses to the question "Which of the following people have contributed to your selection of a career path?"). In the regression models, we normalized all control variables to a scale between 0 and 1 so that estimates were comparable across variables.

Table 1 Sustainability-Related Outcome Expectations for Engineering Students and Other Students

Outcome expectation	Percentage engineering (n)	Percentage other (n)	p^a	d^b
Energy (supply or demand)	48 (413)	13 (754)	<.001	0.39
Climate change	12 (106)	6 (320)	<.001	0.12
Environmental degradation	18 (152)	9 (528)	<.001	0.17
Water supply (shortages, pollution)	21 (180)	12 (686)	<.001	0.02
Terrorism & war	15 (131)	11 (633)	<.001	0.11
Opportunities for future generations	53 (457)	47 (2681)	<.01	0.25
Food availability	15 (127)	15 (879)	n.s.	0.10
Disease	21 (185)	28 (1609)	<.001	0.07
Poverty & distribution of resources	18 (154)	24 (1369)	<.001	0.03
Opportunities for women & minorities	16 (141)	25 (1413)	<.001	0.02

[a]Significance calculated using Wilcoxon rank-sum tests. [b]Effect size calculated using Cohen's *d*.

Findings

Our findings are described here, organized by our guiding research questions.

How do career outcome expectations related to sustainability vary between engineering students and other students? Table 1 shows the percentage of engineering and other students who hope to address the corresponding sustainability-related outcome expectation in their careers. Students likely to major in engineering are significantly more likely than other students to want to address energy (supply or demand), climate change, environmental degradation, water supply (shortages, pollution), terrorism and war, and opportunities for future generations. These differences are statistically significant. We used $p < 0.01$ as a threshold for significance to reduce the possibility of Type 1 error because we have a large dataset and ran multiple tests. Many of these differences are also quite large in magnitude. In particular, 48% of engineering students, compared with just 13% of other students, have outcome expectations related to energy. On the other hand, those interested in engineering are significantly less likely than other students to indicate an interest in addressing disease, poverty and distribution of resources, and opportunities for women and minorities. Of the outcome expectations we evaluated, only food availability was selected at the same rate by engineering students and other students.

The most common overall response in Table 1, selected by nearly half of all students, was opportunities for future generations, which is the response most closely related to our explicit definition of sustainability. Opportunities for future generations was selected more than twice as often among the total population as any other outcome expectation with the exception of disease. When interpreting overall occurrence of outcome expectations, remember that they are not all mutually exclusive; some of the broader outcome expectations, such as opportunities for future generations, encompass a number of more specific ones. Students who hope to address energy (supply or demand), water supply (e.g., shortages, pollution), or climate change may be more likely to indicate that they hope to address opportunities for future generations. The opposite is not necessarily true. A student interested in providing opportunities for future generations may not always see himself doing so by working on energy issues.

Within the engineering student population, several gender differences are significant. Female engineering students are significantly (using Wilcoxon rank-sum tests) less likely than male engineering students to have energy outcome expectations ($p < 0.001$, $d = 0.30$).

Table 2 Sustainability-Related Outcome Expectations Predicting Engineering Career Intention

Outcome expectation	Est.	*SE*	*p*	*z*	Odds ratio
Intercept	−2.67	0.17	<.001	−15.30	0.07
Controls					
Gender (female = 0, male = 1)	0.99	0.09	<.001	11.29	2.69
Math Academic Performance Index	1.28	0.18	<.001	7.12	3.60
Female guardian's highest education level					
High school diploma/GED	−0.45	0.16	<.01	−2.82	0.64
Some college or associate/trade degree	−0.41	0.16	<.01	−2.65	0.66
Bachelor's degree	−0.55	0.16	<.001	−3.48	0.58
Master's degree or higher	−0.64	0.18	<.001	−3.63	0.52
Race (Caucasian)	−0.61	0.08	<.001	−7.43	0.54
Sustainability outcome expectations					
Energy (supply or demand)	1.55	0.09	<.001	17.9	4.72
Water supply (shortages, pollution)	0.42	0.12	<.001	3.59	1.53
Opportunities for future generations	0.31	0.08	<.001	3.62	1.36
Food availability	−0.35	0.12	<.01	−2.99	0.71
Poverty and distribution of resources	−0.57	0.11	<.001	−5.08	0.56

Notes. Results from logistic regression analysis. Est. = the estimate (logit), or log odds change in likelihood of engineering intention for a given a change in the predictor. *SE* = the standard error of the estimate, which is used to calculate the significance (p). z = the z-statistic, or ratio of estimate to *SE*. The odds ratio is an estimate of the size of the effect of each predictor.

On the other hand, for several of the outcome expectations in which engineering students generally are less interested, female engineering students indicate an interest at a significantly higher rate than do male engineering students. These categories include disease ($p < 0.001$, $d = 0.50$), poverty and distribution of resources ($p < 0.001$, $d = 0.51$), and opportunities for women and minorities ($p < 0.001$, $d = 0.95$). In other words, engineering students are less likely than other students to want to address these issues, and male engineering students are even less likely (compared with female engineering students) to want to address them.

How do career outcome expectations related to sustainability predict the choice of an engineering career? We extended the comparisons in Table 1 by constructing a binary logistic regression model to predict engineering career intentions from sustainability-related outcome expectations (Table 2). The regression allowed us to examine the effects of the aforementioned control variables (student prior performance, socioeconomic status, gender, race, and family support) simultaneously with the various career outcome expectations. The odds ratio column in Table 2 provides an estimation for the magnitude of the effect in each case. For instance, as expected, male students have close to three times higher odds (2.64 odds ratio) than female students to intend a career in engineering. Our math performance index (6.62 odds ratio) is also a strong positive predictor of engineering career intentions. On the other hand, academic performance in English, identifying as Caucasian, and an increasing level of mother or female guardian education all have odds ratios below 1; these variables are negative predictors of engineering career intentions.

When the sustainability variables are added to the regression model along with the controls, energy remains a strong positive predictor. Students have nearly five times higher odds of choosing engineering if they wish to address energy-related issues (4.61 odds ratio). To a

Table 3 Engineering Students' Perception of Sustainability Issues Associated with Engineering

Issue	Engineering		Other			
	M	*SE*	*M*	*SE*	p^a	d^b
Creating economic growth	2.54	0.043	2.21	0.017	<.001	0.27
Preserving national security	2.50	0.042	2.16	0.017	<.001	0.27
Improving quality of life	3.10	0.037	2.67	0.016	<.001	0.37
Saving lives	2.93	0.040	2.53	0.016	<.001	0.32
Caring for communities	2.75	0.040	2.49	0.016	<.001	0.22
Protecting the environment	2.80	0.040	2.50	0.016	<.001	0.24
Including women	2.72	0.042	2.41	0.016	<.001	0.25
Including racial & ethnic minorities	2.79	0.041	2.45	0.016	<.001	0.27
Addressing societal concerns	2.64	0.040	2.37	0.016	<.001	0.22
Feeling a moral obligation to other people	2.50	0.042	2.24	0.017	<.001	0.21

Note. Responses provided on a scale from "0 - Not at all" to "4 - Very much so."
[a]Significance calculated using Wilcoxon rank-sum tests. [b]Effect size calculated using Cohen's *d*.

lesser degree, students who hope to address water supply (1.50 odds ratio) and opportunities for future generations (1.37 odds ratio) are also more likely to choose engineering. Less likely to choose engineering are students who hope to address poverty and distribution of resources (0.56 odds ratio) and food availability (0.68 odds ratio). Note that, when controls are added to the model, interest in addressing food availability becomes a negative predictor of intent to pursue engineering. This interest was not significant without controls (see Table 1). Conversely, predictors that showed significant differences in Table 1, but were not significant after controls were added, include desire to address climate change, environmental degradation, terrorism and war, disease, and opportunities for women and minorities.

Which broader sustainability-related outcomes do engineering and other students perceive as related to engineering? In addition to examining students' sustainability-related outcome expectations, we also evaluated whether students saw certain broader sustainability-related outcomes as related to engineering. More so than other students, as shown in Table 3, engineering students perceived all of the outcomes we measured as related to engineering, at the $p < 0.001$ level in each case. Within the engineering student group, we found no significant differences between male and female students in perceived relation of these outcomes to engineering.

Are those who associate certain outcomes with engineering more likely to choose a career in the field? Looking more deeply into the variables considered in Table 3, we constructed a binary logistic regression model to predict engineering intention from sustainability-related perceptions (Table 4). Control variables are similar to our first regression model (Table 2), with an additional pair of factors now significant (mother and father having contributed to a student's career path). Career influence from a male parent or guardian positively predicts engineering, while career influence from a female parent or guardian is a negative predictor.

Two of the sustainability perceptions remain significant when controls are added to the model. Students who perceive engineering to involve improving quality of life are more likely to choose an engineering career (2.45 odds ratio). Similarly, students who perceive engineering as involving saving lives are more likely to pursue an engineering career (1.78 odds ratio).

Table 4 Relationship between Sustainability Issues and Engineering and Choice of Engineering

Variable	Est.	*SE*	*p*	*z*	Odds ratio
Intercept	−3.42	0.20	<.001	−17.05	0.03
Controls					
Gender (female = 0, male = 1)	1.25	0.08	<.001	14.95	3.50
Race (Caucasian)	−0.58	0.08	<.001	−7.30	0.56
Academic Performance Index (math)	2.03	0.29	<.001	7.09	7.58
Academic Performance Index (English)	−0.98	0.28	<.001	−3.55	0.37
Highest level of education for female parent/guardian					
High school diploma/GED	−0.41	0.16	<.01	−2.67	0.66
Bachelor's degree	−0.46	0.15	<.01	−2.99	0.63
Master's degree or higher	−0.56	0.17	<.01	−3.27	0.57
Mother/female guardian contributed to career path selection	−0.32	0.10	<.01	−3.10	0.73
Father/male guardian contributed to career path selection	0.31	0.10	<.01	3.00	1.36
Sustainability perceptions					
Improving quality of life	0.89	0.18	<.001	5.01	2.45
Saving lives	0.58	0.16	<.001	3.54	1.78

Notes. Results from logistic regression analysis. Est. = the estimate (logit), or log odds change in likelihood of engineering intention for a given a change in the predictor. *SE* = the standard error of the estimate, which is used to calculate the significance (*p*). *z* = the *z*-statistic, or ratio of estiamte to *SE*. The odds ratio is an estimate of the size of the effect of each predictor

Discussion

Public perceptions of engineering actions and culture are barriers to much-needed diversity in engineering (NAE, 2008). For example, girls are more comfortable with images of engineering that include people (NAE, 2008), and we know that outcome expectations are among several mediating factors influencing career goals. Previous research also tells us that female engineering students are more likely to report helping other people as a career outcome expectation (Orr, Hazari, Sadler, & Sonnert, 2010) and that sustainability may be a topic that can help increase diversity in engineering (Harrison & Klotz, 2010).

Our results complement these earlier findings, in particular by showing that emphasizing social sustainability perceptions of engineering (e.g., improving quality of life and saving lives) could help bring more students to engineering. The engineering community does not appear to be taking advantage of this opportunity. Our results show that the students, both male and female, who are currently attracted to engineering are less likely than others to have outcome expectations related to disease, poverty, and opportunities for underrepresented groups. In order to broaden ways of thinking and the skills necessary for sustainable engineering, it is increasingly important to diversify the outcome expectations of students who participate in engineering in parallel with efforts to increase the proportion of traditionally underrepresented students in engineering. In other words, if students who aspire to be engineers do not include those who care about affecting sustainability-related outcomes, then the future solutions posed by these engineers will be limited accordingly.

Actions to Consider

Our analysis highlights undesirable trends related to sustainability and participation in engineering. In particular, engineering is not attracting an appropriate share of students interested in issues related to social sustainability such as poverty and disease, even though engineers are needed to help address these problems. This finding suggests opportunities for action.

The engineering community needs to communicate what those who pursue engineering can do, as opposed to just describing what most engineers currently do. We should heed the counsel of the *Changing the Conversation* report (NAE, 2008), in which two of the four main themes found to resonate with students were "Engineers make a world of difference" and "Engineering is essential to our health, happiness, and safety." Both of these themes connect engineering with social sustainability outcome expectations. Students convinced of either of these themes may see how they could address poverty and disease through a career in engineering. Yet students may not recognize these connections if they are only exposed to engineering through interactions with practicing engineers who ignore these connections in their work.

Many of NAE's Grand Challenges (NAE, 2012) for engineering do align with the outcome expectations of those students we would like to be attracting. "Advance health informatics" and "engineer better medicines," for example, are Grand Challenges that could appeal to students with career outcome expectations related to disease, an underrepresented group in engineering. But even these Grand Challenges are a missed opportunity to reach more diverse students because the wordings of the challenges emphasize concepts, such as medicine and informatics, rather than people.

Opportunities abound to emphasize the human impact of engineering through sustainability issues. Our results suggest that students with sustainability-related outcome expectations are underrepresented in engineering. Future research could study exemplary college-level engineering programs that are emphasizing human issues and attracting underrepresented students at a higher rate. For high schools, the recently released *Next Generation Science Standards* (Next Generation Science Standards Lead States, 2013) brings engineering topics into the K–12 curriculum and also encourages the requisite flexibility to make connections to human issues. Capitalizing on this opportunity to increase the number and diversity of students who intend to major in engineering should be a goal of future research and implementation efforts of engineering stakeholders.

Communicating that prospective engineers will be able to help people appears useful for recruitment. However, making sure that engineers really are trained to help people is even more important. Students choosing to pursue engineering must have opportunities to engage with problems that highlight human concerns. Using revised conceptual frameworks in courses can help (Valdes-Vasquez & Klotz, 2013). Probably of greater impact is having students respond to real problems that directly affect humans. Exemplary are service-oriented programs such as Engineers without Borders, the D-lab at Massachusetts Institute of Technology, University of Colorado Boulder's Engineering for Developing Communities, and Penn State's Humanitarian Engineering and Social Entrepreneurship program.

Limitations

Our interpretations of the study's findings are limited to correlational (not causational) analyses. We also acknowledge that many students lack an in-depth understanding of sustainability; we tried to respond to this issue by asking about more familiar topics that are related to environmental, economic, and social spheres of sustainability. Responses we have analyzed identify sustainability-related outcome expectations and not the level, degree, or nature of planned actions; both students who intend to mine tar sands and those who want to work in the wind power industry may have energy outcome expectations. Outcome expectations may also have different levels of specificity, especially when comparing broad concepts like opportunities for future generations with more narrow ones like climate change. We have avoided topical comparisons like these and instead focused on differences between student groups. Finally, many other important barriers to broader, more diverse participation in engineering are not dealt with in this article. Sustainability topics may help attract a more diverse group, but discrimination and prejudice may continue to inhibit progress towards attracting this group.

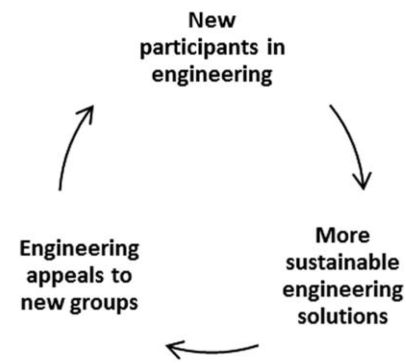

Figure 3 Vision for a participation and sustainability positive feedback loop.

Future Vision

We recognize that no single solution will allow us to overcome the numerous barriers to broader, more diverse participation in engineering. But we also believe that those striving to increase the diversity of thought in engineering and those pursuing more sustainable engineering solutions can encourage the vision for a positive feedback loop, as shown in Figure 3. We hope that increased participation of those with different outcome expectations for engineering will lead to more sustainable engineering solutions, solutions that will increase the appeal of engineering to these groups.

In other words, if the engineering community can accurately communicate the connection between sustainability and engineering, we could increase the appeal of engineering for students we are not currently reaching, including those who possess desirable outcome expectations. We need students like these to develop the responses to our sustainability challenges that will shape our current and future quality of life.

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