

Engineering students' agency beliefs and career goals to engage in sustainable development: Differences between first-year students and seniors

Abstract

Purpose—This paper explores the differences in first-year and senior engineering students' engineering agency beliefs and career goals related to sustainable development. We also sought to understand how topics related to sustainable development in engineering courses affect senior engineering students' goals to address these issues in their careers. This work provides evidence of how students' agency beliefs may be shaped by higher education, which is essential to workforce development.

Design/methodology/approach—Findings stem from two national surveys of engineering first-year (Sustainability and Gender in Engineering [SaGE], $n = 7,709$) and senior students (Student Survey about Career Goals, College Experiences, $n = 4,605$). We compared both groups using pairwise testing by class standing.

Findings—The results indicate that undergraduate studies tend to reinforce students' engineering agency beliefs to improve quality of life and preserve the environment. Significantly more senior students selected career goals to address environmental issues, compared to first year students. In general, students undervalue their roles as engineers in addressing issues related to social inequities. Those topics rarely addressed in engineering courses. Findings from this work suggest discussing sustainability in courses positively impact setting career goals to address such challenges.

Research limitations/implications—The study compares results from two distinct surveys, conveyed at different periods. Nonetheless, the sample size and national spread of respondents across U.S. colleges and universities are robust to offer relevant insights on sustainable development in engineering education.

Practical implications—Adapting engineering curriculum by ensuring that engineering students are prepared to confront global problems related to sustainable development in their careers will have a positive societal impact.

Social implications—This study highlights shortcomings of engineering education in promoting social and economic sustainability as related to the engineering field. Educational programs would benefit from emphasizing the interconnectedness of environmental, social, and economic dimensions of sustainable development. This approach could increase diversity in engineering education and the industry, and by ripple effect, benefit our communities and local governance.

Originality/value—This work is a first step toward understanding how undergraduate experiences impact students' engineering agency beliefs and career goals related to sustainability. It explores potential factors that could increase students' engineering agency and goals to make a change through engineering.

Keywords Sustainable development, engineering education, engineering agency, career goals

Paper type Research paper

1 Introduction

Sustainable development implies achieving human development goals by meeting the needs of the present without compromising the ability of future generations to meet their needs (World Commission on Environment and Development, 1987). The United Nations (UN) defined 17 Sustainable Development Goals (SDG) in their 2020 report highlighting the need for a shared vision to address the world's challenges by 2030—from eliminating poverty and hunger to reversing climate change (United Nations, 2020). The report clearly emphasizes that sustainable development is a global agenda. It calls for systemic answers from interdisciplinary communities to address the socio-economic crisis (i.e., social equity, food and water security, and rising poverty) and the environmental crisis (i.e., depletion of resources and climate change). Such challenges are not new; the Brundtland Report raised many of the UN 2020 SDG more than 30 years ago (World Commission on Environment and Development, 1987). Our society still falls short in addressing these challenges and more reflection is needed on the interconnectedness of these issues for current and future development practices (Clark, 2007; World Commission on Environment and Development, 1987). The COVID-19 pandemic has exacerbated existing inequalities and injustices, making the achievement of sustainable development goals even more crucial, and the necessity to take action more pressing.

Engineers will play a critical role in meeting the sustainable development goals outlined by the United Nations (Jowitt, 2020). For example, sustainable engineering solutions can be found in designing new manufacturing processes that reduce greenhouse emissions through closed-cycle loops (Clark, 2007). This solution aligns with the UN SDG #9 “Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation” (United Nations, 2020). Engineers are also needed to help develop stronger materials, for instance, to combat roadway buckling from urban heat island effect and a thawing permafrost which echoes the UN SDG #13 “Take urgent action to combat climate change and its impacts” (National Research Council, 2008; United Nations, 2020). Ensuring these types of solutions for the future requires the engineering workforce to possess the skills to develop complex and transdisciplinary solutions and the motivation to meeting these sustainable development goals (Jowitt, 2020).

Engineering education faces a challenge to prepare students to address sustainable development goals more effectively, specifically climate change and its implications for sustainability (Anderson, 2010; Barth *et al.*, 2016). A survey of first-year students in engineering

from 2014 highlighted that only half of those students believe in human-caused climate change (Authors, 2017). Such skepticism in anthropogenic climate change also surfaces in the civil engineering profession (Grubert, 2018). This incertitude suggests an opportunity in sustainable development education to train better engineers about climate change and prepare them to address these concerns in the workforce. Engineering students tend to recognize technical issues associated with global warming but lack awareness of its effect on social justice and poverty (Authors, 2020). This disconnect highlights an issue in students' understanding of the climate crisis given the interconnectedness of sustainable development goals and opportunities for synergistic solutions. Such perceptions from engineering students about sustainable development and climate change is similar to the public's ambiguous awareness of the causal relationships between human activities and climate perturbations, as well as the distant representation of climate change impact on communities (Hanson-Easey *et al.*, 2015; Pruneau *et al.*, 2010, Wang *et al.*, 2019). Misconceptions about climate change, like the conflation of climate change and the ozone hole, hinder engagement from communities and the development of long-term solutions to ensure a sustainable livelihood for future generations.

Engineering students also risk being less prepared for and competitive in a sustainable economy without education that provides a foundation to address sustainable development goals. Engineering students' misunderstandings about climate change may lead to unintended consequences by perpetuating fallacies about sustainable development or climate change into their careers or failure to address these key concerns in their work (Clark, 2007). The abstract qualities and distance of the effects from climate change in highly developed countries (Brügger, 2020; Hanson-Easey *et al.*, 2015; Spence *et al.*, 2012) makes preparing for and designing long-lasting infrastructure to handle the climatic changes more challenging (Grubert, 2018). Without an intentional effort to address climate change, engineering solutions will continue to perpetuate the status quo with significant and deleterious consequences.

The formative process that engineers experience during their undergraduate program is an opportunity to increase their understanding and motivation to tackle the complexity of sustainable development (Lönngren *et al.*, 2016). Several strategies to deploy the United Nation's 17 Sustainable Development Goals (SDG) within engineering courses are outlined in Romero *et al.*'s (2020) systematic review, including: the use of a sustainability rubric, incorporating sustainable development concepts into final degree projects, sustainable development through project-based

learning and problem-solving, through internships, laboratory experiments, and others. By implementing such strategies, engineering education can begin to shape future professionals' motivation to address multiple dimensions of sustainable development within their career (Authors 2016; Authors 2014; Authors 2016; Authors 2017). Faculty in engineering need to emphasize that the current challenges for more sustainable development are connected to the discipline of engineering and help develop students' engineering agency to address these prominent challenges (United Nations, 2020).

This study investigates differences in students' engineering agency beliefs about sustainable development and goals to address sustainable development challenges in their career depending on their class standing. Our findings stem from the analysis of two national surveys in the United States. The first national survey focused on first-year engineering students. The second targeted senior engineering students. We analyzed differences in students' agency beliefs by class standing (first-year versus seniors) in undergraduate engineering programs. By comparing the senior engineering students to the first-year engineering students, we describe the potential effects of undergraduate experiences on students' engineering agency beliefs, and their career goals to address sustainable development challenges. This research focuses on the similarities and differences between these two groups of students. It suggests how engineering education may intervene to better support students' engagement with and preparation for addressing sustainable development goals in the workforce. The findings begin to offer some reflection on upgrading curricula to support students' knowledge of sustainable development for implementing it in engineering practice.

2 Background: Engineering agency beliefs, career goals and education in sustainable development

Education plays a role in defining students' perception of their future profession, their skills, identity, and agency (Chachra *et al.*, 2008; Authors 2016; Winters *et al.*, 2013). The culture of engineering schools strongly fosters students' views on the engineering profession, which evolves throughout the undergraduate program. For example, first-year students in engineering see designing, creating, and building as major characteristics of the engineering profession, followed by science application and problem solving (Chachra *et al.*, 2008). Third-year students' perceptions of engineering shift; half as many students considered designing, creating, and

building as a major theme in engineering, in favor of problem solving (Chachra *et al.*, 2008). These findings support the common representation of engineers as highly technical, although its practice requires sociotechnical skills (e.g., project management, collaboration, and client liaison). The National Academy of Engineering emphasized the importance of addressing social challenges through engineering (i.e., health, diversity, and service to communities; National Academy of Engineering, 2005) and the importance of engineers to address climate change issues (National Academy of Engineering, 2008).

2.1 Engineering education plays a role in defining students' engineering agency beliefs

The concept of critical agency (i.e., ability to initiate and direct actions for social justice) in engineering includes how students identify themselves within engineering to advance their participation in the community for positive change (Basu *et al.*, 2009; Authors 2016). The theoretical framework of engineering agency was developed by Authors (2013, 2016) based on critical agency frameworks in science and mathematics education (Basu *et al.*, 2009, Mallya *et al.*, 2012; Turner & Font, 2003). Agency is characterized by action; however, this behavioral concept is challenging to measure. In this study, we build on prior work that has measured students' agency beliefs. Students' agency beliefs are characterized by their self-beliefs about their own agency to change their world through everyday actions and their broader goals of using STEM to make this change by choosing a career in engineering (Authors, 2013). Students' agency beliefs both theoretically and empirically have been demonstrated as a pre-cursor to the actions taken that are consistent with these beliefs (Authors, 2013).

Students' engineering agency beliefs influence their professional identity development and how they will act as professionals (Authors 2013). It incorporates the expression of engineers' identity through actions related to their field. Engineering agency beliefs can be classified in two factors, global and personal agency, based on the perceived agency of the field of engineering. Global engineering agency relates to the field of engineering in general, whereas, personal engineering agency relates to how one perceives themselves as engineers (Authors, 2013).

Educational interventions impact the development of students' engineering agency as they develop their identity, beliefs and propensity to take action along their training as engineers. For example, through community projects (Mihelcic *et al.*, 2008) and interacting with scientists (Monroe *et al.*, 2019), engineering students can develop technical and people-focused skills. To

meet sustainable development goals, students should develop engineering agency beliefs toward sustainable development as engineering solutions need to integrate social, economic, and environmental aspects (McDonough and Braungart, 2002). Engineering students' identity and self-beliefs as engineers change along undergraduate studies based on the culture of an institution and students' perceptions of engineering practice (Chachra *et al.*, 2008). Considering the institution is important because it can affect their educational choices and, potentially, the development of their engineering identity (Hsieh *et al.*, 2012; Wang *et al.*, 2013).

2.2 *Students' career goals develop during the engineering education*

Multiple factors influence career choices such as cultural and family background, learning experiences like engineering major and self-efficacy expectations or the beliefs about one's ability to successfully perform particular behaviors (Lent *et al.*, 1994, 2003). Self-efficacy is a central mechanism in personal agency as it helps to determinate one's activity (Bandura, 1989; Lent *et al.*, 1994) and is a precursor of engineering students, interests and career goals (Lent *et al.*, 2008), all of which dictate action for change.

Engineering students enter engineering programs with beliefs about what types of issues they can address with an engineering degree (Authors 2014; Verdín *et al.*, 2018). During undergraduate engineering education, the process of becoming an engineer also shapes these beliefs through implicit and explicit messages in coursework, interactions with faculty and professionals, extracurricular service-based activities, and disciplinary societies (Anderson, 2010; McCormick *et al.*, 2015). Undergraduate experiences promoting awareness of sustainability can increase the proportion professional engineers with the skill set to confront complex socio-technical challenges, of which environmental sustainability issues like climate change is most urgent (Friedman, 2008; Pink, 2005). Teaching about sustainability in engineering programs directly aligns with institutional organization guidelines (National Academy of Engineering, 2005, 2008). Moreover, developing a curriculum that incorporates sustainability awareness for social good can allow engineering programs to attract a larger array of students, especially underrepresented groups (Bauer *et al.*, 2007; Filho *et al.*, 2020; Harrison and Klotz, 2010; Kaminsky *et al.*, 2012; Authors 2014).

For such curriculum interventions to succeed, faculty members must understand how to integrate sustainability into engineering education as well as students' beliefs about sustainable

development. Doing so, these curricula will have a sustained impact on workforce development. Helping students recognize how engineering is related to sustainability and maintaining a pedagogical environment for students to feel empowered to address these issues in their career are directions to follow (Anderson, 2010). Engineering students' career goals to engage in sustainable development upon entering the workforce are shaped through their undergraduate experience, by initiatives taken at the university level, curriculum, organizations, and faculty interventions in their courses.

Gaining knowledge of changes in agency beliefs and career goals between the first and the last year of engineering education will help educators refine multilevel educational strategies to prepare students to enter the workforce ready to address broad sustainability challenges.

2.3 Improving engineering education in sustainable development

Educational interventions rooted in experiential learning (Kolb, 1984), such as participation in community projects, or interactions with scientists are widespread to teach about sustainable development (Anderson, 2010; Guerra and Shealy, 2018; Mihelcic *et al.*, 2008; Pruneau *et al.*, 2010). Studies have examined whether a specific curriculum format can lead to an improved understanding of climate change and taking action (Evans and Ferreira, 2020; Monroe *et al.*, 2019).

For example, attitudinal learning, which focuses on altering learners' attitudes, values and behaviors, appear as a relevant pedagogical strategy to motivate students to take actions, like becoming vegan and making other lifestyle changes (Janakiraman *et al.*, 2021). Engineering students' perceptions of sustainable development differ based on their specialty, which highlight a need to adapt teaching strategies and content to resonate with different students (Fourati-Jamoussi *et al.*, 2021). In their review on pedagogical interventions for sustainable education in higher education, Evans and Ferreira (2020) reported the effectiveness of experiential learning, critical thinking, and eco-literacy to increase knowledge on climate science and to change values and ethics concerning sustainable development. However, such interventions still fall short in provoking behavior change. A key challenge for educators is to highlight the personal relevance of sustainable development. Emphasizing the consequences of climate change on local communities by engaging students in learning through student-centered teaching strategies (e.g., debate, field trips, or hands-on labs) emerges as an efficient pedagogy to teach environmental

sustainability (Monroe *et al.*, 2019). Merging both experiential learning (Kolb, 1984) and social constructivist approaches, or learning in situ (Lave and Wenger, 1991; Vygotsky, 1978) through community projects, provide relevant directions to follow in sustainable development education.

Unlike professionals, students tend to connect sustainable development to environmental and technological aspects only, without much consideration for the effects on people and society (Segalàs *et al.*, 2012). To address this issue, engineering education frameworks for sustainable development need to shift from a technique driven to a process driven one. A process driven pedagogical framework would emphasize the interconnectedness between social, economic, and environmental objectives in decision-making (Jowitt, 2020; Mihelcic *et al.*, 2008). Sustainable development addresses complex multidisciplinary societal problems and fine-tuning relevant teaching approaches to integrate learning modules like ‘energy systems’, ‘agricultural and food systems’, ‘sustainability tools’ among others, is a lengthy process (Sharma *et al.*, 2017).

How students learn about sustainable development affects the perception of their role and identity as engineers. Higher education affects learners on a cognitive, behavioral, and affective dimension (Rogaten *et al.*, 2019). While much of earlier work on learning outcomes has focused on its cognitive impacts (Douglass *et al.*, 2012; Pascarella & Blaich, 2013), more and more research in education and psychology highlights benefits on focusing on affective and behavioral outcomes of sustainable development education (Janakiraman *et al.*, 2021). Educational opportunities in engineering should include the development of people-focused skills and an emphasis on systems thinking for engineering solutions to be relevant for our society, and to promote sustainability and social justice (Delatte, 2020; Hall and Linzell, 2019). Implementing such changes can influence students’ engineering agency beliefs and career goals (Authors 2013; Authors 2014), and ultimately engineers’ actions to address climate change.

3 Research questions

The purpose of this paper is to explore the differences in first-year and senior engineering students’ engineering agency beliefs and career goals related to sustainable development. Moreover, we explore if covering topics related to sustainable development in engineering courses influence senior engineering students’ goals to address such issues in their careers. The research questions that guided this research were:

- (1) How does engineering agency beliefs to address sustainable development challenges differ between first-year and senior engineering students?
- (2) How do career goals to address sustainable development challenges differ between first-year and senior engineering students?
- (3) What topics related to sustainable development in engineering courses affect senior engineering students' goals to address these issues in their career?

We expect senior students to have higher engineering agency beliefs to address sustainable development challenges with aligned career goals based on the assumption that engineering education should promote awareness of sustainability and empower students to take action.

4 Methods

4.1 Data collection

The data utilized for this research were drawn from the Sustainability and Gender in Engineering survey ($n = 7,709$) and the Student Survey about Career Goals, College Experiences, and Sustainability ($n = 4,605$).

4.1.1 First-year student survey: The Sustainability and Gender in Engineering survey (SaGE)

The data collected from SaGE is a nationally representative sample of students enrolled in introductory English courses throughout the fall semester of 2011 and spring semester of 2012. The first round randomly sampled a stratified list of fifty, two- and four-year institutions from the National Center for Educational Statistics institutional database. The second round only oversampled four-year institutions from a list compiled through the American Society of Engineering Education's online profiles. It ensured that there was a large enough pool of female engineers in the sample. Recruiting from required introductory English courses provided a general sample of college students. Students selected for comparison in this study indicated high interest in engineering and low or equal interest in other STEM subjects (3 or 4 on a 0 – “Not at all likely” to 4-“Extremely likely” anchored scale). Of the total sample ($n = 7,709$), 1,965 students were selected for comparison due to their indication of a high desire to enter an engineering career pathway. Those selected represent the sample of first-year engineering students used in the analysis.

The SaGE survey instrument included 47 anchored, numeric, multiple choice, and categorical questions. The survey was divided into five sections: (1) Your Career Goals, (2) Your High School Experiences, (3) Sustainability and You, (4) About You, and (5) Demographic Questions (placed at the end of the survey to avoid biasing respondents).

Previous work using the SaGE survey investigated students' beliefs about human-caused climate change and possible predictive variables for it from high school experiences (Authors 2019); civil engineering students beliefs in climate change and possible predictive variables for it from high school experiences (Authors 2017); the correlation between career choices (civil engineering or non-civil engineering) and interest in addressing sustainability challenges (Authors 2016); career outcome expectations (engineering versus non-engineering related to sustainability and relation between sustainability challenges and engineering (Authors 2014); or focused on understanding Authors 2013) and modeling students' decisions to pursue a career in engineering (Authors 2013, 2016).

4.1.2 Senior student survey: Student Survey about Career Goals, College Experiences, and Sustainability (CLIMATE)

The collection of data from senior engineering students occurred in two rounds, during Spring and Fall 2018. Similar to the first-year sample, the sampling frame included four-year institutions chosen from the National Center for Education Statistics institutional database. A stratified random list was created by categorizing institutions by undergraduate enrollment including small ($< 5,400$), medium ($5,400-14,800$), and large institutions ($> 14,800$). The engineering department head for each institution was contacted before capstone instructors at the institutions were asked to distribute the survey. A total of 83 capstone instructors distributed the survey during their class. No incentives were given to students for completing the survey, similarly to first-year data collection. Capstone instructors were allowed access to the de-identified data in exchange for their cooperation, as authorized by IRB procedures. A total sample of $n = 4,605$ senior engineering students responded to the survey.

The CLIMATE survey was categorized into six sections: (1) Career Goals and Motivation, (2) College Experiences, (3) Agency, (4) Climate Literacy, (5) People and the Planet, and (6) Demographic Information. This survey was based on the SaGE survey, except that it added a section on climate literacy. It aimed to assess students' awareness, literacy, and action to address

anthropogenic climate change (see Authors 2017 for more details). Previous work using the survey focused on the perception of both technical and social issues related to climate change for civil engineers (Authors 2020).

In this paper, we used the same questions asked on both surveys to compare students' career goals based on class standing. Here, we only focus on some sections of the surveys: career goals and motivation (Section 1 in both surveys) and engineering agency (Sections 3 and 4 in the SaGE survey and section 3 in the CLIMATE survey). The survey sections used for this study are presented in the appendix.

4.1.3 Assessing engineering agency beliefs (Research Question One)

Student's agency beliefs are measured upon graduation and reveal possible shifts between the first and last year of undergraduate programs. As previously stated, global engineering agency relates to the field of engineering in general, whereas, personal engineering agency relates to how one perceives themselves as engineers (Authors, 2013). The question from the surveys that assessed respondents' global engineering agency beliefs toward addressing climate change issues asked: "In your opinion, to what extent are the following associated with the field of engineering?" This question was asked for several outcomes: "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 options were an anchored numeric five-point rating scale from 0-"Not at all" to 4-"Very much so." Cronbach's alpha for this item was 0.86 for seniors and 0.89 for first year students, demonstrating good internal consistency.

Personal engineering agency beliefs toward addressing climate change issues was measured through the evaluation of statements mostly phrased in the first person: "We can pursue sustainability without lowering our standard of living; Human ingenuity will ensure that we do not make the earth unlivable; I feel a responsibility to deal with environmental problems; Environmental problems make the future look hopeless; I can personally contribute to a sustainable future; Nothing I can do will make things better in other places on the planet; Pursuit of sustainability will threaten jobs for people like me; Sustainable options typically cost more; I have the knowledge to understand most sustainability issues; I think of myself as part of nature, not

separate from it; We should be taking stronger actions to address climate change”. The options were an anchored numeric five-point rating scale from 0-“Strongly disagree” to 4-“Strongly agree.” Cronbach’s alphas for this item were 0.65 for seniors and 0.64 for first year students, demonstrating acceptable internal consistency.

4.1.4 Assessing career goals (Research Question Two)

To measure students’ career goals, respondents were asked, “Which of these topics, if any, do you hope to address in your career?” Possible choices were based on Nobel Prize winner Richard Smalley’s list of the 10 most pressing challenges facing humanity (Smalley, 2003): “energy (supply or demand); water supply (e.g., shortages, pollution); disease; food availability; poverty and distribution of wealth and resources; opportunities for future generations; climate change; opportunities for women and/or minorities; terrorism and war; environmental degradation”. These options represent many of the sustainable development goals recognized by the United Nations (United Nations, 2020) on environmental sustainability challenges (e.g., SDG #3 ensure availability and sustainable management of water and sanitation for all; SDG #6 ensure access to affordable, reliable, sustainable and modern energy for all; SDG #13 take urgent action to combat climate change and its impacts or; SDG #15 protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss) and social or economic sustainability goals (e.g., SDG #1 end poverty in all its form everywhere; SDG #2 end hunger, achieve food security and improved nutrition, and promote sustainable agriculture; SDG #5 achieve gender equality and empower all women and girls or SDG #16 Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels).

4.1.5 Assessing impacts of covering sustainable development topics in engineering courses on senior students’ career goals (Research Question Three)

To address the third research question, we explored if covering topics related to sustainable development impacted senior engineering students’ career goals. Senior students were asked if the ten topics presented as possible career goals were covered in their engineering courses (discipline-

specific or elective courses) to reflect the potential effect of engineering education on their career choices.

4.2 Demographic representation of participants

The demographic representation of first-year and senior engineering students differed mostly by racial and ethnic identities, but not gender (Table 1). The survey of senior engineering students included non-binary options, but the SaGE survey treated gender as binary (i.e., female and male). When comparing the binary variables of gender (of those who responded) and class standing, the chi-square value was nonsignificant, indicating independence with first years being 22.9% female and seniors being 24.9% female. The distribution of gender is representative of the national demographic characteristics of undergraduate engineers' enrollment in the U.S. In a survey from 2016, 21.4% of the students identified as female and 78.6% identify as male (National Center for Science and Engineering Statistics, 2018).

For racial and ethnic identities, individuals were allowed to select multiple options, and the chi-square value for all options was statistically significant at the $\alpha = .05$ level (Table 1). The distribution of racial and ethnic identity is also representative of the national demographic characteristics of undergraduate engineers' enrollment in the U.S. In a survey from 2016, 55.4% of the students identified as Caucasian or White, 13.2% identified as Hispanic or Latinx, 10.3% identify as Asian, and 5.1% as Black or African American (National Center for Science and Engineering Statistics, 2018). Our data sample distribution of gender, racial and ethnic identity is similar to national average, therefore our analysis was not subject to sampling bias.

Table 1. Participants' self-identified demographics. The higher value of significantly different representation in the two samples are bolded.

Groups	First-year (SaGE) Representation in percent	Seniors (CLIMATE) Representation in percent
<i>Gender</i>		
Female	22.9	24.9
Male	65.0	73.2
<i>Racial and ethnic identity</i>		
African American or Black	9.4	4.6
South Asian	2.3	3.3
East Asian	6.0	7.8
Other Asian	4.3	2.4

American Indian or Alaskan Native	5.0	1.7
Native Hawaiian or Pacific Islander	2.1	1.1
Hispanic or Latinx	16.9	10.6
Caucasian or White	55.6	62.0

4.3 Data analysis

The primary tool used for the statistical analysis was the programming language R (R Core Team, 2020). A chi-square test of independence was used to compare categorical data, and a Welch's t-test was used to compare continuous one (Likert-scale data). Effect sizes (Phi [ϕ] and Cohen's d , respectively) were calculated to understand the practical significance of the results. The chi-square test of independence allowed the determination of whether class standing was independent from goals set to address several key sustainability topics in their career. The use of Welch's t-test, which differs from a standard t-test only in its calculation of degrees of freedom, was necessary due to the difference in sample sizes between the data. The effect-size calculations quantify the changes in response means facilitating categorization into small, medium, and large transformations. Quantifying the extent of differences is useful because large datasets, like this one, can produce significant but small differences that may be misleading. The steps followed in this study are illustrated in Figure 1. Three elements were analyzed from both surveys with statistical tests adapted to the data variable type.

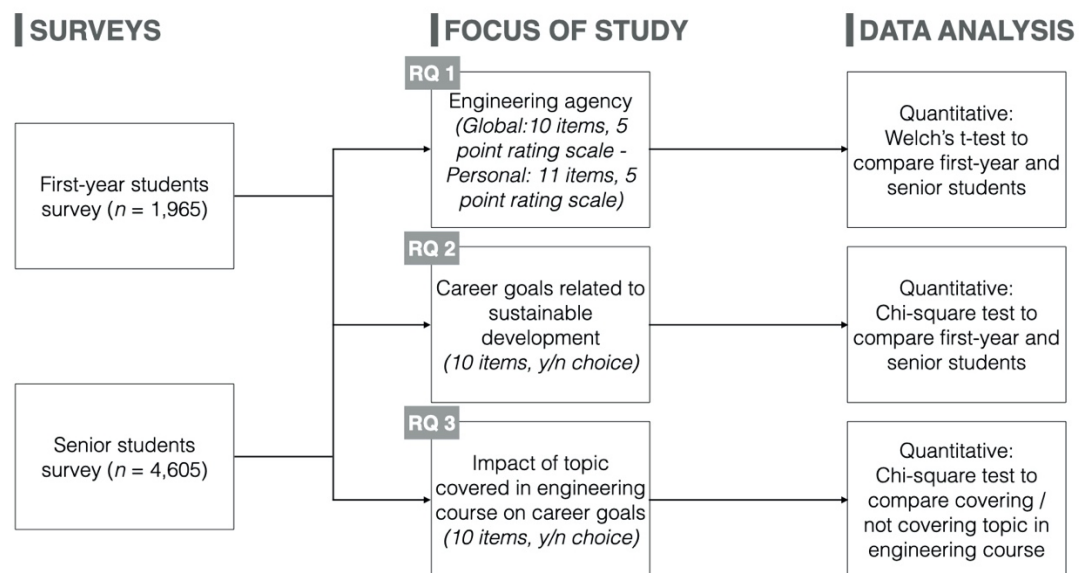


Figure 1. Steps followed to analyze relevant items from the survey to address the research questions. First year and senior engineering students were surveyed about engineering agency beliefs (RQ1), career goals (RQ1) and topics covered in their courses (RQ3). The differences in engineering agency beliefs are analyzed with Welch's t-test, while the differences in career goals and topic covered are assessed with Chi-Square tests.

5 Results

5.1 *Engineering agency beliefs differences between first year and senior engineering students*

5.1.1 Global engineering agency

We found a common trend in engineering students' agency beliefs on issues related to engineering but also some differences between first-year and senior students. Overall, seniors' perceived associations between any of the ten outcomes and engineering were either greater or similar to first-year students (Table 2). Associating engineering with the improvement of quality of life, saving lives, and protecting the environment was the strongest among both first-year and senior engineering students. Seniors perceived these three outcomes as related to engineering significantly more than first-year students. Students' association of engineering with issues related to social equity: caring for communities, including women as participants in the field, including racial and ethnic minorities as participants in the field, and addressing societal concerns with engineering as a profession was the same for first-year and seniors. Seniors ranked addressing societal concerns, and including women and ethnic minorities as participants in the field as the lowest association to engineering. Seniors perceive, to a greater extent than first-year engineering students, that engineering is associated with creating economic growth and preserving national security ($p > .001$; see Table 2) with small to medium effect sizes (i.e., $.2 < d < .5$).

Table 2. Results of the Welch's t-test to compare first-year (SaGE) and senior (CLIMATE) students' global engineering agency.

Items from the survey associated to global engineering agency	First-year score average	Senior score average	<i>t</i>	df	Cohen's <i>d</i>	Sig.
Creating economic growth	2.61	3.02	13.1	2749.2	0.40	***
Preserving national security	2.55	2.89	10.7	2876.3	0.32	***
Improving quality of life	3.25	3.53	11.3	2503.7	0.37	***
Saving lives	3.01	3.18	5.7	2789.5	0.18	***
Caring for communities	2.84	2.85	0.2	3079.8	0.01	n/s
Protecting the environment	2.94	3.15	7.0	2820.6	0.21	***
Including women as participants in the field	2.75	2.73	-0.4	3195.2	-0.01	n/s
Including racial and ethnic minorities as participants in the field	2.79	2.76	-0.9	3167.7	-0.03	n/s
Addressing societal concerns	2.74	2.74	-0.1	3197.4	0.00	n/s
Feeling a moral obligation to other people	2.60	2.74	4.4	3108.7	0.13	***

Anchored scale measured from 0 = "Not at all" to 4 = "Very much so."

Note: Skewness < |2|, Kurtosis < 7, $p < .001$ ***, $p < .01$ **, $p < .05$ *, n/s = not significant

5.1.2 Personal engineering agency

We also examined differences in students' opinions about their ability to address sustainable development and climate change issues in their careers as engineers (Table 3). These opinions about their agency, or ability to take action, indicate not only an understanding of these topics but beliefs in their capability to make changes in these areas. Overall, senior engineering students scored higher on nine out of the eleven sustainability and climate change agency beliefs items compared to first-year engineering students. Seniors had significantly stronger beliefs in two areas: 1) that engineering solutions will improve sustainability outcomes and 2) that they had the knowledge and responsibility to address sustainability in their careers.

Seniors more strongly believed that society can pursue sustainability without lowering the standard of living ($p < .001$, $d = .35$). They also had higher scores on beliefs that they have a personal responsibility to deal with environmental problems ($p < .001$, $d = .28$) and that society should take more actions to address climate change ($p < .001$, $d = .33$), with medium effect sizes. Seniors were more likely to recognize the severity of environmental issues and the largest mean difference was students' beliefs that we should be taking stronger actions to address climate change ($p < 0.001$, $d = 0.33$). The largest difference indicates that senior engineering students are less likely to perceive sustainability as a threat to their future careers ($p < 0.001$, $d = -0.37$).

Table 3. Results of the Welch's t-test to compare first-year (SaGE) and senior (CLIMATE) students' personal engineering agency.

Items from the survey associated to personal engineering agency	First-year mean	Senior mean	<i>t</i>	df	Cohen's <i>d</i>	Sig.
We can pursue sustainability without lowering our standard of living.	2.73	3.10	11.9	3247.1	0.35	***
Human ingenuity will ensure that we do not make the earth unlivable.	2.49	2.67	5.7	3597.3	0.16	***
I feel a responsibility to deal with environmental problems.	2.50	2.79	9.4	3284.7	0.28	***
Environmental problems make the future look hopeless.	1.93	2.07	3.9	3483.6	0.11	***
I can personally contribute to a sustainable future.	2.77	2.94	6.0	3360.4	0.17	***
Nothing I can do will make things better in other places on the planet.	1.23	1.25	0.4	3390.9	0.01	n/s
Pursuit of sustainability will threaten jobs for people like me (reverse worded).	1.60	1.16	-12.8	3407.6	-0.37	***
Sustainable options typically cost more.	2.47	2.50	1.0	3471.1	0.03	n/s
I have the knowledge to understand most sustainability issues.	2.48	2.66	6.2	3363.2	0.18	***
I think of myself as part of nature, not separate from it.	2.57	2.66	2.7	3321.9	0.08	**
We should be taking stronger actions to address climate change.	2.63	3.00	11.5	3344.5	0.33	***

Anchored scale measured from 0 = "Not at all" to 4 = "Very much so."

Note: Skewness $< |2|$, Kurtosis < 7 , $p < .001$ ***, $p < .01$ **, $p < .05$ *, n/s = not significant

5.2 *Personal career goal differences between first year and senior engineering students*

The selection of goals to address sustainability topics in their future career is largely dependent on class standing (i.e., first-year compared to senior; Table 4). Energy and opportunities for future generations were two main career goals for engineering students as these options were selected for almost half of the engineering students. Addressing energy issues was chosen by 48.7% of first years and 57.0% of senior students while promoting opportunities for future generations was selected by 55.4% of first years and 49.6% of senior students. Seniors indicated significantly more often career goals to address climate change ($p < .001$, $\phi = .19$), environmental degradation ($p < .001$, $\phi = .16$), and water supply ($p < .001$, $\phi = .1$) compared to first-year students (with small effect sizes). Seniors' goals to address opportunities for underrepresented groups in their careers was significantly greater compared to first-year students but with a small effect size ($\phi < |.1|$). Addressing disease as well as poverty and distribution of wealth was more valued by first-year than seniors as career goals, although the effect sizes are small ($\phi < |.1|$).

Table 4. Results of the Chi-square test on the selection of career goals related to sustainability topics for first-year (SaGE) and senior (CLIMATE) engineering students.

Topics in sustainability to address in future career	Distribution of first-year students selecting topic (%)	Distribution of senior students selecting topic (%)	Chi-square	ϕ	Sig.
Energy	48.7	76.9	38.8	.08	***
Disease	20.3	13.9	40.7	.08	***
Poverty and distribution of wealth	21.0	18.2	6.7	.03	*
Climate change	13.8	31.8	227.3	.19	***
Terrorism and war	18.1	16.2	3.7	.02	n/s
Water supply (e.g., shortages, pollution)	24.8	35.1	67.6	.10	***
Food availability	15.7	16.5	0.7	.01	n/s
Opportunities for future generations	55.4	49.6	18.4	.05	***
Opportunities for women/minorities	18.4	25.4	38.0	.08	***
Environmental degradation	19.9	36.0	166.1	.16	***

Note: $p < .001$ ***, $p < .01$ **, $p < .05$ *, n/s = not significant

5.3 *Effect of covering sustainable development topics in engineering courses on selecting career goals for senior engineering students*

When students covered any of the ten most pressing challenges facing humanity reflecting the United Nations SGDs (United Nations, 2020) in an engineering course, it had a positive effect on selecting that topic as a career goal (Table 5). For sustainable development topics related to environmental sustainability like climate change, environmental degradation, energy and water supply, the percent increase of students that selected these career goals when covering it in courses reached more than 18%. Nonetheless, those results need to be contrasted as only one student out of three who learned about climate change, environmental degradation, and water supply in their engineering courses. Energy was the most covered topic—more than half of the cohort learned about it in engineering courses.

On the other hand, topics focusing on social or economic sustainability were less often covered in engineering courses—fewer than one student out of five was taught about poverty, food availability or providing opportunities for underrepresented groups in their engineering courses. When covered, those topics tend to motivate students to hold such challenges as career goals. Analyzing concurrently career goals and topics covered in engineering courses provides first insights on engineering education on the career goals of students about to enter the workforce.

Table 5. Results of the Chi-square test on the selection of career goals related to sustainability topics for senior engineering students that did / did not cover that topic in engineering courses.

Topics in sustainability to address in future careers	Distribution of senior students selecting goal when they did not cover topic (%)	Distribution of senior students selecting goal when they cover topic (%)	Chi-square	ϕ	Sig.
Energy	45.6	65.7	80.6	.13	***
Disease	10.5	36.7	261.1	.24	***
Poverty and distribution of wealth	16.9	30.1	44.3	.10	***
Climate change	25.2	44.5	116.6	.16	***
Terrorism and war	15.5	26.3	14.1	.06	***
Water supply (e.g., shortages, pollution)	26.3	51.5	190.0	.20	***
Food availability	15.5	23.8	21.6	.07	***
Opportunities for future generations	48.2	56.3	14.1	.06	***
Opportunities for women/minorities	23.9	36.2	34.3	.09	***
Environmental degradation	28.3	53.0	180.5	.20	***

Note: $p < .001$ ***, $p < .01$ **, $p < .05$ *

6 Discussion

This study indicates particular ways in which engineering students may be socialized in the education process. Undergraduate experiences inside and outside the classroom may affect

students' conceptualization of engineering careers and how they can address sustainable development topics through engineering.

6.1 Engineering education reinforces engineering agency beliefs in sustainability

The results show a similar trend in students' personal and global engineering agency beliefs between first-year and senior engineering students. Three outcomes are perceived by students from both class standings as the most related to engineering: *improving quality of life, savings lives, and protecting the environment*.

Students' perceptions of global engineering agency beliefs align with the three dimensions of sustainable development—environmental, economic, and social (World Commission on Environment and Development, 1987) and expert views on the engineering profession (National Academy of Engineering, 2005, 2008; Segalàs *et al.*, 2012). Nonetheless, senior students, similar to first-year students, still undervalue their roles as engineers in addressing issues related to social inequity. Senior students perceived relation to these three engineering attributes is significantly greater compared to first-year students. A possible explanation is that engineering education reinforces the relationship between engineering and environmental sustainability which corresponds to current trends in engineering education (Filho *et al.*, 2020; Jowitt, 2020; Lund, 2020).

Seniors have significantly stronger beliefs than first-year students that they should be taking actions to address climate change, that we can pursue sustainability without lowering the standard of living, and that they feel responsible to deal with environmental problems. Undergraduate engineering education may empower students to address many of the issues related to sustainability and climate change. These results align with prior studies showing that education about sustainability tends to reinforce views of human-nature relations and could lead to pro sustainability values (Sidiropoulos, 2018). The changes measured in our study could also reflect a general change in perception of sustainable development in engineering over time as the two studies were conveyed six years apart. For example, over the last decade, the general public concerns about the environmental crisis largely increased (Gallup Survey: Environment, 2019). Nonetheless, attitudes and concerns about the environment are only a first step to taking action and behavior change. Education in sustainability helps raise awareness on human nature relations but falls short into provoking behavioral change (Evans and Ferreira, 2020; Sidiropoulos, 2018).

6.2 Engineering education reinforces students' goals to address environmental sustainability in their careers

Examining career goals, the highest increase in selecting topics to address as professionals were climate change and environmental degradation, which aligned with students' engineering agency beliefs. Moreover, first-year students expressed a higher concern than seniors on sustainability being a threat to their career. This shift could also account for a positive effect of engineering education to promote knowledge of sustainable development strategies as a strength for their career goals. Career goals from the survey reflect the UN SDG from their 2020 report. Yet, most of the UN SDG were rarely covered in engineering courses. Environmental sustainability goals related to energy and water supply or climate change were some of the few topics most covered from the list. Still, less than half of the students covered climate change and environmental degradation in their engineering courses. When covered, such topics significantly increased students' goals to address sustainable development in their future career. Students perceive that science related courses influence environmental knowledge to a larger extent than courses in humanities (Goldman and Yavetz, 2014). It highlights the benefit of integrating sustainable development within engineering courses.

Previous results from the SaGE study emphasized that students attracted to engineering are less likely than others to have career goals related to disease, poverty, and opportunities for underrepresented groups (Authors 2014). Results show that senior students in engineering expect to address challenges related to opportunities for underrepresented groups more likely than first years but are less likely to address issues related to disease and poverty in their career. This finding suggests a possible failure of engineering education to emphasize the role of engineers in addressing not only environmental sustainability but also social sustainability. When looking at topics covered in engineering courses, less than 15% of senior students learned about the underrepresentation of females and racial minorities in engineering, disease, poverty, and distribution of wealth and resources or food availability. The lack of coverage of such topics in engineering courses explains the unawareness of engineers' role in addressing social inequities.

6.3 Implication for engineering education

Rethinking curriculums to integrate sustainability into existing programs instead of creating new dedicated courses and programs is a way forward (Goldman and Yavetz, 2014; Sidiropoulos,

2018). In engineering education, it implies embedding environmental education for all engineering disciplines. Curricular adjustments are needed for all dimensions of sustainable development to become pervasive across engineering disciplines (McCormick *et al.*, 2015). The study showed a lack of coverage of social sustainability in engineering courses. Embedding social dimensions into environmental education is necessary for students to develop values that enable future action toward a more sustainable future (Goldman and Yavetz, 2014). For instance, curricular initiatives that emphasize social aspect of sustainable engineering like Engineers Without Borders or international programs including service, training, and research abroad (Mihelcic *et al.*, 2008) are directions to follow. Extracurricular activities have a positive effect on self-efficacy, beliefs about one's own ability toward sustainable engineering, which suggests that extracurricular activities should be included and valued in curriculums (McCormick *et al.*, 2015). Systematically teaching about sustainable development, with an emphasis on its social dimensions, across engineering programs can help increase diversity (Harrison and Klotz, 2010). Indeed, above average representation among women are found in sustainability leadership positions in the industry (Harrison and Klotz, 2010), in the Engineers without Borders Program, which emphasizes the social aspect of sustainability (Kaminsky *et al.*, 2012); and in engineering with a focus on community service (Bauer *et al.*, 2007).

Teaching sustainable development is a challenge for faculty members as it requires diverse pedagogic strategies like social-constructivist approach and experiential learning (Anderson, 2010; Filho, 2000; Leiserowitz *et al.*, 2013; Monroe *et al.*, 2019), combined with extracurricular activities (McCormick *et al.*, 2015; Mihelcic *et al.*, 2008). Cross disciplinary skills are key elements of sustainable development knowledge (Felgueiras *et al.*, 2017). Teaching such skills requires collaborative teaching by educators from multiple disciplines which is difficult to implement (Ashford, 2004). Our findings suggest that engineering education could make students more aware of the complex challenges that need to be solved to make significant changes in sustainable development. When graduating, students should be confident about their knowledge and abilities to work toward addressing sustainability issues.

Effort is also needed at the university level, as not enough resources have been dedicated to understanding and correcting misconceptions about sustainability (Filho *et al.*, 2020; Filho, 2000). For example, interviews among more than thirty officials in higher education reveal a common perception that sustainability is too abstract and too broad, causing an obstacle for

institutions to engage in sustainable development (Filho, 2000). Higher education institutions should lead by example, for instance, by setting up working groups to debate how best to pursue sustainable development via specific initiatives (university's energy use or sustainable water consumption) or by developing networks (intra-institutional and inter-institutional) to exchange ideas and experiences (Filho, 2000).

7 Limitations and Future Work

The main limitation of this study is that it compares surveys from two cohorts of students at different periods, in 2012 for first years and in 2018 for seniors. A longitudinal study assessing engineering agency beliefs and career goals of students when they enter undergraduate programs and when they graduate would have provided more reliability to our findings. Despite this limitation, the sample size and national spread of respondents selected through a random sample of institutions from a comprehensive list of U.S. colleges and universities are robust. Findings from both surveys provide relevant insights on sustainable development in engineering education.

This paper focused on specific sections of the survey. Our future work will focus on relationships between students' engineering agency beliefs, career goals, engineering education, and climate literacy to widen the current understanding of shortcomings in current practices in engineering pedagogy.

8 Conclusion

This study explored differences in engineering agency beliefs and career goals between first-year students starting an engineering program and senior students graduating from an undergraduate program. The results highlight similar trends in students' personal and global engineering agency beliefs between first-year and senior students. For all participants, global challenges associated with the field of engineering appear in *improving quality of life, savings lives, and protecting the environment*. Senior students show a significantly higher engineer agency to address climate change especially in relation to environmental problems.

Students' career goals, in their first and last year of undergraduate engineering programs, are centered around dealing with energy supply and demand or securing opportunities for future generations. In general, their professional goals relate to environmental sustainability more than

social and economic sustainability. It reflects the topics they covered or not in their engineering courses. One student out of every two in the senior cohort covered energy supply and demand while one student out of every three studied climate change and environmental degradation in their engineering courses. Social and economic sustainability challenges such as poverty or diseases were covered by less than one student out of every five in the senior cohort. These findings suggest that undergraduate studies reinforce students' goals to address issues related to sustainability in their future career. The study also highlights that social sustainability is less covered in engineering courses than environmental sustainability.

Results from this study open a reflection on rethinking engineering curriculums. Implementing systemic solutions in engineering education for graduates to gain interest in addressing sustainable issues, including social sustainability, by embedding sustainability in engineering courses is a relevant direction to follow. More importantly, students need to become aware of the interconnectedness between all the facets of sustainable development (environmental, economic, and social). Therefore, educational programs in engineering need to be refined and adjusted for students to go beyond only addressing environmental sustainability, for example by offering community-related projects and by supporting extracurricular activities. Teaching about Sustainable Development Goals (SDG) within all engineering courses can help to mobilize similar strategies (i.e., sustainability rubric, flipped classroom, project-based learning) in universities worldwide (Romero et al., 2020). Adapting the content and teaching strategies could increase diversity in engineering education and the industry, and by a ripple effect, benefit our communities and local governance. Changes are not only needed at the curricular level. Universities should lead by example, through policy concerns and integrated governance involving board leaders and administration offices (Anderson, 2010; Filho *et al.*, 2020).

9 References

- Anderson, A. (2010). *Combating climate change through quality education*. Global Economy and Development, The Brookings Institution.
- Ashford, N. A. (2004). Major challenges to engineering education for sustainable development: What has to change to make it creative, effective, and acceptable to the established disciplines? *International Journal of Sustainability in Higher Education*, 5(3), 239–250. <https://doi.org/10.1108/14676370410546394>
- Bandura, A. (1989). Human agency in social cognitive theory. *American Psychologist*, 10.

- Barth, M., Michelsen, G., Rieckmann, M., & Thomas, I. (Eds.). (2016). *Routledge Handbook of Higher Education for Sustainable Development*. Routledge.
- Basu, S. J., Calabrese Barton, A., Clairmont, N., & Locke, D. (2009). Developing a framework for critical science agency through case study in a conceptual physics context. *Cultural Studies of Science Education*, 4(2), 345–371. <https://doi.org/10.1007/s11422-008-9135-8>
- Bauer, E. H., Moskal, B., Gosink, J., Lucena, J., & Muñoz, D. (2007). Faculty and student attitudes toward community service: A comparative analysis. *Journal of Engineering Education*, 129–140.
- Brügger, A. (2020). Understanding the psychological distance of climate change: The limitations of construal level theory and suggestions for alternative theoretical perspectives. *Global Environmental Change*, 60, 102023. <https://doi.org/10.1016/j.gloenvcha.2019.102023>
- Chachra, D., Kilgore, D., Loshbaugh, H., McCain, J., & Chen, H. (2008). Being and becoming: Gender and identity formation of engineering students. *2008 Annual Conference & Exposition Proceedings*, 13.250.1-13.250.20. <https://doi.org/10.18260/1-2--3597>
- Clark, G. (2007). Evolution of the global sustainable consumption and production policy and the United Nations Environment Programme's (UNEP) supporting activities. *Journal of Cleaner Production*, 15(6), 492–498. <https://doi.org/10.1016/j.jclepro.2006.05.017>
- Delatte, N. (2020). Evolution of the ASCE civil engineering body of knowledge. *Civil Engineering and Environmental Systems*, 37(4), 244–252. <https://doi.org/10.1080/10286608.2020.1832477>
- Douglass, J., G. Thomson, and C-M Zhao. (2012). The learning outcomes race: The value of self-reported gains in large research universities. *Higher Education* 64 (3), 317–35. <https://doi.org/10.1007/s10734-011-9496-x>.
- Evans, N. & Ferreira, J.-A. (2020). What does the research evidence base tell us about the use and impact of sustainability pedagogies in initial teacher education? *Environmental Education Research*, 26(1), 27–42. <https://doi.org/10.1080/13504622.2019.1703908>
- Felgueiras, M. C., Rocha, J. S., & Caetano, N. (2017). Engineering education towards sustainability. *Energy Procedia*, 136, 414–417. <https://doi.org/10.1016/j.egypro.2017.10.266>
- Filho, L. W., Eustachio, J. H. P. P., Caldana, A. C. F., Will, M., Lange Salvia, A., Rampasso, I. S., Anholon, R., Platje, J., & Kovaleva, M. (2020). Sustainability leadership in higher education institutions: An overview of challenges. *Sustainability*, 12(9), 3761. <https://doi.org/10.3390/su12093761>
- Filho, W. L. (2000). Dealing with misconceptions on the concept of sustainability. *International Journal of Sustainability in Higher Education*, 1(1), 9–19. <https://doi.org/10.1108/1467630010307066>
- Fourati-Jamoussi, F., Dubois, M. J. F., Chedru, M., & Belhenniche, G. (2021). Education for Sustainable Development and Innovation in Engineering School: Students' Perception. *Sustainability*, 13(11), 6002. <https://doi.org/10.3390/su13116002>
- Friedman, T. L. (2008). *Hot, Flat and Crowded: Why We Need a Green Revolution and How It Can Renew America*. Farrar, Straus and Giroux, NY.
- Gallup Survey: Environment. (2019). <https://news.gallup.com/poll/1615/environment.aspx>.

- Goldman, D., & Yavetz, B. (2014). Student teachers' attainment of environmental literacy in relation to their disciplinary major during undergraduate studies. *International Journal of Environmental & Science Education*, 9(4), 369–383.
- Authors (2013).
- Authors (2016).
- Authors (2013).
- Grubert, E. (2018). Civil engineering's internal skepticism on climate change. *Journal of Professional Issues in Engineering Education and Practice*, 144(3).
- Authors (2018).
- Hall, K., & Linzell, D. (2019). *ASCE Civil Engineering Education Summit, Mapping the Future of Civil Engineering Education*. ASCE, Dallas, Texas, USA.
- Hanson-Easey, S., Williams, S., Hansen, A., Fogarty, K., & Bi, P. (2015). Speaking of climate change: A discursive analysis of lay understandings. *Science Communication*, 37(2), 217–239. <https://doi.org/10.1177/1075547014568418>
- Harrison, J., & Klotz, L. (2010). Women as sustainability leaders in engineering: Evidence from industry and academia. *International Journal of Engineering Education*, 26(3), 727–734.
- Hsieh, P.-H., Sullivan, J. R., Sass, D. A., & Guerra, N. S. (2012). Undergraduate engineering students' beliefs, coping strategies, and academic performance: An evaluation of theoretical models. *Journal of Experimental Education*, 80(2), 196–218. <http://dx.doi.org/10.1080/00220973.2011.596853>
- Janakiraman, S., Watson, S. L., Watson, W. R., & Cheng, Z. (2021). Creating environmentally conscious engineering professionals through attitudinal instruction: A mixed methods study. *Journal of Cleaner Production*, 291, 125957. <https://doi.org/10.1016/j.jclepro.2021.125957>
- Jowitt, P. W. (2020). Systems and sustainability. *Civil Engineering and Environmental Systems*, 37(4), 253–263. <https://doi.org/10.1080/10286608.2020.1839892>
- Kaminsky, J., Casias, C., Javernick-Will, A., Leslie, C., & Student, P. D. (2012). Expected outcomes of a construction career: Gender identity and engineers without borders-USA. *Construction Research Congress*, 10.
- Authors (2020).
- Authors (2014).
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs.
- Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press.
- Leiserowitz, A., Maibach, E. W., Roser-Renouf, C., Feinberg, G., & Howe, P. (2013). Climate change in the american mind: Americans' global warming beliefs and attitudes in April 2013. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.2298705>
- Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of Vocational Behavior*, 45(1), 79–122. <https://doi.org/10.1006/jvbe.1994.1027>
- Lent, R. W., Brown, S. D., Schmidt, J., Brenner, B., Lyons, H., & Treistman, D. (2003). Relation of contextual supports and barriers to choice behavior in engineering majors: Test of

- alternative social cognitive models. *Journal of Counseling Psychology*, 50(4), 458–465.
<https://doi.org/10.1037/0022-0167.50.4.458>
- Lent, R. W., Sheu, H.-B., Singley, D., Schmidt, J. A., Schmidt, L. C., & Gloster, C. S. (2008). Longitudinal relations of self-efficacy to outcome expectations, interests, and major choice goals in engineering students. *Journal of Vocational Behavior*, 73(2), 328–335.
<https://doi.org/10.1016/j.jvb.2008.07.005>
- Lönngren, J., Svanström, M., Ingerman, Å., & Holmberg, J. (2016). Dealing with the multidimensionality of sustainability through the use of multiple perspectives – a. *European Journal of Engineering Education*, 41(3), 342–352.
<https://doi.org/10.1080/03043797.2015.1079811>
- Lund, J. (2020). Systems engineering knowledge and skills for water and environmental problems. *Civil Engineering and Environmental Systems*, 37(4), 183–196.
<https://doi.org/10.1080/10286608.2020.1850701>
- McCormick, M., Bielefeldt, A. R., Swan, C. W., & Paterson, K. G. (2015). Assessing students' motivation to engage in sustainable engineering. *International Journal of Sustainability in Higher Education*, 16(2), 136–154. <https://doi.org/10.1108/IJSHE-06-2013-0054>
- McDonough, W., & Braungart, M. (2002). *Cradle to cradle: Remaking the way we make things*. North Point Press.
- Mallya, A., Mensah, F. M., Contento, I. R., Koch, P. A., & Calabrese Barton, A. (2012). Extending science beyond the classroom door: Learning from students' experiences with the choice, control and change (C3) curriculum. *Journal of Research in Science Teaching*, 49(2), 244–269. <http://dx.doi.org/10.1002/tea.21006>
- Mihelcic, J. R., Paterson, K. G., Phillips, L. D., Zhang, Q., Watkins, D. W., Barkdoll, B. D., Fuchs, V. J., Fry, L. M., & Hokanson, D. R. (2008). Educating engineers in the sustainable futures model with a global perspective. *Civil Engineering and Environmental Systems*, 25(4), 255–263. <https://doi.org/10.1080/10286600802002981>
- Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective climate change education strategies: A systematic review of the research. *Environmental Education Research*, 25(6), 791–812.
<https://doi.org/10.1080/13504622.2017.1360842>
- National Academy of Engineering. (2005). *Educating the engineer of 2020: Adapting engineering education to the new century*. National Academies Press.
- National Academy of Engineering. (2008). *NAE Grand Challenges for Engineering*. National Academies Press.
- National Research Council. (2008). *Potential Impacts of Climate Change on U.S. Transportation: Special Report 290*. National Academies Press.
<https://doi.org/10.17226/12179>
- National Center for Science and Engineering Statistics, special tabulations (2018) from the Integrated Postsecondary Education Data System Fall Enrollment Survey, National Center for Education Statistics, U.S. Department of Education.
<https://nces.nsf.gov/pubs/nsf19304/data/>
- Pascarella, E. T., and C. Blaich. (2013). Lessons from the Wabash National Study of Liberal Arts education. *Change: The Magazine of Higher Learning*, 45(2), 6-15. <https://doi.org/10.1080/00091383.2013.764257>

- Pink, D. H. (2005). *A Whole New Mind: Moving from the Information Age to the Conceptual Age*. Riverhead Hardcover.
- Authors (2013).
- Pruneau, D., Khattabi, A., & Demers, M. (2010). Challenges and possibilities in climate change education. *US-China Education Review*, 7(9), 15–24.
- R Core Team (2020). R: A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria. URL <https://www.R-project.org/>
- Rogaten, J., Rienties, B., Sharpe, R., Cross, S., Whitelock, D., Lygo-Baker, S., & Littlejohn, A. (2019). Reviewing affective, behavioural and cognitive learning gains in higher education. *Assessment & Evaluation in Higher Education*, 44(3), 321-337. <https://doi.org/10.1080/02602938.2018.1504277>
- Romero, S., Aláez, M., Amo, D., & Fonseca, D. (2020). Systematic Review of How Engineering Schools around the World Are Deploying the 2030 Agenda. *Sustainability*, 12(12), 5035. <https://doi.org/10.3390/su12125035>
- Segalàs, J., Mulder, K. F., & Ferrer-Balas, D. (2012). What do EESD “experts” think sustainability is? Which pedagogy is suitable to learn it?: Results from interviews and Cmaps analysis gathered at EESD 2008. *International Journal of Sustainability in Higher Education*, 13(3), 293–304. <https://doi.org/10.1108/14676371211242599>
- Sharma, B., Steward, B., Ong, S. K., & Miguez, F. E. (2017). Evaluation of teaching approach and student learning in a multidisciplinary sustainable engineering course. *Journal of Cleaner Production*, 142, 4032–4040. <https://doi.org/10.1016/j.jclepro.2016.10.046>
- Authors (2017).
- Authors (2019).
- Authors (2016).
- Authors (2017).
- Sidiropoulos, E. (2018). The personal context of student learning for sustainability: Results of a multi-university research study. *Journal of Cleaner Production*, 181, 537–554. <https://doi.org/10.1016/j.jclepro.2018.01.083>
- Smalley, R. E. (2003). *Top ten problems of humanity for the next 50 years*. Energy and Nano-Technology Conference, Houston, Texas, USA.
- Spence, A., Poortinga, W., & Pidgeon, N. (2012). The psychological distance of climate change. *Risk Analysis*, 32(6), 957–972. <https://doi.org/10.1111/j.1539-6924.2011.01695.x>
- Turner, E., & Font, B. (2003). Fostering critical mathematical agency: Urban middle school students engage in mathematics to understand, critique and act upon their world. Paper presented at *American Education Studies Association Annual Meeting*, Mexico City.
- United Nations. (2020). *The Sustainable Development Goals Report*.
- Verdín, D., Godwin, A., & Ross, M. (2018). STEM roles: How students’ ontological perspectives facilitate STEM identities. *Journal of Pre-College Engineering Education Research (J-PEER)*, 8(2). <https://doi.org/10.7771/2157-9288.1167>
- Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes* (Harvard University Press).
- Wang, M.-T., Eccles, J. S., & Kenny, S. (2013). Not lack of ability but more choice: Individual and gender differences in choice of careers in science, technology, engineering, and

- mathematics. *Psychological Science*, 24(5), 770–775.
<http://dx.doi.org/10.1177/0956797612458937>
- Wang, S., Hurlstone, M. J., Leviston, Z., Walker, I., & Lawrence, C. (2019). Climate Change From a Distance: An Analysis of Construal Level and Psychological Distance From Climate Change. *Frontiers in Psychology*, 10, 230.
<https://doi.org/10.3389/fpsyg.2019.00230>
- Winters, K., Matusovich, H., Brunhaver, S., Chen, H., Yasuhara, K., & Sheppard, S. (2013). From freshman engineering students to practicing professionals: Changes in beliefs about important skills over time. *2013 ASEE Annual Conference & Exposition Proceedings*, 23.621.1-23.621.20. <https://doi.org/10.18260/1-2--19635>
- World Commission on Environment and Development. (1987). *Our common future*. Oxford University Press.

10 Appendix

A1. Assessing global engineering agency beliefs

Question: In your opinion, to what extent are the following associated with the field of engineering?

- 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
- Feeling a moral obligation to other people

Rating scale: 0 = “Not at all”, 4 = “Very much so”

A2. Assessing personal engineering agency beliefs

Question: To what extent do you disagree or agree with the following.

- We can pursue sustainability without lowering our standard of living
- Human ingenuity will ensure that we do not make the earth unlivable
- I feel a responsibility to deal with environmental problems
- Environmental problems make the future look hopeless
- I can personally contribute to a sustainable future
- Nothing I can do will make things better in other places on the planet
- Pursuit of sustainability will threaten jobs for people like me
- Sustainable options typically cost more

- I have the knowledge to understand most sustainability issues
 - I think of myself as part of nature, not separate from it
 - We should be taking stronger actions to address climate change
- Rating scale: 0 = “Strongly disagree”, 4 = “Strongly agree”

A3. Assessing career goals

Question: Which of these topics, if any, do you hope to directly address in your career?

(Mark all that apply)

- Energy (supply or demand)
- Disease
- Poverty and distribution of wealth
- Climate change
- Terrorism and war
- Water supply (e.g. shortages, pollution)
- Food availability
- Opportunities for future generations
- Opportunities for women and/or minorities
- Environmental degradation

Rating: 0 = no, 1 = yes.

A4. Assessing topic covered in engineering courses

Question: Please indicate whether the following topics were covered in your courses.

(Mark all that apply)

- Energy (supply or demand)
- Disease
- Poverty and distribution of wealth
- Climate change
- Terrorism and war
- Water supply (e.g. shortages, pollution)
- Food availability
- Opportunities for future generations
- Opportunities for women and/or minorities
- Environmental degradation

Rating: 0 = no, 1 = yes.