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Students' attitude toward sustainability and humanitarian engineering education using project-based and international field learning pedagogies

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Abstract

Purpose – Environmental sustainability and social contexts are becoming increasingly important concepts. The infusion of sustainability and humanitarian engineering (HE) into the academic core curriculum is often challenging. This study aims to provide an understanding of students' perceptions and attitudes toward the incorporation of active learning of sustainability and humanitarian concepts into engineering education.

Design/methodology/approach – A project-based sustainability course was developed and offered to engineering undergraduates. A HE international field experience was also provided to students as an extracurricular activity. Pre- and post-surveys were conducted to assess students' perceptions and attitudes toward sustainability and HE project learning experience. An analysis of variance (ANOVA) was performed to determine the statistical significance of the results and demographic influences on students' experiences.

Findings – Both project-based and international field learning experiences positively influenced the students' perceptions of sustainable practices, social change and appreciation of the engineering profession. Multidisciplinary learning also helped students become more motivated, engage in sustainability-promoted activities and community work and improve their social interactions. Students gained practical engineering skills that they did not typically receive in traditional classroom settings and recognized the global and social responsibilities that are core to sustainable development education.

Originality/value – The study demonstrates a mixed undergraduate educational model in which students acquired sustainability concepts through a project-based engineering course and practiced social responsibility through international HE projects. The findings help engineering educators understand students' perceptions toward sustainability and HE, providing insight into effective curriculum design and strategic inclusion of social responsibility in traditional engineering education.

Keywords Sustainability, Active learning, Engineering education, International field experience, Humanitarian engineering, Students' perceptions and attitude

Paper type Case study

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1. Introduction

The catastrophic impact of climate change and air pollution on the world's population, especially the most vulnerable and marginalized, prompted the United Nations to call for systemic change in higher education in the past two decades (Pangarhar, 2015; United Nations, 2005). In response to the call for action, many higher education institutions have created sustainability-related initiatives since the early 2000s (Abdul-Wahab *et al.*, 2003; Boyle, 2004; Capdevila *et al.*, 2002; Gutierrez-Martin and Hüttenhain, 2003; Kennedy *et al.*, 2002; Mulder, 2004; Peet *et al.*, 2004; Perdan *et al.*, 2000; Van Berkel, 2000). These initiatives ranged from waste reduction and alternate energies on campus to academic programs to promote sustainability, especially in engineering disciplines. Civil and environmental engineering programs were most popular among the academic programs with sustainability transformation because of their disciplinary emphasis on environmental practices (Aurandt and Butler, 2011; Dancz *et al.*, 2018; Stanford *et al.*, 2013; Watson and Barrella, 2017; Weatherton *et al.*, 2015; Wolcott *et al.*, 2011). Chemical engineering programs were also noteworthy in their efforts to integrate sustainability into the curricula (Glassey and Haile, 2012; Jollands and Parthasarathy, 2013; Othman *et al.*, 2012; Shing *et al.*, 2016; von Blottnitz, 2006; Zadorsky, 2006).

The introduction of sustainability components into engineering disciplines could benefit academic institutions in several ways. Through sustainability educational initiatives, higher education institutions established the foundation for developing responsible, global citizens to solve the world's most challenging problems (Sibbel, 2009). They were able to build new partnerships with local industries and community partners (Lishawa *et al.*, 2010) and advance university campuses toward waste, energy and water reduction (Berchin *et al.*, 2017).

For undergraduate engineering programs, the two most common sustainability educational approaches were often implemented:

(1) Redesigning existing courses with incorporated sustainability concepts.

(2) Developing new elective courses on sustainability topics (Aurandt and Butler, 2011; Thürer *et al.*, 2018).

Challenges associated with successful implementation and long-term commitment regarding these programs include the potential elimination or loss of in-depth coverage of existing course content with the addition of new concepts and faculty's unfamiliarity with current sustainability concepts and applications. As a result, the second approach is more popular because of its flexibility in course content design and adaptability (Thürer *et al.*, 2018). Nevertheless, the lack of materials, teaching resources and time commitment are still obstacles in the widespread implementation of new sustainability courses (Dancz *et al.*, 2018). The multidisciplinary nature of sustainability concepts demands broader knowledge and experience from faculty, and faculty buy-in is often a challenge (Weatherton *et al.*, 2015).

Effective sustainability practices demand global social change in the way one lives and works. Two of the current Accreditation Board of Engineering and Technology (ABET)'s student learning outcomes (Criterion 3, student outcomes # 2 and # 4) for programs in the United States of America (USA) specifically call for the consideration of "global," "social" or "societal" and "environmental" aspects of the solutions or conclusions (ABET, 2018). United Nations Educational, Scientific and Cultural Organization (UNESCO) declared 2005–2014 as the "Decade of Education for Sustainable Development" (United Nations, 2005). The United Nations sustainable development goals established in 2015 aim to eradicate poverty by 2030 (United Nations, 2015). Social responsibility has been shown to be a critical and integrated component of engineering education (Cabedo *et al.*, 2018). Numerous academic institutions around the world have offered learning through service opportunities to their engineering students, designed to link engineering to social issues. Service learning in this context is defined as "an experience-based learning method that responds to social demand" (Cabedo *et al.*, 2018, p. 3). Several studies have concluded that learning through service can help students develop and enhance skills in communication, multidisciplinary teamwork, cultural awareness and tolerance, social responsibility, ethics, curiosity, commitment and dedication to personal values (Eyler and Gilers, 1999; Zitomer *et al.*, 2003). Student retention has also been claimed to be one of the major positive outcomes of service learning (Cabedo *et al.*, 2018).

Several humanitarian engineering (HE) educational programs have attempted to address both global sustainability and social change, especially targeting marginalized and vulnerable populations around the world. The term "HE" in this context refers to engineering work that addresses basic needs and helps improve the quality of life of people in underserved communities. El-Gabry and Jaskolski (2019) reported a "wind energy and sustainability" project conducted in Egypt with both American and Egyptian students. Ellzey *et al.* (2019) shared a solar power system design and installation experience of engineering students in Guatemala. Although the number of these programs has been rising since 2000, the international, experiential learning opportunities for students remain limited. The goals of these HE programs mainly focus on increasing student diversity and success and equipping students with a social and global understanding of the world's marginalized or underserved populations (Smith *et al.*, 2019). The incorporation of HE, especially experiential learning and international projects, into an existing traditional engineering program can be challenging and sometimes impractical because it requires a greater level of commitment from faculty, students, travel and volunteer work (Smith *et al.*, 2019). As a result, the offerings of HE opportunities as extracurricular activities (i.e. no academic credits) are more feasible but potentially less sustainable, especially in undergraduate engineering programs.

Teaching sustainability and HE concepts have been proven to be most effective with active learning pedagogies, including project-based and experiential learning (Aurandt and Butler, 2011; Cabedo *et al.*, 2018; Dancz *et al.*, 2018; El-Gabry and Jaskolski, 2019; Ellzey *et al.*, 2019; Goralnik *et al.*, 2018; Ramanujan *et al.*, 2019; Smith *et al.*, 2019; Thürer *et al.*, 2018; Weatherton *et al.*, 2015; Zitomer *et al.*, 2003). Active learning helps students apply abstract and theoretical concepts to real-world case scenarios, "facilitate[s] reflection on identity, interests and abilities" and transition from knowledge to action more effectively (Goralnik *et al.*, 2018, p. 323), thus improving student retention and engagement in the subjects. Dancz *et al.* (2018) found that active and experiential learning could help students retain the engineering design and sustainability concepts that they struggled with before the hands-on experience. The addition of international field experiences to the active learning concept could further improve sustainability education and immerse students in another culture (El-Gabry and Jaskolski, 2019). Despite all the benefits, active learning also requires significant effort and time commitment from both students and faculty, which makes it challenging for successful implementation and long-term sustainability (Thürer *et al.*, 2018).

Literature on student learning experiences in sustainability-oriented, international HE projects is limited. Moreover, sustainability learning and international field experience have not often reported and compared for the same student population. This case study aims to help bridge this literature gap by comparing student perceptions and attitudes toward both sustainability education and HE learning experiences offered within the same academic program.

2. Purpose

This paper presents a case study in which project-based learning and active learning with international field experience approaches were used to infuse sustainability and humanitarian concepts into undergraduate engineering education. Students' perceptions and attitudes toward the concepts and their experiences were measured. Changes in student experiences were analyzed to assess the benefits and weaknesses of the programs. The findings provide insights into effective curriculum development and program design.

3. Methodology

This study targeted engineering undergraduate students at the University of San Diego (USD), a private, Catholic, liberal arts and primarily undergraduate institution located in southern California, USA. At the time of this study, the USD school of engineering offered only three undergraduate engineering programs, namely, electrical engineering, industrial and systems engineering and mechanical engineering. The total engineering student enrollment was approximately 600. The class size was relatively small (15–25 students per class). The undergraduate programs followed a 4 ½-year plan, with students obtaining a dual Bachelor of Science/Bachelor of Arts degree in engineering upon graduation. Sustainability and HE learning experiences were offered under the industrial and systems engineering department, with student participation from across the school. The industrial and systems engineering student cohort size was approximately 20.

3.1 Sustainability education through project-based learning

A sustainability and engineering upper-division undergraduate course was developed and offered as a technical elective to industrial and systems engineering, mechanical engineering and electrical engineering majors at USD. The course followed a project-based learning approach. It was designed to provide students with an overview of core sustainability concepts over a one-semester (14 weeks) period. Students were introduced to carbon footprint, greenhouse gas, life cycle assessment (LCA), waste and recycling, energy, water and green engineering design principles.

The class had three major projects. The first group project, assigned after two weeks into the course, aimed to stimulate students' thinking about sustainability practices in their daily routines and generate ideas for preventing or solving current issues. After learning more about sustainable engineering concepts, students were assigned a second group project, where they applied the 12 green engineering principles (Anastas and Zimmerman, 2003) to design and construct a product or system prototype for specific use. As part of the project's final deliverables, student teams were expected to identify the problem, explain how they incorporated the green engineering principles into their proposed solution and address the potential impacts of the solution to end users, the environment and society as a whole. Preliminary economic analysis was also required in the final proposal. At the end of the semester, students were assigned a third project, which provided them with an opportunity to apply their acquired sustainable engineering knowledge to redesign a product or a process/system for their local campus community for sustainability improvement purposes.

In addition to the group projects, several other assignments were incorporated into the curriculum; for example, LCA using hand calculations and software estimations, greywater system cost analysis and energy debates. Case studies and reflective discussions on the social implications of engineering solutions were also embedded throughout the course. Group projects and assignments were mostly multidisciplinary, and the end-results were expected to reflect the multidisciplinary backgrounds of team members. Students practiced both writing and oral presentation skills during the semester.

3.2 Humanitarian engineering education with international and experiential learning through service

To broaden students' knowledge and experience of global sustainability while addressing social change, USD engineering students were provided the opportunity to participate in international HE experiential learning as an extracurricular activity. This learning through service experience took place in El Cercado, a rural town located in the southwest of the Dominican Republic. An international setting was selected over a local community project because the program was intentionally designed to provide students with a cultural immersion experience in addition to technical work. According to Zitomer *et al.* (2003), the learning experience becomes more informative and beneficial when the learning environment is unfamiliar to the learners. Learners naturally gain knowledge of another culture, language and location. In addition, the new economic framework and constraints often force learners to be more creative and to consider new technical and societal issues that they normally would not have considered.

The experiential learning in El Cercado was designed to engage students in humanitarian projects aiming to help improve the living conditions of people in remote, underserved communities around the world. Student participants in the experiential learning trip were recruited within the school of engineering at USD through school email announcements and flyers. An initial informational session, which was open to all students, was held to provide an overview of the trip. Several additional trip planning sessions were also conducted for the committed trip participants after the registration deadline. Students were asked to share trip preparation duties, such as acquiring materials, supplies, tools and equipment and transporting them to the field. There were no specific criteria to select the participants. However, students were required to register for the trip at least two months in advance with an initial deposit (US$200), which was refunded a few days before the trip if the students kept their commitment. In case of a cancellation initiated by the student after the deadline for non-emergency reasons, the deposit was used for the project expenses in the field. This policy was communicated to all students during the initial informational session. All student participants were responsible for their individual costs associated with the trip, including airfare, lodging, ground transportation, meals and any other personal expenses. Project-related costs such as materials, supplies, tools and equipment were funded through grants within the university, which were sought by the lead faculty and volunteer student participants.

A group of university faculty and student researchers (some of whom participated in the trip) completed research and development work on specific products or systems to be implemented during service trips in advance. The projects were initially identified in partnership with local Dominican community leaders during the assessment trip (not included in the data of this study) conducted by the lead faculty and USD engineering students. Examples of projects included efficient wood-burning stove construction for the families, chlorination system design and installation for water distribution centers in the villages and solar water heater design and installation at the residences and communal living centers. Details on specific product development can be found in previous literature (Blair *et al.*, 2016; Ngo *et al.*, 2018). The project's approach was community-driven, end user-oriented and long-term sustainability by local groups (Blair *et al.*, 2016). Project work was facilitated through San Pedro Parish in El Cercado, who employed skilled and talented local Dominicans, pioneered various regional development initiatives from healthcare to agriculture, and organized educational activities for youth in the region. Community partnership was built and maintained on trust, collaborative field implementation strategy and quality project outcomes over the years.

Green engineering and sustainability concepts were incorporated into the design. For example, locally sourced materials were used in all products, considering affordability. Only non-hazardous materials were included in the design. Material diversity was minimized to promote disassembly and value retention during recycling at the end of life. Products and systems, with a targeted lifetime range, were designed to address a specific need for the local community rather than to serve a multipurpose function. Product design was aimed at simple installation and construction, user-friendly operation and easy maintenance and repairs. Reversible fasteners and sub-assemblies were incorporated as much as possible to allow convenient replacements, future upgrades and modifications. In addition, product designs took advantage of renewable resources, including the capture of solar thermal energy to heat water and the use of gravitational energy to meet the water flow requirement for the chlorination system.

The international service trip typically lasted 10–13 days and consisted of three elements:

(1) Introducing students to living challenges facing various groups in the community.

(2) Implementing sustainably designed engineering products/systems to address some of the challenges.

(3) Immersing students in the local culture, language, economic and social frameworks.

During the first two days of the trip, students visited various local groups, including youth programs and a women's cooperative and assessed potential sites for implementation. Students were then organized into subgroups based on their skillsets and project needs. They worked alongside community members of various ages and genders throughout the trip, ensuring that the end products and systems served the best interest of the community. Tasks involved the construction of previously designed products, testing products, monitoring and adjusting systems, collecting and analyzing data, collecting samples and measuring sample characteristics, depending on the project. After the installations and testing, training sessions were conducted for community leaders and/or designated individuals with respect to operations, maintenance and repairs. This was also part of the transfer of product ownership strategy, aimed at long-term sustainability with provided tools and support. Before leaving El Cercado and the Dominican Republic, students experienced local culture, sports, religious and traditional celebrations, including tourist activities in the country's capital (Santo Domingo) in the past two days, where they further explored the history of the country and compared urban and rural living and culture in the Dominican Republic. Ellzey *et al.* (2019) also reported that this extra time outside of the work location contributed positively to the overall cultural immersion experience of the service trip participants.

3.3 Assessment of students' experiences

To assess students' perceptions and attitudes toward sustainability and HE experiential learning, pre- and post-surveys were conducted. The same questions were used in the pre- and post-surveys. The survey questions were designed considering the general student population at the university, the nature of the projects and academic and international settings related to the learning experiences. Basic demographic information, such as age range, gender, major, class level and citizenship origin, was also collected from the participants as part of the survey. Appropriate institutional review board approvals were sought before conducting the survey, and proper procedures were followed during and after the survey.

Table A1 in the Appendix summarizes the questions included in the sustainability pre- and post-course surveys. The questions were divided into six parts. Parts I and IV: students' perceptions about sustainable practices based on their personal view, the view of their social circle and the societal view. Part II: students' current sustainable practices. Part III: students' knowledge of sustainability and sustainable engineering concepts. Part V: students' personal principles and general behaviors. Part VI: students' interest level in other non-traditional engineering educational topics, including HE, entrepreneurship and cross-disciplinary project experience. Parts I, II and IV were designed using a five-point scale answer format; Parts V and VI used a seven-point scale answer format; and Part III used a multiple-choice format.

Table A2 in the Appendix lists the questions included in the HE learning experience. Question 1 (Q1) of the survey used a five-point scale answer format, where 1 = beginner and 5 = advanced. For Q2–Q18, in addition to the 1–5 scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree), students were also given the answer options of "not applicable" (NA) and "do not know" (DK). This survey sought to find out students' perceptions and attitudes toward various aspects of HE. Work motivation, academic enhancement, knowledge application, skill development and change-making were among the key characteristics used in the survey to investigate and compare the changes before and after the learning experience. Students were also asked to self-rate their engineering skills, targeting their perceptions on their own engineering ability before and after participating in a field experience in an unfamiliar international setting.

3.4 Data analysis

The sustainability and engineering course surveys were administered over two consecutive years, with 28 students. The response rate was 96.4% for the pre-surveys and 67.9% for the post-surveys. Students' demographic data included age, gender, class level, major and citizenship (Table A3 in the Appendix). International students came from South America, Mexico, Eastern Europe and the Middle East. It is noteworthy that the female enrollment in the sustainability and engineering course during the study period (42.9%) was significantly higher than the typical female representation in undergraduate engineering majors. McCormick *et al.* (2015) reported similar results in another sustainability education study. Female students made up 32% of the total engineering undergraduates in the school of engineering at USD in 2019. The American Society for Engineering Education data shows that 21.9% of bachelor's degrees in engineering disciplines were earned by women (Roy, 2018). A higher female representation in this study could suggest that sustainability concepts and liberal arts education were more appealing to female students than to male students.

The HE surveys were conducted with 40 student participants in the learning through service experience in El Cercado, Dominican Republic, over a three-year period (service trips were offered annually). In this study, only two students participated in both educational activities (the sustainability and engineering course and the international HE experience). The remaining students participated in only one of the two learning experiences. The response rate for the international field experience was 87.5% for the pre-surveys and 70.0% for the post-surveys (Table A3 in the Appendix). Among the service trip participants, 87.5% were USD students majoring in engineering, 2.5% were USD students majoring in biology and 10.0% were students from other colleges/universities in the USA (University of California-Berkeley, Arizona State University, San Diego City College). Although the target was USD engineering students, a few students from other majors and institutions were indirectly recruited through the network of USD engineering students who had committed to participating in the trip. Similar to the sustainability course, female representation in the HE experience was significantly higher than the typical female makeup in undergraduate engineering programs both at USD and across the nation. Cabedo *et al.* (2018) also reported a similar observation in a service learning experience in Spain. A greater female representation suggests that HE and the concept of helping underserved communities could be more attractive to female students than to male students.

Summary statistics were calculated using pre- and post-surveys. A single-factor analysis of variance (ANOVA) was performed for pre- versus post- data comparison for students' responses to each survey question. A p-value of ≤ 0.05 implied a statistical significance in the data comparison. For the questions showing statistically significant differences, another single-factor ANOVA was conducted based on several demographic parameters. This was done to characterize the influence of student demographics on their perceptions and attitude toward sustainability and HE learning experiences. Academic major, gender and United States (US) citizenship were selected for the sustainability survey data, whereas major, gender and age were selected for the HE survey data. For the sustainability course topic-specific multiple-choice questions, the total number and percentage of correct responses along with changes between the pre- and post-surveys were also calculated and analyzed.

4. Results and discussion

4.1 Sustainability project-based learning influences

ANOVA on pre- versus post-survey comparison of data showed mostly positive changes in students' perceptions and attitudes toward sustainability and sustainable practices after taking the sustainability and engineering course. See Table A4 in the Appendix for data summary and corresponding p-values obtained from the ANOVA for each question (except for the multiple-choice questions of Part III).

The result showed that students were generally aware of the impact of sustainable practices on their personal lives, society and the world, with pre-ratings being mostly in the "positive" to "very positive" range. This could be because the sustainability and engineering course was offered as a technical elective, and students chose the course mostly because of their personal interest in the course topics. Students also had a positive view of the shift toward sustainability (pre-rating = 4.41/5 in QI.3). However, they did not seem to consider that sustainable practices had much influence on their friendships and social relations before taking the course (Q.I.1d, pre-rating = 3.33/5). Students rated their friends' engagement in sustainable practices as "sometimes" (QIV.2.a, pre-rating = 3.07/5). After completing the course, students seemed to think of sustainable practices as being more impactful on their social life than before (Q.I.1d), provided an average post-rating of 3.95/5 (an 18.42% increase, p-value = 0.02). They also changed their view of friends' engagement in sustainable practices (QIV.2.a), with an average post-rating of 3.53/5 (14.71% change, p-value = 0.05). This could mean that students connected better with people with similar sustainability awareness and knowledge and influenced their friends to engage more in sustainable practices. The knowledge gained from the course might have helped students become more engaged in on-campus activities that promoted sustainability. Students' ratings for QII.6 moved from 1.63 ("never" to "rarely") in the pre-survey to 2.21 ("rarely" to "sometimes") in the post-survey, a statistically significant increase of 35.65% (p-value = 0.01). Although the level of student participation in sustainability-related activities on campus was still relatively low, taking the course seemed to have swayed our students in the right direction. It was also noted that at the time of the study, the sustainability activities offered on campus were limited and geared more toward awareness than toward technically challenged directives.

The sustainability survey also included 10 questions focusing on students' daily behaviors and personal principles. Overall, the students viewed themselves as confident young adults with respectful behaviors. The sustainability course experience seemed to have influenced them to become more open to other opinions and perspectives (+18.31% change, p-value = 0.04), more conscientious of their shared environment (+30.33% change, p-value = 0.04) and more compliant with the laws (+23.16% change, p-value = 0.04). Students had ample opportunities to work with others outside of their discipline, whom they had not associated with before the class. The multidisciplinary aspects of project work appeared to play a positive role in broadening students' perspectives, learning experience and interests. This was evidenced by a statistically significant increase of 11.71% in students' interest level in cross-disciplinary work (QVI.3, p-value = 0.03).

Part III of the sustainability course survey included 10 multiple-choice, technical questions related to the following course topics, namely, carbon footprint, greenhouse gas, LCA, water, energy, waste and recycling. After completing the sustainability and engineering class, students' scores on questions related to carbon footprint, greenhouse gas, LCA and energy showed mild to significant improvement. A 56% increase in the students' total number of correct responses was recorded. Students scored less favorably on waste and recycling and water-related questions, with a 0.8%–12% decrease in the total number of correct responses. Overall, the results suggest that the course enhanced students' knowledge in sustainable engineering, especially carbon footprint, greenhouse gas, LCA and energy, but not waste/recycling and water topics. This observation helped us identify the strengths and weaknesses of our curriculum and assisted with the program's continuous improvement efforts.

A second ANOVA was performed to characterize the influence of student demographics on their perceptions and attitude toward sustainability learning experience. The demographics-based analysis focused on the students' responses with statistically significant differences between pre- and post-survey data (QI.1d, QII.6, QIV.2a, QV.2, QV.6, QV.8 and QVI.3, Table A1). Academic major, gender and US citizenship were selected for the demographic data analysis because there were insignificant variations in age and class levels among the student participants.

Results showed no statistically significant effect of gender on students' change of behavior and attitude toward sustainability. However, academic major had a statistically significant impact on students' opinions on their participation in on-campus activities that promoted sustainability (QIV.2a, p-value < 0.01) and how often their friends engaged in sustainable practices (QII.6, p-value < 0.01). Electrical engineering majors increased their ratings by 1.67 (on a scale of 1–5) after completing the course. Mechanical engineering majors' ratings increased by 0.8, on average, for QII.6 and were relatively unchanged for QIV.2a. On the other hand, industrial and systems engineering majors remained relatively unchanged on both matters. This was an interesting observation, which could imply the differences in the level of sustainability topic inclusion within each major curriculum and program activity. The industrial and systems engineering discipline appeared to be a more natural fit to sustainability concepts than the other traditional engineering disciplines because of its inherent system approach to problem-solving, focusing on waste reduction and continuous improvement. Moreover, industrial and systems engineering majors were allowed to take more elective courses than the other engineering majors at USD. The electrical engineering program allowed essentially no elective courses outside of its discipline at the time of the study. This sustainability and engineering course was the first to be offered to all engineering students at the university, focusing solely on sustainability-related topics in relation to the engineering profession and was accepted by all majors to count toward their degree requirements.

Another interesting finding involves the potential influence of US citizenship on survey outcomes. When only considering students' responses in the post-surveys, the only statistically significant effect of US citizenship status was on students' attitudes toward buying organic and locally grown foods (QII.2, p-value = 0.02). Non-US resident students seemed more committed to buying organic and local foods than US students were. This could be attributed to differences in economic status and culture. The USD international student population often came from a more affluent background than the domestic students. International students paid the full tuition to attend the university, whereas almost all domestic students received some sort of financial aid for their studies. Moreover, many international students earned an additional salary from their governments while attending university in the US. The US citizenship status also seemed to affect students' change of opinion about their ability to obey laws (QV.8) after completing the sustainability and engineering course (p-value = 0.03). The US domestic students increased their ratings by 0.89 (on a scale of 1–7), whereas the non-US students' ratings essentially remained the same on this matter. The difference in behavioral changes, in this case, was most likely because of the vast differences in law enforcement policies between the US and other countries.

The evidence of positive influences on students' perceptions toward sustainability and change-making attitude suggests that the project-based and multidisciplinary curriculum approach was effective in educating students about sustainability and motivating them to engage in sustainable practices. Certain areas of the sustainability course curriculum (e.g. water, waste and recycling) could be enhanced and strengthened to improve students' learning outcomes. This educational model could entail some potential challenges, similar to other sustainability programs reported in the literature (Dancz *et al.*, 2018; Weatherton *et al.*, 2015). Existent undergraduate engineering curriculum must have the flexibility to support new course offerings and allow students to earn credits toward their major requirements. There need to be one or more faculty champions knowledgeable in multiple aspects of sustainability and sustainable engineering to develop and instruct the course. The multidisciplinary aspect of the course also requires the participation of students from multiple engineering disciplines.

4.2 Experiential humanitarian engineering learning influences

Table A5 in the Appendix summarizes the survey results on the HE project learning experience, along with the percent change in students' ratings (pre versus post) and corresponding statistical significance obtained from a single-factor ANOVA.

Students' perceptions and attitude toward experiential HE learning showed consistently positive improvements, with one exception of students' own rating of their engineering skills. Interestingly, students' self-ratings of their engineering skills (Q1) decreased by 2.78% after completing the international field experience, although this change was not statistically significant (p-value > 0.05). This slight change could be because, when students worked on a real-world project with direct implications on a community with whom they closely interacted throughout the learning experience, they felt more responsible and held a higher expectation on themselves to deliver a robust solution for the community. They were able to test the results and witness the impact of their work, instead of limiting themselves to the typical hypothetical designs and proposals in a traditional classroom project setting. The over-estimation of student skills could have posed a challenge when students first started working on the project. However, the intensity of project work from the first field day often helped students quickly readjust and be more prepared for the duration of field experience. To further characterize students' perceptions of their own engineering skills before and after the international field experience, additional in-depth questions in future studies could include students' self-assessment on different aspects of their engineering skills, including theoretical concepts, real-world application and field implementation.

The most significant changes in students' opinions were their appreciation of the engineering profession and community involvement. Students' level of agreement to the statement "working on an HE project gives me a better appreciation of the usefulness of engineering" (Q2) rose from 4.57 to 4.85 on average after the learning experience, a 6.13% improvement with a p-value of 0.02. Students seemed to have already recognized the practical application of a HE project before participating in the trip (pre-trip rating was 4.57/5). However, the international field learning experience further reinforced their understanding and appreciation of the engineering profession. In addition, experiential learning through a HE project seemed to have a positive influence on students' interest and work motivation while being involved with a diverse group to develop and implement solutions to help the communities. Students' ratings increased from 3.94/5 (mostly "agree," pre) to 4.46/5 ("agree" to "strongly agree," post) for Q5 "working with an HE community to develop a project has increased my interest in engineering" (a 13.27% increase, p-value = 0.02). In addition, students' ratings rose from 4.34/5 (pre) to 4.71/5 (post) for Q6 "I enjoyed working on an HE project because it allowed me to participate in a diverse community of people interested in HE" (an 8.53% change, p-value = 0.03).

Overall, students responded positively to HE learning through service experience (Q14) (17.86% improvement in the level of learning satisfaction, p-value < 0.01). Students gained field experience in a HE project (Q13), as evidenced by a 22.22% improvement in ratings (p-value = 0.03). They also strongly agreed that their participation in a HE project taught them more about engineering than what they might learn in a traditional classroom setting (Q15), showing a 12.50% increase in ratings (p-value = 0.03). The field learning experience positively changed students' perceptions about the inclusion of a HE field project as a component of their engineering educational experience (Q17), with a +12.88% increase in ratings (p-value < 0.01). Finally, almost all student participants strongly agreed to the statement "I would recommend participating in an HE project to other students" (Q18), with ratings increasing from 4.62/5 to 4.93/5 or+ 6.73% (p-value < 0.01).

A significant decrease was observed in the number of "NA" and "DK" answers to the questions in the post-surveys compared to the pre-surveys: 73% decrease in "DK" answers and 85% decrease in "NA" answers. This was most likely because students had gained more self-confidence, becoming more knowledgeable in HE project work. International field learning might have also contributed to students' awareness of the relevance and impact of HE experience on themselves personally and on the serviced community.

Academic major, gender and age data was used to characterize the influences of demographics on students' learning through HE projects. Of the three studied demographic parameters, age did not appear to be an influencing factor (p-values > 0.05). Although there was no statistically significant difference with respect to gender in students' motivation to work on a diverse community project, the female students seemed to have become more appreciative of this opportunity after the experience than the male students did (Q6, p-value = 0.03).

Another noticeable difference in students' responses was attributable to academic majors. No statistically significant change between pre- and post-survey data was observed in students' attitudes toward HE field learning versus traditional classroom learning with respect to majors (Q15, p-value > 0.05). However, when considering post-survey data only, students majoring in mechanical engineering seemed to strongly believe that their participation in the international field experience and HE projects had taught them more about engineering than what they might have learned in a typical classroom setting, compared to those majoring in industrial and systems engineering and electrical engineering (p-value = 0.01). Specifically, the average rating in Q15 for students majoring in mechanical engineering in the post-survey was 4.72/5, compared to 4.00/5 for industrial and systems engineering students and 3.67/5 for electrical engineering students. This observation could be explained by project tasks. The selected projects for implementation during the service trips involved product and system designs, hands-on construction and installation using powered tools and mechanical parts, and field testing of the products/systems. Mechanical engineering students could relate to these engineering practices in the field more naturally, based on the training focus within their discipline compared to the other two engineering majors; thus, they valued the learning experience more than the other students did.

It was also noted that 100% of the non-USD students (civil engineering and math majors, from research (R1) public institutions) strongly agreed to the Q15 statement. However, the non-USD sample size was small ($N = 2$). Therefore, a definitive conclusion could not be drawn about the influence of institution type on students' attitudes toward experiential HE learning.

The international humanitarian projects provided students with a real-world learning experience, direct interaction with end users and sustainable engineering practice on the field. Students learned to work with international communities and made positive changes in their lives. However, this learning model also presents several challenges, namely, community partnership, faculty leadership, project research and development and costs. These challenges were also reported by other researchers with international field experience involving undergraduate students (Smith *et al.*, 2019; Vander Steen *et al.*, 2009). Community partnerships could be initiated through existing networks and collaborations. In this case study, the initial partnership was formed through referrals from other colleagues who had previously worked with this international community. Partnership can be maintained and strengthened through a collaborative work approach, trust building and community-oriented designs. To ensure a successful learning experience for students on the field, much research and development work must be done in advance and championed by a research team, typically led by a faculty member. This challenge could be overcome naturally with a match between the faculty's research interests and community project needs. However, research funding must be sought regularly to support the projects through all phases, namely, design, test and implementation. In this case study, travel costs were self-funded by the participants, and project costs were supported through internal university grants. The self-funding aspect limited the learning opportunity to only those students who were financially capable. Fundraising events could be organized to seek additional financial support for broader student participation.

5. Conclusions

An impactful infusion of sustainability and humanitarian concepts into engineering education can add significant value to student learning and help shape the future of a more environmentally and socially sustainable world. Through strategic partnerships and a balanced design approach, challenges faced during the implementation of new curriculum and student activities can be overcome. In this study, both project-based learning and international field experiences were proven to be effective in positively influencing undergraduate students' perceptions regarding sustainable practices, social change and appreciation of the engineering profession. The multi-disciplinary learning also helped students become more motivated, engaged in sustainability-promoted activities and community work and improved their social interactions. Academic major and US citizenship appeared to play a role in students' perceptions and attitudes toward sustainability, attributable to academic program structure, economic status and cultural differences. While students in the sustainability course learned various green engineering principles and conceptually applied them to project scenarios, students working on international humanitarian projects practiced implementing sustainable solutions to solve real-world problems. Through both educational experiences, students were able to gain practical engineering skills that they did not typically receive in a traditional classroom setting. They were also able to recognize the global and social responsibilities that are core to sustainable development education. The insights obtained from this case study provided meaningful input to the sustainability curriculum development and strategic infusion of HE experiential learning into traditional engineering education. A follow-up study of the integrated educational model, where the two learning experiences are combined to reinforce sustainability applications and international field implementation, would be helpful to further characterize student learning and to explore long-term sustainment strategies for the program.

References

Abdul-Wahab, S.A., Abdulraheem, M.Y. and Hutchinson, M. (2003), "The need for inclusion of environmental education in undergraduate engineering curricula", *International Journal of Sustainability in Higher Education*, Vol. 4 No. 2, pp. 126-137.

ABET (2018), "Criteria for accrediting engineering programs, effective for reviews during the 2019-2020 accreditation cycle", *ABET Engineering Accreditation Commission*, available at: www.abet.org/wp-content/uploads/2018/11/E001-19-20-EAC-Criteria-11-24-18.pdf (accessed 15 June 2020).

Anastas, P.T. and Zimmerman, J.B. (2003), "Design through the twelve principles of green engineering", *Environmental Science and Technology*, Vol. 37 No. 5, pp. 94A-101A.

Aurandt, J.L. and Butler, E.C. (2011), "Sustainability education: approaches for incorporating sustainability into the undergraduate curriculum", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 137 No. 2, pp. 102-106.

Berchin, I.I., Grando, VdS., Marcon, G.A., Corseuil, L. and Guerra, JESOdA. (2017), "Strategies to promote sustainability in higher education institutions – a case study of a federal institute of higher education in Brazil", *International Journal of Sustainability in Higher Education*, Vol. 18 No. 7, pp. 1018-1038.

Blair, S., Jooste, D., Bryant, D., Ashkar, C., Kuwahara, K., Burt, S., Wolf, D., Peterson, J. and Ngo, T.T. (2016), "Humanitarian engineering opportunities and challenges in rural Dominican Republic: a case study of El cercado", in *Institute of Electrical and Electronics Engineers (IEEE) (Ed.), Proceedings of the Sixth IEEE Global Humanitarian Technology Conference (GHTC 2016), Seattle, Washington, DC*, pp. 709-716.

Boyle, C. (2004), "Considerations on educating engineers in sustainability", *International Journal of Sustainability in Higher Education*, Vol. 5 No. 2, pp. 147-155.

Cabedo, L., Royo, M., Moliner, L. and Guraya, T. (2018), "University social responsibility towards engineering undergraduates", *Sustainability*, Vol. 10 No. 6, pp. 1-17.

Capdevila, I., Bruno, J. and Jofre, L. (2002), "Curriculum greening and environmental research coordination at the technical university of Catalonia, Barcelona", *Journal of Cleaner Production*, Vol. 10 No. 1, pp. 25-31.

Dancz, C.L.A., Bilec, M.M. and Landis, A.E. (2018), "Active experiential sustainable engineering module for engineering education", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 144 No. 1, 4017011-1-12.

El-Gabry, L. and Jaskolski, M. (2019), "Offering engineering students global perspective through experiential learning project in wind energy and sustainability", *Journal of Engineering for Gas Turbines and Power*, Vol. 141 No. 10, 101008-11.

Ellzey, J.L., O'Connor, J.T. and Westerman, J. (2019), "Projects with underserved communities: case study of an international project-based service-learning program", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 145 No. 2, 5018018-1-12.

Eyler, J. and Gilers, D.E. (1999), *Where's the Learning in Service-Learning*?, Jossey-Bass, San Francisco, CA, pp. 23-54.

Glassey, J. and Haile, S. (2012), "Sustainability in chemical engineering curriculum", *International Journal of Sustainability in Higher Education*, Vol. 13 No. 4, pp. 354-364.

Goralnik, L., Thorp, L. and Rickborn, A. (2018), "Food system field experience: STEM identity and change agency for undergraduate sustainability learners", *Journal of Experiential Education*, Vol. 41 No. 3, pp. 312-328.

Gutierrez-Martin, F. and Hüttenhain, S.H. (2003), "Environmental education: new paradigms and engineering syllabus", *Journal of Cleaner Production*, Vol. 11 No. 3, pp. 247-251.

Jollands, M. and Parthasarathy, R. (2013), "Developing engineering students' understanding of sustainability using project based learning", *Sustainability*, Vol. 5 No. 12, pp. 5052-5066.

Kennedy, C., Hyde, R. and Karney, B. (2002), "Development of environmental knowledge and attitudes in engineering students", *Bulletin of Science, Technology and Society*, Vol. 22 No. 6, pp. 460-473.

Lishawa, S., Schubel, A., Verty, A. and Tuchman, N. (2010), "Sustainability education as a catalyst for university and community partnerships", *Metropolitan Universities Journal*, Vol. 21 No. 1, pp. 58-72.

McCormick, M., Bielefeldt, A.R., Swan, C.W. and Paterson, K.G. (2015), "Assessing students' motivation to engage in sustainable engineering", *International Journal of Sustainability in Higher Education*, Vol. 16 No. 2, pp. 136-154.

Mulder, K. (2004), "Engineering education in sustainable development: sustainability as a tool to open up the windows of engineering institutions", *Business Strategy and the Environment*, Vol. 13 No. 4, pp. 275-285.

Ngo, T.T., Medina, J., White, D., Jooste, D., Jerman, K., Hagen, J. and Peterson, J. (2018), "Design and implementation of an alternative, low-cost water chlorination system in El cercado, Dominican Republic", *International Journal of Modern Engineering*, Vol. 18 No. 2, pp. 13-20.

Othman, M.R., Hady, L., Repke, J.U. and Wozny, G. (2012), "Introducing sustainability assessment and selection (SAS) into chemical engineering education", *Education for Chemical Engineers*, Vol. 7 No. 3, pp. e118-e124.

Pangarhar, V.G. (2015), "Education for sustainable development", *Chemical Weekly*, pp. 203-205, 10 November.

Peet, D.J., Mulder, K.F. and Bijma, A. (2004), "Integrating SD into engineering courses at the delft university of technology: the individual interaction method", *International Journal of Sustainability in Higher Education*, Vol. 5 No. 3, pp. 278-288.

Perdan, S., Azapagic, A. and Clift, R. (2000), "Teaching sustainable development to engineering students", *International Journal of Sustainability in Higher Education*, Vol. 1 No. 3, pp. 267-279.

Ramanujan, D., Zhou, N. and Ramani, K. (2019), "Integrating environmental sustainability in undergraduate mechanical engineering courses using guided discovery instruction", *Journal of Cleaner Production*, Vol. 207, pp. 190-203.

Roy, J. (2018), "Engineering by the numbers", *American Society for Engineering Education*, available at: www.asee.org/documents/papers-and-publications/publications/college-profiles/2018-Engineering-by-Numbers-Engineering-Statistics-UPDATED-15-July-2019.pdf (accessed 30 July 2020).

Shing, C.K., Mohamad, Z.F. and Raman, A.A.A. (2016), "Integrating components of sustainability into chemical engineering curricula", *International Journal of Engineering Education*, Vol. 32 No. 6, pp. 2653-2664.

Sibbel, A. (2009), "Pathways towards sustainability through higher education", *International Journal of Sustainability in Higher Education*, Vol. 10 No. 1, pp. 68-82.

Smith, J., Tran, A.L.H. and Compton, P. (2019), "Review of humanitarian action and development engineering education programmes", *European Journal of Engineering Education*, Vol. 45 No. 2, pp. 1-24, doi: 10.1080/03043797.2019.1623179.

Stanford, M.S., Benson, L.C., Alluri, P., Martin, W.D., Klotz, E.E., Ogle, J.H., Kaye, N., Sarasua, W. and Schiff, S. (2013), "Evaluating student and faculty outcomes for a real-world capstone project with sustainability considerations", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 139 No. 2, pp. 123-133.

Thürer, M., Tomasevic, I., Stevenson, M., Qu, T. and Huisingh, D. (2018), "A systematic review of the literature on integrating sustainability into engineering curricula", *Journal of Cleaner Production*, Vol. 181, pp. 608-617.

United Nations (2005), "UN decade of ESD", *United Nations Educational, Scientific and Cultural Organization*, available at: https://en.unesco.org/themes/education-sustainable-development/what-is-esd/un-decade-of-esd (accessed 15 June 2020).

United Nations (2015), "UNESCO and sustainable development goals", *United Nations Educational, Scientific and Cultural Organization*, available at: https://en.unesco.org/sustainable developmentgoals (accessed 15 June 2020).

Van Berkel, R. (2000), "Integrating the environmental and sustainable development agendas into minerals education", *Journal of Cleaner Production*, Vol. 8 No. 5, pp. 413-423.

Vander Steen, J.D.J., Baillie, C.A. and Hall, K.R. (2009), "International humanitarian engineering: Who benefits and who pays?", *IEEE Technology and Society Magazine*, pp. 32-41.

von Blottnitz, H. (2006), "Promoting active learning in sustainable development: experiences from a 4th year chemical engineering course", *Journal of Cleaner Production*, Vol. 14 Nos 9/11, pp. 916-923.

Watson, M.K. and Barrella, E. (2017), "Using concept maps to explore the impacts of a learning-cycle-based sustainability module implemented in two institutional contexts", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 143 No. 2, *D4016001-1-11*.

Weatherton, Y.P., Sattler, M., Mattingly, S., Chen, V., Rogers, K.J. and Dennis, B. (2015), "Multipronged approach for incorporating sustainability into an undergraduate civil engineering curriculum", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 141 No. 2, *C5014003-1-13*.

Wolcott, M., Brown, S., King, M., Ascher-Barnstone, D., Beyreuther, T. and Olsen, K. (2011), "Model for faculty, student, and practitioner development in sustainability engineering through an integrated design experience", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 137 No. 2, pp. 94-101.

Zadorsky, W.M. (2006), "Education for sustainable development: integration of sustainable development into engineering education in Ukraine", *Clean Technologies and Environmental Policy*, Vol. 8 No. 1, pp. 64-68.

Zitomer, D.H., Gabor, M. and Johnson, P. (2003), "Bridge construction in Guatemala: linking social issues and engineering", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 129 No. 3, pp. 143-150.

Appendix

Sub-section	Questions
Part I Five-point rating scale: *1 = very negative* *2 = negative* *3 = neutral* *4 = positive* *5 = very positive*	1. What impact do you expect sustainable practices to have on these aspects of your life? a) life satisfaction b) career c) health and well-being d) friendships and social relations 2. What impact do you expect sustainable practices to have on our society and world? a) The next generation b) The quality of local communities c) US economy d) Natural environments 3. Overall, what is your view of the shift toward sustainability?
Part II Five-point rating scale: *1 = never* *2 = rarely* *3 = sometimes* *4 = usually* *5 = always*	Rate your engagement in: 1. Recycle newspaper, glass or plastic bottles on campus 2. Buy organic or locally grown vegetables at places such as Farmer's market, local stores or on campus 3. Take classes that have a focus in sustainability 4. Conserve water by taking shorter showers 5. Consume beverages in a reusable bottle or cup 6. Participate in activities on campus that promote sustainability (e.g. housing energy competitions) 7. Use the stairs rather than the elevator when possible 8. Use reusable bags when shopping 9. Wash laundry only when you have a full load 10. Use both sides of the paper when printing out notes or bring a laptop to class
Part III Multiple choice questions	10 different technical questions relating to various sustainability topics: greenhouse gases, life cycle assessment, waste and recycling, water and energy
Part IV Five-point rating scale: *1 = very negative* *2 = negative* *3 = neutral* *4 = positive* *5 = very positive*	1. How the following groups in your social circle view sustainable practices? a) Friends b) Family c) Professors
Part IV Five-point rating scale: *1 = never* *2 = rarely* *3 = sometimes* *4 = usually* *5 = always*	2. How often the following groups in your social circle engage in sustainable practices? a) Friends b) Family c) Professors
Part V Seven-point rating scale: *1 = not true* *2–3 = somewhat untrue*	Rate your level of agreement: 1. I do not care to know what other people really think of me 2. Once I have made up my mind, other people can seldom change my opinion 3. I never regret my decisions

(*continued*)

Table A1. Summary of survey questions for sustainability course

Sub-section	Questions
4 = neutral *5–6 = somewhat true* *7 = very true*	4. The reason I vote is because my vote can make a difference 5. I am very confident of my judgments 6. I have never dropped litter on the street 7. I never take things that do not belong to me 8. I always obey laws, even if I am unlikely to get caught 9. It is all right with me if some people happen to dislike me 10. When I hear people talking privately, I avoid listening
Part VI Seven-point rating scale: *1 = very uninterested* *2–3 = somewhat uninterested* *4 = neutral* *5–6 = somewhat uninterested* *7 = very interested*	1. What is your level of interest in participating in a humanitarian-related project during your time at USD? 2. What is your level of interest in having an entrepreneurship component in one of your courses, such as sustainability or senior design? 3. What is your level of interest in having the cross-disciplinary experience while working on a project (could be associated or not associated with a class)?

Table A1.

Table A2.
Summary of survey questions for humanitarian engineering learning experience *(students were asked to answer or rate their agreement level on a five-point scale)*

#	**Questions/statements** *(HE = humanitarian engineering)*
1	How would you characterize your engineering skills?
2	Working on an HE project gives me a better appreciation for the usefulness of engineering
3	I wanted to work on an HE project because I want to help the people who would benefit from the project
4	Knowing that my project will help people motivates me to do my best on the HE project.
5	Working with an HE community to develop a project has increased my interest in engineering
6	I enjoyed working on an HE project because it allowed me to participate in a diverse community of people interested in HE
7	Working on an HE project increases my interest in engineering
8	I enjoyed working on an HE project because the project can positively impact the world
9	Participating in an HE project made me more comfortable with engineering
10	Participation in an HE project has positively reinforced my decision to make engineering my major
11	Participation in an HE project has caused me to consider taking additional elective engineering courses
12	The subject matter of this HE project is highly relevant to my future career plans
13	I have a high level of experience in the HE subject matter
14	Overall, I am very satisfied with my learning in the HE project
15	My participation in an HE project has taught me more about engineering than what I might learn in a typical classroom setting
16	Participation in an HE project strongly compliments typical classroom learning
17	Participation in an HE project should be a component of the engineering educational experience
18	I would recommend participating in an HE project to other students

Demographic category	Sustainability and engineering course survey	Humanitarian engineering experience survey
Age	19–23	18–23
Gender	47.4% female 52.6% male	45.0% female 55.0% male
Class level	0.0% freshman 7.4% sophomore 11.1% junior 81.5% senior	7.5% freshman 30.0% sophomore 25.0% junior 37.5% senior
Major	15.8% electrical engineering 57.9% industrial and systems engineering 26.3% mechanical engineering 0.0% others	15.0% electrical engineering 15.0% industrial and systems engineering 57.5% mechanical engineering 12.5% others
Citizenship	47.4% US citizens 52.6% non-US citizens	90% US citizens 10% non-US citizens

Table A3. Demographic summary of student participants

Table A4.
Pre- vs post-survey comparison for sustainability course ($N = 27$) *(excluding Part III multiple-choice questions)*

Survey questions *(from Table A1)*	Pre-rating average	Pre- vs post-change (%)	*p*-value
I.1.a	3.96	6.25	0.15
I.1.b	4.11	3.70	0.34
I.1.c	4.33	4.45	0.30
I.1.d	*3.33*	*18.42*	*0.02*
I.2.a	4.78	−0.86	0.76
I.2.b	4.33	3.24	0.52
I.2.c	3.96	0.93	0.88
I.2.d	4.70	−1.53	0.67
I.3	4.41	3.89	0.43
II.1	3.89	8.27	0.29
II.2	2.78	11.79	0.34
II.3	2.52	19.12	0.09
II.4	2.96	6.58	0.51
II.5	3.56	9.54	0.30
II.6	*1.63*	*35.65*	*0.01*
II.7	4.04	−0.92	0.88
II.8	2.30	16.13	0.23
II.9	4.37	8.05	0.13
II.10	3.85	−0.48	0.95
IV.1.a	3.63	2.95	0.64
IV.1.b	3.74	−0.10	0.99
IV.1.c	4.22	4.71	0.30
IV.2.a	*3.07*	*14.71*	*0.05*
IV.2.b	3.26	9.81	0.20
IV.2.c	3.64	7.00	0.27
V.1	4.23	15.69	0.09
V.2	*3.69*	*18.31*	*0.04*
V.3	3.65	8.03	0.54
V.4	4.69	7.68	0.57
V.5	5.23	3.64	0.50
V.6	*4.04*	*30.33*	*0.04*
V.7	5.81	11.47	0.11
V.8	*4.62*	*23.16*	*0.04*
V.9	5.35	4.35	0.59
V.10	4.88	−4.10	0.66
VI.1	5.00	10.53	0.24
VI.2	5.92	8.41	0.12
VI.3	*5.65*	*11.71*	*0.03*

Survey questions *(from* Table A2*)*	Pre-rating average	Pre- vs post-change (%)	*p*-value
1	3.09	−2.78	0.72
2	*4.57*	*6.13*	*0.02*
3	4.66	4.29	0.12
4	4.74	2.41	0.32
5	*3.94*	*13.27*	*0.02*
6	*4.34*	*8.53*	*0.03*
7	4.03	8.13	0.10
8	4.55	5.68	0.08
9	3.93	9.02	0.09
10	4.27	4.89	0.28
11	3.55	6.12	0.42
12	3.27	12.82	0.09
13	*2.52*	*22.22*	*0.03*
14	*4.00*	*17.86*	*< 0.01*
15	*4.00*	*12.50*	*0.03*
16	3.87	10.99	0.11
17	*4.18*	*12.88*	*< 0.01*
18	*4.62*	*6.73*	*< 0.01*

Table A5. Pre- vs post-survey comparison for humanitarian engineering learning experience ($N = 35$)

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