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Teaching engineering design through a team-based multi-disciplinary humanitarian engineering project: effects on engineering identity and sense of belonging

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Abstract:

Humanitarian engineering is the application of skills or services for humanitarian aid purposes; and with crises occurring at an ever-increasing rate, more and more people and systems are being affected. There are global challenges facing the world with regard to accessible clean water, shelter, waste disposal, food security, and health. These challenges present opportunities for engineers to address real-world problems in collaborative teams, and propose viable solutions that take into account not only technical issues, but also issues of equity, culture, religion, society, and politics. Humanitarian academic exercises like the one described here, introduces students to the many of these skills that are necessary to better address today's complex societal challenges.

First year introductory engineering courses are where engineering schools often make their first impressions on brand new undergraduate students, and are spaces to actively introduce them to engineering tools and processes in a safe and supportive environment. This paper discusses how one such introductory engineering course used a team-based multi-disciplinary humanitarian engineering project to teach students about the design process, relevant socio-technical factors, team collaboration, and various forms of effective communications.

The final deliverables for this project included a written proposal, using the Gates Foundation Concept Note as a template, and a seven-minute pitch of their designs to an imaginary investment firm. Regular home works were due along the way to the final deliverables to ensure that students stayed on track and received plenty of feedback at each step.

A mixed methods approach, using a one group pre/post survey, was used to assess what role participation in this project had on the students' ability to apply the design process, and on the students' self-reported engineering identity and sense of belonging within the school community. We show that collaboration on a multi-disciplinary humanitarian engineering project improves students' comfort level with engineering design and the complex human factors that must be considered to address such challenges; and that this in turn contributes to students' engineering identity and sense of belonging.

Background and Motivation

Given engineers' outsized impact on a variety of sectors, including technology, healthcare, infrastructure, and the environment, it is critical that engineering work be conducted socially and takes into consideration the effects of engineering solutions on both individuals and society. Educating future engineers to think beyond the technical and consider the full spectrum of factors involved in solving complex global challenges is an ever-increasing imperative in engineering education programs [1]. The National Academy of Engineering recommends that engineering programs "communicate clearly to students throughout their college experience that engineering is about understanding, defining, and solving important problems for people and society, and that it requires a mix of technical and professional skills, and ability to communicate and work effectively across disciplinary boundaries and with many different stakeholders, strong social consciousness, creativity, multicultural understanding, and business/entrepreneurial understanding [2]. The Engineers Without Borders organization defines a global engineer as one who "takes into account socioeconomic realities and is sensitive to cultural differences." (www.ewb-usa.org). And finally, the ABET accreditation body recently included the two following learning outcomes into their criteria: a) "produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors," and b) "create a collaborative and inclusive environment" [3].

Engineering programs have responded to these developments by designing curricula that consolidates these factors in their technical frameworks [4-7], using a variety of approaches, including problem-based learning [8], project-based learning [9], and service learning [10]. Outcomes using these approaches have demonstrated that students who utilize a wide range of factors in their consideration of a complex problem tended to produce better solutions.

Humanitarian engineering has proven to be an effective approach to instilling students with the need to consider multiple complex factors in solving global problems. Humanitarian engineers develop solutions that provide access to basic human needs and enhances quality of life [11-12]. The United Nations Millennium Development goals and the current Sustainable Development agenda have identified accessible clean water, shelter, waste disposal, health, and well-being for improvement in developing countries (www.undp.org). By integrating humanitarian engineering projects into an engineering curriculum, students are exposed to these unprecedented needs around the globe, and are also better prepared to tackle them. Students learn to involve and empathize with the users, and to include socio-economic, cultural, political, historical, and environmental elements into their problem-solving approach, all attributes of a global engineer [13-15].

First-year introductory engineering courses provide a perfect opportunity for students to first learn about these sociotechnical aspects as they begin their engineering journey. It's in these courses that students become comfortable with the engineering design process, and how instructors introduce these processes can have a large impact on how students view the role of engineers in society. Additionally, these courses play a large part in engineering identity and sense of belonging in that critical first year. [16-19]. Previous work has suggested that when a student fails to see themselves as engineers or that they don't belong to the engineering community, they are more likely to leave the program [20-21]. Further, first year projects that ask students to consider both the technical and non-technical components of a problem have been linked to improved retention for students, especially those that are socially inclined, such as female and underrepresented students [22-23].

This work describes a first-year introductory engineering course that guides student teams through a multi-disciplinary humanitarian engineering team project and analyzes the effect on students' comfort with engineering fundamentals, their view on how important different factors are when approaching a complex engineering problem, as well as their engineering identity and sense of belonging. Our research questions are as follows:

1. What, if any, role does participation in a team-based multi-disciplinary humanitarian engineering project have on students' ability to apply the engineering fundamentals to the design process to solve engineering problems?
2. What changes, if any, occurred in how important different factors are when approaching an engineering problem following participation in a team-based multi-disciplinary humanitarian engineering project?
3. What, if any, role does participation in a team-based multi-disciplinary humanitarian engineering project have on students' self-reported engineering identity, sense of belonging, and feelings of inclusion in their academic engineering community?

Methods: Course Design:

The study was conducted in two sections of an introductory engineering course taken by all first-year engineering undergraduate students, typically in their very first semester. It should be noted that there are many sections of this course, taught by different instructors. This study was only conducted in the two sections taught by the first author. As students do not declare a major until March of their first year, students in this course are general engineering students, interested in a wide variety of disciplines. The learning objectives for this course are as follows:

- Recognize the value of the engineering design process and how it is implemented to solve engineering problems
- Understand and practice applying the engineering design process to solve real-world challenges in collaborative teams
- Learn the importance of effective communications, and practice both technical and non-technical forms of communications
- Identify possible disparities or access issues that can arise when designing solutions to challenges
- Feel confident in your capacity to be an engineer, and identify as belonging to the engineering community

Teams*:* The class was divided into teams with the assistance of the Comprehensive Assessment for Team-Member Effectiveness (CATME) [24], an online tool that assists instructors in forming student teams based on best practices, and students stayed in their assigned team for the entire semester.

Learning the Basics of the Engineering Design Process: Teams worked on two short design projects prior to the larger 10-week humanitarian engineering project. The purpose of these two projects were to familiarize students with the engineering design process and design thinking in a low-stakes environment. Students were asked to design a ping pong ball launcher and a toy that moved like something from nature (a bio-inspired design project).

Humanitarian Engineering Project: The 10-week project included in this study asked student teams to design the following components of a block in a Rohingya refugee camp that had burned down in March of 2021: a) overall block layout, b) a distribution system for food and non-food items, c) water, sanitation, and hygiene (WASH) systems, d) emergency shelters, and e) a system to reduce the spread of communicable diseases. Each component had to be designed to solve the pressing issues within the camp, while considering the refugee needs and characteristics, as well as the local environmental factors. The introduction of the project to the students included information about the global challenges facing the world and how these present opportunities for engineers to address real-world problems in collaborative teams while considering both technical and non-technical factors. Students were also given several resources on the background of the Rohingya refugee plight, details of the large refugee camp in Bangladesh where the fire occurred, and the effects of the fire itself.

Student Support: Several kinds of student support were available throughout the project, including informational resources [Table 1], subject matter expert input and guidance, just-in-time lectures, office hours with all seven members of the teaching team (including the instructor and six teaching assistants), and a Slack channel, where students could ask the teaching team and several subject matter experts questions.

Table 1: Class Support Resources

Category	Resources
Background information	- A list of web links to various humanitarian organizations - Demographic information on camp blocks, including gender, age groups, and persons with specific needs - A map of the camp blocks before and after the March 2021 fire - The SPHERE humanitarian standards handbook - Geographic Information System data
Project management	- Two tutorials on project management and how to make and use Gantt charts
Building empathy	- A collection of refugee stories - Persona worksheet - Customer journey map worksheet
Problem definition	- Problem definition worksheet
Ideation	- A link to the Engineering for Change solutions library - Ideate Mixtape - IDEO Rules for Brainstorming
Prototyping & testing	- Prototype testing plan - Prototyping Mixtape
Funding proposal and pitch	- Three examples of Gates Foundation proposals - The Gates Foundation Call for proposals - Three examples of pitches to non-profit organizations - A guide to making an effective pitch deck - How-to tutorials on making non-profit pitches

Board of Experts: A Board of Experts was put together, consisting of subject matter experts in humanitarian engineering and in each of the camp components. These experts met with student teams one-on-one, monitored the Slack channel for questions from students, reviewed student deliverables and gave feedback, and provided an abundance of informational resources to help guide students through the process.

Class Lectures: The just-in-time lectures focused on the engineering design process as applied to humanitarian engineering. Topics and descriptions of each lecture are included in Table 2.

Table 2: Just-In-Time Lectures

Topic	Descriptions
Overview of humanitarian engineering	- Discussion led by two individuals with field expertise in humanitarian crises - Review of specific refugee camp - Review of typical planning process - Challenges at the refugee camp - Where to seek help
Empathy in engineering & design	- Discussion led by instructor - Importance of empathy in engineering and design - Examples of the use (or not) of empathy in engineering - Methods used to build empathy, especially when you cannot speak with the actual users - Explanation and application of empathy mapping - Explanation and application of personas - Explanation and application of customer journey maps
Five lectures on the individual camp design components	- Each discussion led by an expert in that particular design component - Factors to consider for each component - Where to seek more information for each component

Project Deliverables: The final project deliverables included an oral pitch to the Board of Experts, who were playing the part of a philanthropic investment firm, and an eight-page Gates Foundation Concept Note-style proposal. The pitch could be no longer than seven minutes. The proposal should include a project description, background and rationale, the project objectives, the project design and implementation plan, and a summary of potential risks and limitations. Each deliverable was graded using a deliverable-specific rubric, which was shared with students at the beginning of the project.

In order to help students stay on track toward their deliverables and to provide ample opportunity for feedback from the teaching team and Board of Experts, several homework assignments were due along the way toward the final deliverables. These assignments are summarized in Table 3.

Table 3: Supporting Homework

Assignment title	Description	Due date (week of project)
Project management plan	Included assigned roles and responsibilities of each team member, clear expectations for team engagement, and a Gantt chart for the project	Week 1
Background summary	Included background context of the project, a review of the current situation in the camp block, a summary of the refugees effected and their needs, a summary of the challenges, risks, and unintended consequences involved in each camp component.	Week 3
Problem definition	Included the problem statement for each camp component, the desired impact, a summary of the relevant SHERE standards, restrictions, constraints, and requirements for each camp component, a summary of what designs have been used before in camps and what worked/didn't work, and metrics for success for each component	Week 4
Ideation summary	Included a reminder of the problem statement, key insights from the research conducted, a summary of the brainstorming sessions, visualizations from the brainstorming sessions, and a description of the initial concepts for each camp component	Week 5
Summary of design	Included a detailed summary of final designs for each component and how each addressed the user needs, sketches and technical drawings of each component	Week 7
Prototyping & testing summary	Included a summary of visualization of both a low-fidelity and a high-fidelity prototype, and a plan for how field testing might be carried out.	Week 8
Outline of pitch and proposal	Included an outline for each deliverable, using the rubrics as guides	Week 9
Practice pitch	A run through of the oral pitches for the class and the teaching team	Week 10

Finally, at the end of the project, each student wrote a personal reflection and completed a peer evaluation of each team member. The personal reflection assignment asked each student to describe what was learned during the project and why it was significant for them. Prompt questions around the design process itself were used as a guide to help students focus their reflection. The peer evaluations were an opportunity for students to provide honest and constructive feedback to their team mates using a rubric, which was provided to them at the beginning of the semester. Students completed these rubrics at the end of each of the two earlier projects, and then at the end of the major ten-week project, with each peer evaluation grade counting progressively more toward the final grade (0% for project 1, 5% for project 2, and 10% for project 3).

Methods: Assessment

The study occurred in the Fall 2021 semester at a major R1 university and was conducted with full Institutional Review Board (IRB) approval (protocol #4581). We employed a mixed methods approach, collecting both quantitative and qualitative data in response to the research questions. This methodology was accomplished using a pre/post survey approach conducted anonymously at the beginning of the semester and the end of the semester. For quantitative data collection, the survey contained 33 Likert scale questions, nine aimed at understanding students' comfort level with various components of engineering fundamentals, eight assessing what factors students consider important in approaching a complex engineering problem, 11 evaluating students' engineering identity and capacity, and five investigating their sense of belonging in the academic engineering community. The engineering identity and capacity questions were adapted from Godwin's tool to measure these identity frameworks in post-secondary students [25] To measure sense of belonging, we utilized a modified version of the Studying Underlying Characteristics of Computing and Engineering Student Success (SUCCESS) survey instrument, which has been validated in engineering programs from 17 ABET-accredited institutions in the U.S. [26-27]. Toward collecting qualitative data, the post-semester survey also included six open-ended questions that ask participants about what aspects they enjoyed about the project, what areas could be improved, and how participation in the project impacted their comfort with engineering design and their feelings around engineering identity and sense of belonging.

Participants

Participants included 43 of the 53 students (81%) enrolled in both sections of the course who completed both the pre- and post-semester surveys, 23% of whom were female and 77% male. Of the participants, 68% identified as White and five identified as first-generation college students.

Data Analysis

Likert scale quantitative survey data collected from the pre/post-semester surveys were analyzed for changes between answers on the pre-semester survey and answers on the post-semester survey. Each Likert scale option was assigned a score between 1-5, as shown in Appendix Table 1, and score comparisons between the pre- and post-semester responses were analyzed using two-tailed t-tests and 95% Confidence Interval value calculations. For the open-ended qualitative data, a general inductive content analysis approach was employed. The entire data set was iteratively coded and analyzed for emergent themes.

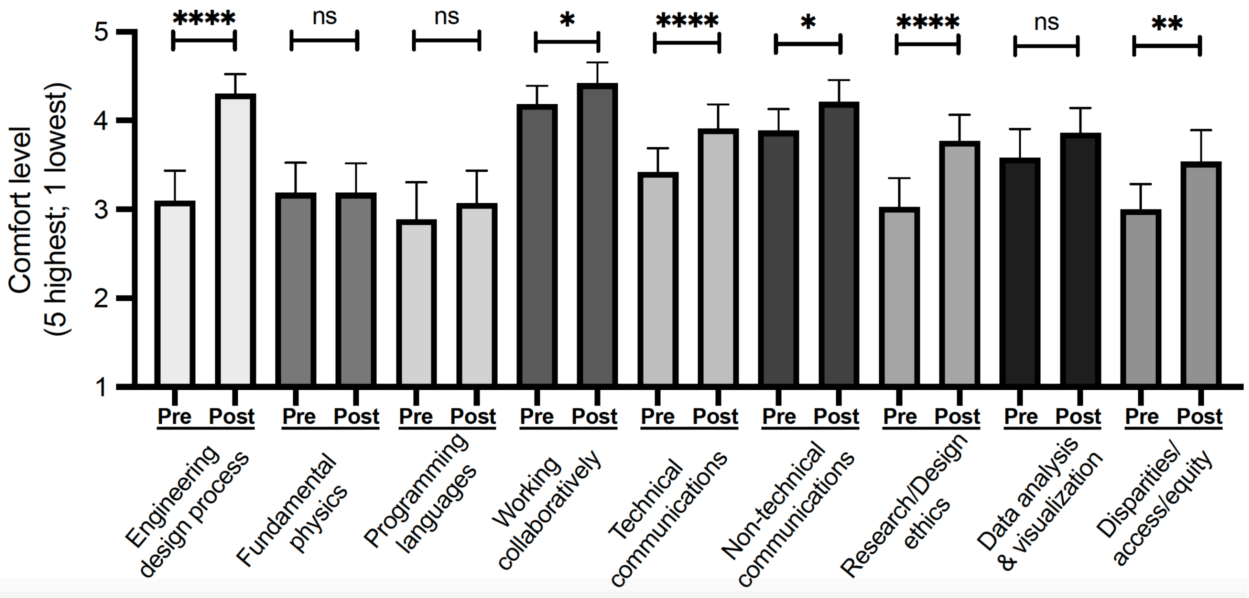
Results

Project participation effects on students' comfort level with engineering fundamentals

In order to address research questions 1, *What, if any, role does participation in a team-based multi-disciplinary humanitarian engineering project have on students' ability to apply engineering fundamentals to the design process to solve engineering problems, w*e assessed for any changes pre- and post-semester in students' comfort level with engineering fundamentals, including the engineering design process, fundamental physics, computer programming, team collaboration, technical communications, non-technical communications, engineering ethics, data visualization/analysis, and engineering disparities & issues of access/equity. Likert scale response options and their assigned scores are shown in Appendix Table 1.

Students reported highly significant increases ($p<0.0001$ or $p<0.001$) in comfort levels with engineering design, technical communications, and engineering ethics [Figure 1]. Significant increases ($p<0.01$ or $p<0.05$) were also observed for team collaboration, non-technical communications, and disparities/issues of equity. No significant differences were seen between pre- and post-semester responses for fundamental physics, computer programming, and data analysis/visualization.

Figure 1: Student Comfort Level with Engineering Fundamentals Pre- and Post-Semester



95% confidence interval analyses, **** = p<0.0001; *** = p<0.001; ** = p<0.01; * = p<0.05

When students were asked in what ways participation in the project helped them learn and apply the engineering design process, inductive coding analysis revealed that a large majority of responses focused on the real-world nature of the problem [Table 4]. Other themes that emerged were the importance of empathy and problem definition.

Table 4: Inductive Coding Analysis of free response question focused on engineering design.

In what ways did participation in the project help you learn and apply the engineering design process?	Number of responses
By applying each step using a real-world problem	15
The importance of empathy in design	6
How to solidly define a problem	5
How to brainstorm	3
How to collaborate in teams	3
How to communicate solutions	4
It did not	3

Some examples of responses are listed below:

> *"The bulk of the project helped me to learn how to define a solid problem and connect to the users to create a solution that meets their values."*
>
> *"All the steps I had to take in this project were a clear replication of what is expected in the design process, and I saw how this would be applied in real world projects."*

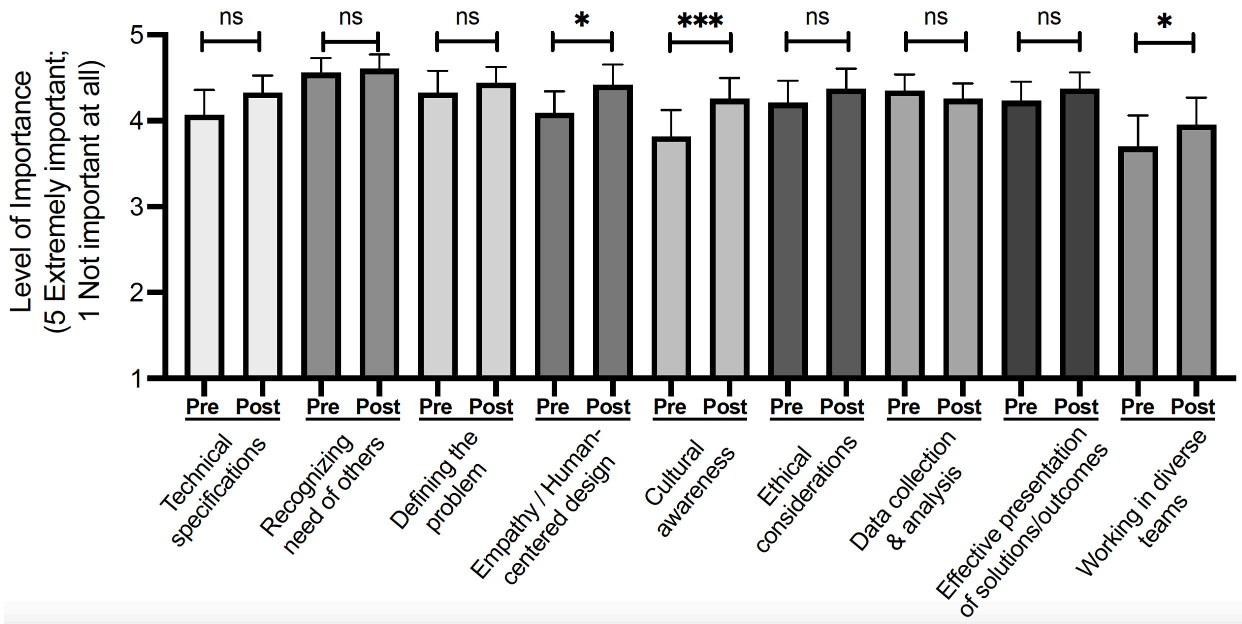
> *"The project helped me learn the engineering design process by having to come up with solutions to meet the SPHERE requirements and the needs of the refugees."*

Project participation's effect on the factors students value when approaching an engineering problem

Next, we evaluated any changes from pre- to post-semester in what factors students consider important when approaching an engineering problem. The factors included technical specifications, recognizing the needs of the users, problem definition, empathy & human-centered design approaches, cultural awareness & sensitivity, the ethics surrounding the problem and solution, data collection & analyses, and working in diverse teams. This analysis addresses research question 2: *What changes, if any, occurred in how important different factors are when approaching an engineering problem following participation in a team-based multi-disciplinary humanitarian engineering project.* Likert scale response options and their assigned scores are shown in Appendix Table 1.

Responses reported a highly significant increase ($p<0.001$) in the importance of cultural awareness and significant increases $p<0.05$ in the importance of empathy/human-centered deign and working in diverse teams [Figure 2]. No significant differences were seen in the importance of technical specifications, recognizing the needs of others, problem definition, ethical considerations, data collection/analyses, and effective presentations of outcomes/solutions.

Figure 2: Importance Level of Various Factors When Approaching an Engineering Problem



95% confidence interval analyses, **** = $p<0.0001$; *** = $p<0.001$; ** = $p<0.01$; * = $p<0.05$

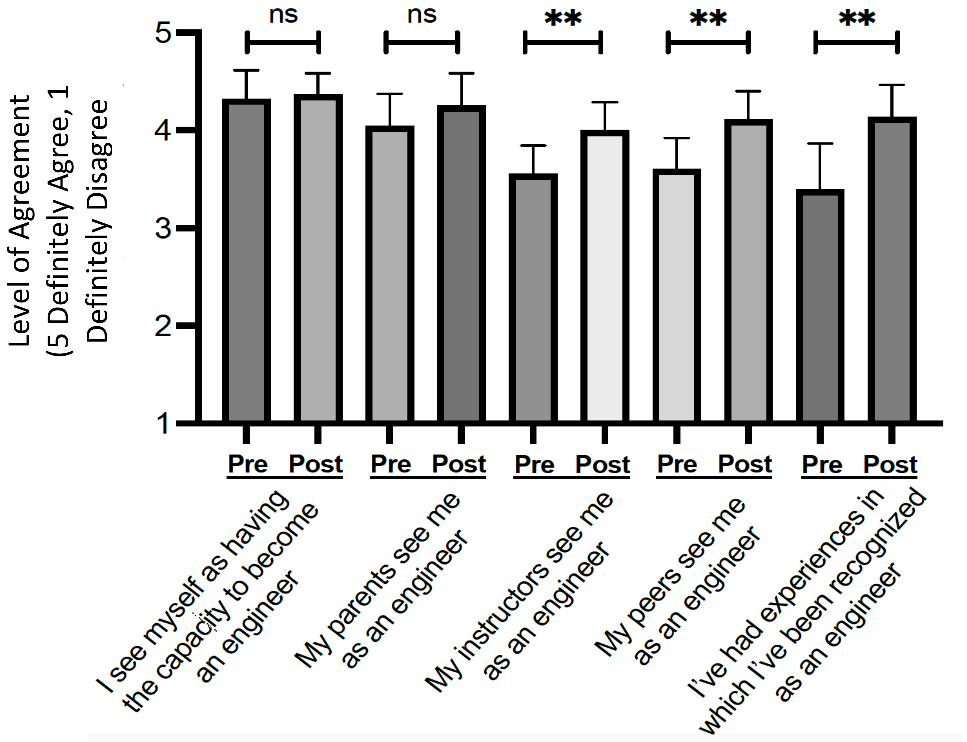
Engineering Identity/Capacity, Sense of Belonging, & Inclusion

Toward answering research question 3, *What, if any, role does participation in a team-based multi-disciplinary humanitarian engineering project have on students' self-reported engineering identity & capacity, sense of belonging, and feelings of inclusion in their academic engineering community*, we looked for changes in responses from the pre-semester to the post-semester survey.

For engineering identity, we asked students to rate their level of agreement with the following statements: 1) I see myself as having the capacity to become an engineer, 2) my parents see me as an engineer, 3) my instructors see me as an engineer, 4) my peers see me as an engineer, and 5) I have had experiences in which I was recognized as an engineer. Likert scale response options and their assigned scores are shown in Table 4.

Significant increases ($p<0.01$) in post-semester vs pre-semester responses can be seen for the following statements: a) My instructors see me as an engineer, b) My peers see me as an engineer, and c) I've had experiences in which I've been recognized as an engineer [Figure 3]. No statistical differences were seen with students' own view of their capacity or in how their parents view them.

Figure 3: Engineering Identity Pre- and Post-Semester

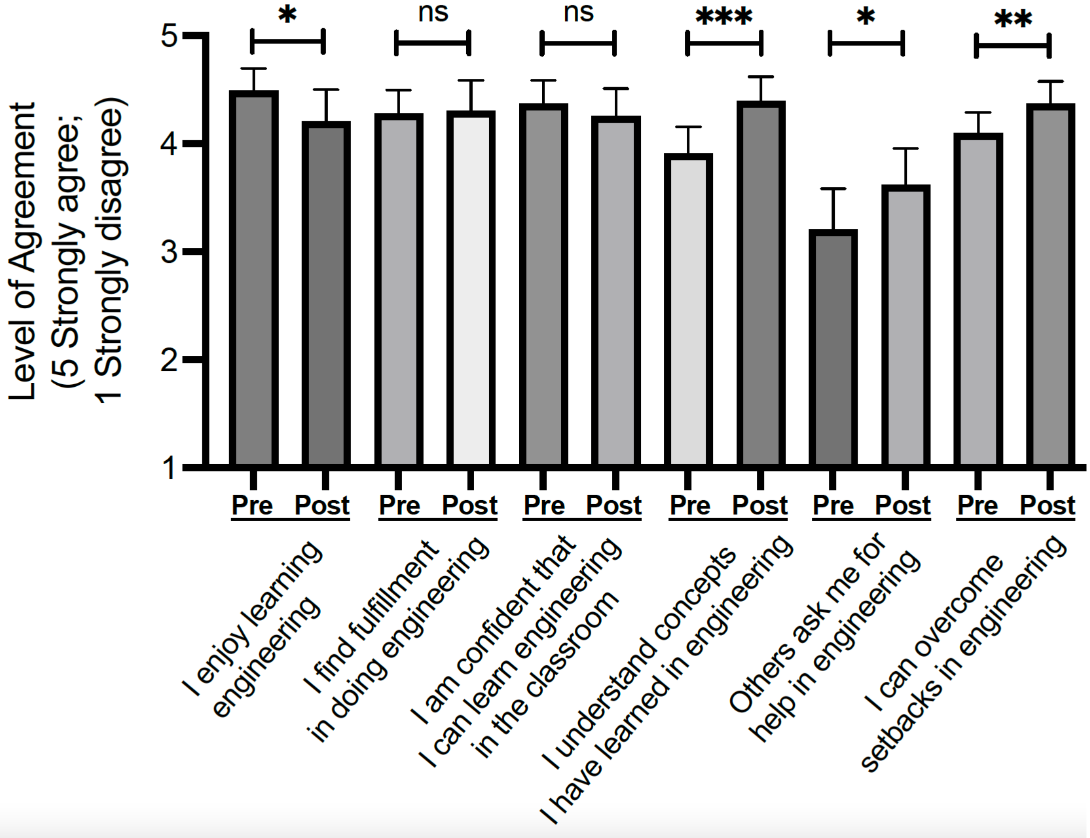


95% confidence interval analyses, **** = p<0.0001; *** = p<0.001; ** = p<0.01; * = p<0.05

For engineering capacity, we asked students to rate their level of agreement with the following statements: 1) I enjoy learning engineering, 2) I find fulfillment in engineering, 3) I am confident I can learn engineering in the classroom, 4) I understand the concepts I have learned in engineering, 5) others ask me for help in engineering, and 6) I can overcome setbacks in engineering. Likert scale response options and their assigned scores are shown in Appendix Table 1.

Highly significant increases ($p<0.001$) were observed in student's agreement with the phrase "I understand concepts I have learned in engineering" [Figure 4]. Significant increases ($p<0.01$ and $p<0.05$) were also observed for "I enjoy learning engineering," "Others ask me for help in engineering," and "I can overcome setbacks in engineering." No significant differences were seen for "I fund fulfillment in doing engineering" and "I am confident that I can learn engineering in the classroom."

Figure 4: Engineering Capacity Pre- and Post-Semester

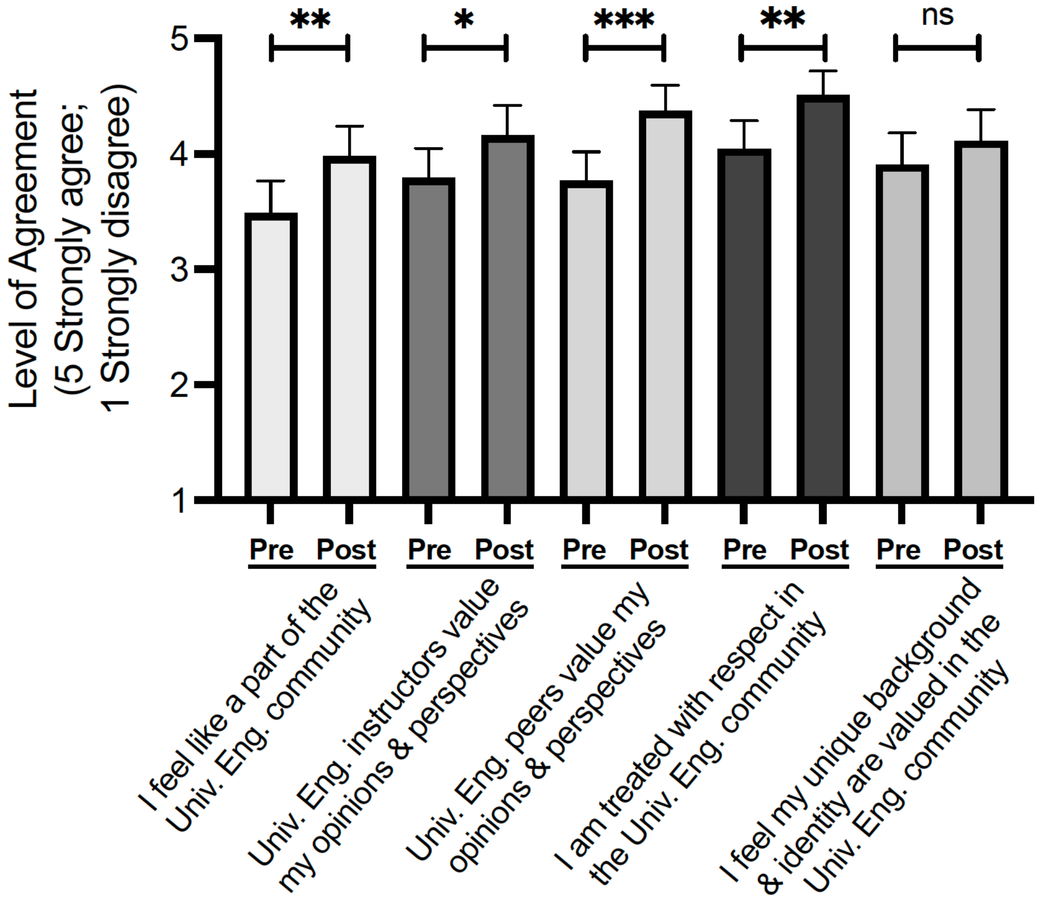


95% confidence interval analyses, **** = $p<0.0001$; *** = $p<0.001$; ** = $p<0.01$; * = $p<0.05$

For the assessment of sense of belonging and inclusion, we asked students to rate their agreement with the following statements: 1) I feel like part of the engineering community, 2) the engineering instructors value my opinion and perspective, 3) peers in the engineering school value my opinion and perspective, 4) I am treated with respect in the engineering school, and 5) I feel my unique background and identity are valued and respected in the engineering school. Likert scale response options and their assigned scores are shown in Appendix Table 1.

Highly significant increases (p<0.001) were seen in post-semester agreement with the phrase "My engineering school peers value my opinions and perspectives," while significant increases (p<0.01 and p<0.05) are seen for the phrases "I feel like a part of the engineering community," "engineering instructors value my opinions and perspectives," and "I am treated with respect in the engineering community" [Figure 5]. No significant differences were observed for the statement "I feel my unique background & identity are valued in the engineering community."

Figure 5: Sense of Belonging and Inclusion Pre- and Post-Semester



95% confidence interval analyses, **** = p<0.0001; *** = p<0.001; ** = p<0.01; * = p<0.05

The last two open-ended questions attempted to investigate the relationship between participation in the project and the students' engineering identity and sense of belonging. When asked in what ways participation in the project impacted their engineering identity, most responders to this question (57.1%) emphasized how participants felt more capable of being an engineer [Table 5]. Five participants, or 17.9% of responders, felt that the project had no effect on their engineering identity.

Table 5: Inductive Coding Analysis of identity and belonging free response questions

In what ways did participation in the project impact your engineering identity?	Number of responses	In what ways did participation in the project impact your sense of belonging in the engineering community?	Number of responses
It helped me feel capable of being an engineer	16	Working with my team toward a common goal	17
It did not have a large impact	5	It made me realize different people have different strengths and weaknesses	8
I can see the bigger picture of engineering as a system or process	3	It did not have a large impact	6
It revealed my leadership abilities	2	Feedback from the experts made me feel I belong	2
It showed me I am not capable of doing engineering work	2	The fact that each team member worked on a different camp component	2

Some examples of responses are listed below:

> *"It helped me see that engineering is not necessarily just about 'building things' but rather the way you engineer a system or process, and that helped reduce my anxiety around engineering a lot."*
>
> *"It made me more comfortable as an engineer and confident in my future."*
>
> *"It showed me that I did not enjoy engineering."*

When participants were asked how the project impacted their sense of belonging, the most common response (48.6%) centered on the contribution teamwork makes to belonging, while eight participants, or 22.9%, highlighted how the project revealed that different students have different strengths and weaknesses [Table 5]. Six responses, or 17.1%, indicated that no impact was made. Some examples of responses are listed below:

> *"Being able to work with a group of people successfully allows me to see myself as someone who belongs in the community."*
>
> *"I realized everybody in my group had different strengths and weaknesses. The project helped me realize that I also have certain strengths."*
>
> *"It has felt difficult to feel like I belong during this project, but I think that this is because I was doing engineering that I do not see myself doing in the future."*

<u>Students' overall opinions on the multi-disciplinary humanitarian engineering team project</u>

When participants were asked an open-ended question about what aspects of the project they enjoyed, one major theme emerged: students enjoyed collaborating in groups the most [Table 6]. Participants also enjoyed the focus on humanitarian work, the real-world nature of the problem, and the hands-on design work.

Table 6: Inductive Coding Analysis of project free response questions

What aspects of the project did you enjoy?	Number of Responses	What improvements could be made to the project?	Number of Responses
Collaborating with my group	16	More hands-on assignments to replace some written ones	6
The focus on humanitarian work	9	More clear directions on assignments & deliverables	6
The real-world nature of the project	6	Too much work for one project	5
The hands-on design work	5	Project felt too hypothetical and niche	5
It was something I had never done before	4	More meetings with experts	3
The emphasis on empathy	3	Too many assignments due along the way	3
The oral pitch	2	No projects within my major of interest	3
Meeting with experts	2	More time to work in class	3
The open-ended nature of the project	1	A bigger page limit for deliverables	2
Having responsibility for one camp component	1	Increased time for oral pitches	1

Some examples of responses are listed below:

> *"I enjoyed collaborating with my group members and their respective components to create one cohesive design for the camp."*
>
> *"I liked doing work and learning skills that are directly applicable to the real world and emphasize making a positive impact."*
>
> *"I was really able to see the importance of empathy and design specifically for the user."*

When asked what improvements could be made to the project, most participants suggested more hands-on homework assignments instead of written ones, more clear directions for each assignment and deliverable, less work for the project, and that the project should be less hypothetical and niche [Table 6]. Some examples of responses are listed below:

> *"Some of the deliverables felt repetitive and unclear at times."*
>
> *"It would be helpful if there were more class time to work in groups."*
>
> *"Humanitarian projects are important, but niche."*

Discussion

First year introductory engineering courses are the ideal format to introduce brand new students to the many facets of engineering and to help them see themselves as engineers and as belonging to the academic engineering community. Students in these courses come from many different backgrounds, lived experiences, and STEM preparation levels. And in engineering schools where students are undeclared during the first year, these courses also include individuals with a large range of interests and aspirations. Meeting all of these different needs and challenges can be difficult.

Previous studies have shown the educational benefits of team-based humanitarian engineering projects. Working on socially minded engineering projects demonstrates that engineers can do altruistic and socially meaningful problem-solving, which has been linked to higher retention in students who are socially inclined, particularly women and underrepresented minorities [5, 22-23, 31-33]. University students are generally becoming more committed to projects with social impact, with 72% claiming that working in a profession with social impact is a higher priority than a prestigious career [34-35].

Here, we attempted to engage first-year engineering students in a team-based multi-disciplinary project that would provide several benefits: a) application of each stage of the engineering design process using a real-world problem; b) exposure to the large variety of socio-technical factors that must be considered in complex engineering challenges; c) components that are of interest to multiple potential majors; and d) an opportunity to work in teams and take advantage of peer support. Our goal in this study was to demonstrate that participation in this project would strengthen students' comfort with engineering fundamentals, would teach them the importance of both technical and non-technical factors in solving engineering problems, and would bolster students' engineering identity and sense of belonging.

Engineering Fundamentals

When investigating how participation in this study's team-based humanitarian engineering project affected students' self-reported comfort level with engineering fundamentals, stathe highest statistical differences between the pre- and post-semester could be seen for engineering design, technical communications, and engineering ethics (Figure 1}. We also saw smaller, yet still statistically significant, gains in comfort with working collaboratively in teams, non-technical communications, and disparities/access/equity. As we can see from the responses to the open-ended question on the impact of participation on learning the engineering design process, we see that the real-world applicability was the most mentioned component.

These outcomes add to what has been found in the literature. The use of humanitarian engineering projects as a means for engineering education has been shown to improve context understanding, problem analysis, critical thinking, cognitive development, and improved communication skills [36-37]. These projects have also been linked to better professional skills such as cross-cultural competencies and teamwork [38-40]. Others have highlighted the importance of service-learning problems in teaching technical and professional skills [40-43]. We did observe only a small increase in comfort with teamwork. More and more K-12 education involves team-based approaches, and informal discussions with first-year engineering students points to an increasing number of new students entering college with a great deal of experience working in teams. By continuing this trend in higher education and layering its complexity, we can continue building on this essential professional skill.

Factors to Consider in Solving Engineering Problems

Humanitarian engineering projects are, by nature, complex global challenges that involve multiple socio-technical dimensions and therefore demonstrate the many factors that should be considered when tackling an engineering problem. When students must consider a wide range of information when approaching a problem, they tend to produce better solutions [44-45]. Additionally, having students consider factors such as politics, finances, and ethics, reaffirms that these factors are indeed interrelated to the technical and non-technical aspects of a problem [46]. As Faulkner's study of building-design engineers determined, "good engineering (as in engineering which is effective) demands the thorough integration of these elements" [47].

Mazzurco investigated key attributes that define the socio-technical thinking of an expert versus a novel and showed that expert socio-technical thinkers implement three categories of factors: technology, people, and broader context [13]. By assessing the importance a student places on a variety of factors that fall under the three categories above, we can understand any advancement from the novice to the expert, or from the beginning of the semester to the end of it. We saw the most highly significant increase of importance given to cultural awareness/sensitivity, with smaller, but still significantly different, increases in the importance of empathy/human-centered design and working in diverse teams. However, we saw no significant increases in the importance of technical specifications, recognizing the needs of others, problem definition, ethical considerations, data analyses, and effective presentation of outcomes. It should be noted that students in this engineering school must also take an accompanying course centered around science, technology, and society, often simultaneously with this course, which might account for the large increase in student comfort with engineering ethics, but the lack of increase in the importance of ethics in approaching a problem since participating in this humanitarian engineering project.

Engineering Identity & Sense of Belonging

We also assessed what changes may have occurred in participants' engineering identity, engineering capacity, and sense of belonging after participation in this humanitarian engineering project. Identity is defined as "Being recognized as a certain kind of person in a given context." [48]. Students whose identities align with their academic community experience increased persistence and better retention [25, 49-52].

Engineering identity has also been linked to improved sense of belonging, or the feeling of being included in the engineering community [53]. Students are more likely to stay in their engineering programs if they feel they are part of that academic environment [54-55]. Sense of belonging has also been positively correlated to academic engagement and self-efficacy in STEM disciplines [56]; factors that are also linked to retention [57].

Engineering identity and sense of belonging become even more important when considering historically underrepresented groups in engineering. Lack of belonging continues to be one of the top reasons women and underrepresented minorities disproportionately leave engineering

[58]. Women, for example, make up only 22% of engineering undergraduate students, while historically underrepresented students in STEM make up only 20% [59]. Research has shown these groups value social context in their education and profession [60]. For example, 43% of Engineers Without Borders members are women [62]. Adams and Burgoyne showed that by incorporating opportunities for students to explore the ways engineering helps society in an engineering course, they achieved higher retention and successful completion of the course for females and underrepresented minority students compared to a traditional version of the course [63]. The desire of women and underrepresented students to learn and work in service-based, people-oriented settings highlights the need for opportunities like the one in this study to be incorporated throughout an engineering curriculum.

For this study, we used several components of Godwin's measures of engineering identity to evaluate if participants see themselves as engineers or having the capacity to be engineers [25]. Gains in student agreement at the end of the semester were observed with statements centered around how their instructors and peers see them as engineers, how they enjoy learning engineering and understand its concepts, and how they can overcome setbacks in engineering. No significant gains were seen for how they see themselves or how their parents see them. For many of these first-year students, this was there first time participating in any engineering work, which could be a contributing factor.

To measure sense of belonging, we utilized a modified version of the Studying Underlying Characteristics of Computing and Engineering Student Success (SUCCESS) survey instrument, which has been validated in engineering programs from 17 ABET-accredited institutions in the U.S. [26-27]. Here, we saw highly significant gains in agreement for all statements at the end of the semester except for one, "I feel my unique background and identity are valued in the engineering community." On the other hand, significant gains in agreement post-semester could be observed for whether they are part of the engineering school community and whether their instructors and peers value their perspectives and treat them with respect. When assessing the responses to the open-ended question gauging how participation in the project impacted the participants' sense of belonging, it seems as though peer support was the major contributor to the increase sense of belonging.

Lessons learned

Though this first iteration of team-based multidisciplinary humanitarian engineering project had some successes in teaching engineering fundamentals, expanding the factors students consider when approaching a complex engineering problem, and increasing participants' engineering identity, capacity and sense of belonging, several lessons were learned along the way.

Project complexity: The project itself was too complex and with too many different parts to be suitable for a first-year introductory engineering course. Asking each team of five students to produce five designs for five different components of a refugee camp block was initially overwhelming for most of the students. Students felt very anxious and that they did not have enough knowledge to approach the problem. A second iteration of the course focused on designing emergency shelters for the refugee camp only.

Lack of hands-on work: Some of the camp components, such as disease prevention and item distribution, had to be more process-focused rather than actual hands-on prototyping work. Some students found this to be frustrating. Emergency shelter, however, lends itself to hands-on design, prototyping, and testing.

No implementable design: Given the resources for this project, students were never able to build their final designs or processes and had to settle for low-fidelity prototypes and graphic representations of some of their designs. Additionally, students were not able to see their final designs implemented in the real-world setting of the refugee camp. Though it was stressed from the beginning, that this project was an academic exercise meant to expose students to engineering fundamentals and sociotechnical factors using a real-world problem, many students were disappointed and the end of the project felt anti-climactic for some. This is completely understandable given the students' hard work in making user-focused designs.

Limitations

First, this project was not carried out in a vacuum and many of the responses on our survey instrument must be taken in context of the participants' entire first year experience, which includes a rigorous course load of college-level math, physics, chemistry, and programming. It is sometimes difficult to parse out what responses are specifically related to this project versus their overall first semester in college, especially for engineering identity, capacity and sense of belonging. Future work will refine assessment tools to analyze the effects of one project more specifically.

Second, the survey relies on self-report Likert scales to assess key competencies. These scales are useful in evaluating participants' self-concept and confidence but are limited in measuring actual skill development. Future work could utilize more scenario-based assessment techniques, which have been proven to accurately assess potential behaviors of participants in realistic situations [13, 28-30]. These assessments typically include a description of an open-ended realistic situation, questions related to that situation, and a scoring guide.

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Appendix

Appendix Table 1: Likert Scale to Score Conversion Table

Assigned Score	Engineering Fundamentals	Factors in Engineering	Engineering Identity	Engineering Capacity	Sense of Belonging
5	Very Comfortable	Extremely Important	Strongly Agree	Strongly Agree	Strongly Agree
4	Comfortable	Very Important	Somewhat Agree	Somewhat Agree	Somewhat Agree
3	Somewhat Comfortable	Moderately Important	Neutral	Neutral	Neutral
2	Not Very Comfortable	Slightly Important	Somewhat Disagree	Somewhat Disagree	Somewhat Disagree
1	Not Comfortable At All	Not Important At All	Strongly Disagree	Strongly Disagree	Strongly Disagree