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Developing and Piloting a High School Engineering Design Course with Environmental Justice and Geospatial Visualization (Evaluation)

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Abstract

This paper describes the development, implementation, and professional development of the classroom-tested Creative Engineering Design (CED) curriculum for a project-based high school engineering course that centers on sustainable transportation and environmental justice (EJ) themes.

During a three-year pilot from the 2021-22 through 2023-24 school years, fifteen cooperating teachers at ten secondary schools in Colorado, Indiana, Texas, and Utah contributed to CED's curriculum development and instructional feedback. The CED pilot engaged about 1,200 secondary students in instructional time frames ranging from 8-week cycles to year-long classes.

Through participation in CED, students actively collaborated in engineering teams to learn and apply real-world STEM concepts related to electric vehicle (EV) technology. CED explores the intersection of air quality with EJ and sustainable transportation topics from a local geospatial perspective. Initial findings show that CED increased students' understanding of the engineering design process and the role of incorporating EJ in design solutions.

After several years of classroom testing and revisions, CED is now published and freely available through the TeachEngineering online digital library to extend its reach and adoption.

Introduction

Engineers act in the service of healthy communities [1], and Environmental Justice (EJ) is a key element of ethical engineering. This reinforces the importance and necessity that engineers must engage with all stakeholders and assess the value and impacts of engineering projects from the perspective of—and with input from—the communities they serve.

The engineering profession serves the public good and engineers are bound by a code of ethics to safeguard people's health and welfare. Environmental injustices have inordinately and adversely impacted the health of marginalized communities for generations. For example, air pollution disproportionately and systematically harms Black and Latinx people who live by interstate highways that were built through low-income communities [2].

In the US, the transportation sector is the largest contributor of greenhouse gases (GHGs) and produces more emissions than electricity generation [3]. If the nation reduces its transportation emissions then its carbon footprint will undoubtedly shrink. Comparing and contrasting traditional fossil fuel and sustainable renewable energy sources from a global perspective helps people understand their carbon footprint from an individual perspective. The incorporation of such teachings and learnings provides students the ability to begin to assess their personal contribution and agency to help solve real world problems [4].

Creative Engineering Design (CED) explores engineering concepts and applications from the perspective of electric vehicle (EV) technology through an EJ lens. The CED curriculum builds and integrates students' knowledge and understanding of the engineering design process, basic engineering skills (computer-aided design (CAD), circuits and motors), and transportation-related environmental justice themes (air quality, public health, environmental impacts). CED, like other hands-on learning curricula, fosters pre-college engineering literacy and aims to reveal and promote students' interest in engineering [5, 6] to help pave the way for future engineers and STEM leaders who envision themselves changing the world.

To support teaching and learning about EJ concepts, CED integrates the EJ StoryMaps collection, created on the ArcGIS platform, focusing on transportation-related EJ themes of air quality, public health, and environmental impacts. The geospatial visualizations enable a deeper dive into place-based perspectives of EJ issues that impact students' communities by emphasizing the intersection of engineering with transportation sustainability and equity issues. The EJ StoryMap collection supports student awareness of engineering careers and helps teachers expose students to "careers of the future", such as the advancement of EV technology, which is critically necessary in preparing an engineering workforce that can tackle current and future world problems [7]. CED is designed to engage all high school students, yet the environmental justice content speaks to students from underrepresented and underserved communities who disproportionately experience the impacts of environmental injustice in their lives [8].

CED builds students' engineering skills by incorporating affordable and accessible low- and high-tech engineering skills development. CED develops their understanding and application of the engineering design process through a variety of design challenges culminating in a final EV design-build-test-iterate team project.

The target audience for CED is 9th and 10th graders and its modular curriculum offers a flexible instructional schedule (e.g., quarter, trimester, semester, year-long). Though the course is designed at an introductory level, piloting teachers adapted the course for advanced-level engineering courses. During the CED pilot, cooperating teachers received material and instructional stipends to support their participation in the project. Throughout the CED project, teachers received instructional support and provided curriculum feedback during weekly check-in meetings and post-instruction interviews. Virtual and in-person teacher professional development workshops were offered and participants received free material starter kits and completed curriculum activities from a student perspective to help inform their instruction.

This paper first outlines the CED curriculum and then explores a subset of data collected from students' from pre- and post-course surveys, plus feedback from teachers who implemented CED at pilot schools or participated in CED teacher professional development training.

Background

The CED Curriculum

CED is designed as an introductory-level high school course that explores engineering concepts and real-world engineering applications through the lens of sustainable electric vehicle (EV) technology. The NGSS-aligned CED curriculum consists of project- and place-based course modules that can be tailored for a K-12 introductory engineering course or extended into an advanced engineering course. The classroom-piloted curriculum consists of individual, partner, and group hands-on activities and offers a flexible instructional timeframe. The following sections describe the CED framework.

Learning Objectives

The design process and problem-based, iterative design thinking are the cornerstones of professional engineering, and K-12 engineering education lays the foundation [9]. Students' STEM learning increases when they are engaged in design thinking and the design process with real-world applications. CED builds students' knowledge and application of the Engineering Design Process (EDP) via hands-on, partner- and team-based design challenges. The transdisciplinary student learning objectives of CED include:

- *Engineering and Sustainability Content Competencies:*
    - Apply the engineering design process and design thinking skills to explore climate- and energy-related problems.
    - Develop and apply technical engineering skills (e.g., CAD, electronics) in student-led, model-EV-technology, and sustainability-focused design projects.
    - Make design decisions informed by data.
    - Apply critical and creative thinking in student-led design products.
    - Consider sustainable solutions to climate and energy challenges through alternative-energy-powered vehicles and renewable energy technologies.
    - Incorporate environmental justice principles in their designs.
- *Transdisciplinary Engineering Competencies:*
    - Communicate effectively (oral, written, non-verbal, listening forms) within student teams.
    - Apply affective assets, such as empathy, in engineering ethics.
- *Leadership Competencies*:
    - Practice leadership through participatory processes.
    - Collaborate constructively in diverse teams.

Modular Curriculum Units

The course components of CED consist of six modules whose scope and sequence can be adapted according to teachers' instructional timeframes, students' skill levels, and resource availability. CED builds on traditional engineering curriculum approaches by integrating both EJ concepts and skill-building workshops to help prepare students to understand real-world, sustainability-focused design challenges.

Table 1. Creative Engineering Design Curriculum Overview

Module	Activity	Description
1	Rapid Engineering Design Challenges	Paper Tower Design Challenge - Students work as civil engineering teams in small groups to design and construct model towers out of paper with minimal teacher guidance on completing the challenge.
		Efficient Car Design Challenge - Students learn how a car's aerodynamics and rolling resistance affect its energy efficiency by designing and constructing model cars from simple materials.
		Straw Bridges Design Challenge - Working as engineering teams, students use the engineering design process to plan, create, and test model bridges.
2	Engineering Design Process & Design Thinking	Engineering Design Process & Design Thinking - Students are formally introduced to the seven-step EDP using the various EDP steps in the previous design challenges.
		Creative Crash Testing Design Challenge - Students utilize the full EDP as they become next-generation engineers working on the safety features for passenger vehicles.
3	Environmental Justice & Introductory Design Challenge	Environmental Justice StoryMap Collection - A series of EJ StoryMaps explores connections between air quality, public health, transportation, and engineering.
		Mousetrap Car Design Challenge - Students design, build, and test mousetrap cars as they apply the EDP in this individual engineering design challenge.
4	Introduction to CAD and Carbon Footprint	Tinkercad 3D Design & EV Dream Car Workshop - Students follow a guided engineering skills workshop presentation using the free online Tinkercad web app to design a model 3D EV concept car design.
		Carbon Footprint & Transportation Activity - Students consider choices in transportation and calculate their carbon footprint to learn about their impacts and make informed choices.
5	Introduction to Circuits & Motors and Fuels Debate	Tinkercad Circuits & EV Motor Workshop - Students follow a guided engineering-skills workshop presentation using the free online Tinkercad web app learning the basics about circuits, using a simulator to create circuits, and applying these skills to build a model EV electric motor.
		Fuels Debate - Student teams learn about transportation fuels and then are assigned to represent the different fuels. Working cooperatively, the students develop arguments on the pros and cons of their fuel with the other fuel types.
6	Final Design Challenge	Electric Vehicle Design Challenge - Students creatively collaborate in teams to design, build, test, and iterate a model EV car that runs on a battery-powered electric motor circuit. In a final design expo, teams can present their final EV model, design process journey, and perspectives on the intersection of engineering and environmental justice regarding EVs. Teams can also participate in fun model EV races and aesthetic design competitions.

Leveraging GIS for Community-Specific Content

Geographic Information Systems (GIS) consists of valuable technologies for many professions, including engineers. GIS uses specialized software to collect, store, analyze, query, and visualize spatial data. GIS supports users in applying critical thinking to solve problems and find solutions from a spatial perspective. In K-12 STEM education, project-based learning is even more meaningful and relatable to students when explored from a place-based perspective, such as a familiar schoolyard or local neighborhood [10].

Geospatial visualization is an important tool in engineering. It helps engineers seek answers to the questions “what’s there?”, “why is it there?”, and “why do we care?”, and view engineering projects from the perspective of the people and communities they serve. To explore real-world, spatial environmental justice data, a series of EJ-focused interactive spatial learning resources were created using Esri ArcGIS StoryMap technology.

Environmental Justice Content

When students learn about transportation planning, environmental justice, and design concurrently with an emphasis on developing solutions it helps them connect STEM concepts to the world around them [11]. As engineering education has become more prevalent in the K-12 space, it is vital to incorporate non-technical skills like empathy [12] and a strong understanding of social inequities to build a future workforce prepared to take on society's complex problems and address issues like environmental injustices [13]. Environmental Justice transportation-related activities are a cornerstone of the CED curriculum. CED introduces students to the concepts of EJ through the interactive ArcGIS EJ StoryMaps collection, which incorporates the Principles of Environmental Justice [14]. This collection comprises interactive EJ StoryMaps that build students' knowledge and understanding of air quality (AQ), the relationship between AQ and public health, connections between transportation and climate, and exploration of electric vehicles as an option for sustainable transportation. ArcGIS StoryMaps is an online storytelling tool that embeds ArcGIS content. The EJ StoryMaps incorporate ArcGIS Living Atlas resources including AirNow.gov and EPA EJScreen interactive spatial maps from a place-based, community perspective.

This series of Environmental Justice (EJ) StoryMaps integrates EJ and GIS by exploring the connections between air quality, transportation, and engineering [15]. The EJ StoryMap collection provides background knowledge from reliable sources to build students' understanding of concepts presented in a visual and interactive format. The EJ StoryMap Collection builds students' understanding of our transportation system and its intersections with particulate matter (PM) air pollution, air quality, health impacts, and environmental injustices of communities related to traffic proximity. During the CED pilot, the Cathedral High School teacher extended the use of StoryMaps by including a differentiated summative assessment where students used the StoryMap software to demonstrate the engineering design process and their learning through the final model EV design challenge.

The EJ StoryMaps outline driving questions and related topics supported by reputable resources including videos, infographics, and interactive spatial data maps. Students explored multimedia learning blocks to build their background knowledge of the StoryMap topics and then interacted with the AirNow.gov Air Quality Aware and the EPA EJ Screen interactive geospatial maps to explore transportation, air quality and public health concepts in the community where they live and go to school.

The framework of each StoryMap includes the following sections:

- Essential Question
- Introduction - Think About It
- Content Knowledge Building
- EJ GIS Data Explorations
- Engineering Connections
- Discussion – Talk About It

The following is a summary of the EJ StoryMap collection:

1. ***What is air quality and why does it matter?***
    - Students learn about particulate matter (PM) pollution, its sources, and how PM air pollution is measured.
2. ***How does poor air quality affect our health?***
    - Students dive into how air pollution affects public health, who is at risk, and actions to take on air quality advisory days.
3. ***Are air quality and transportation impacts equitable?***
    - Students learn about environmental justice and its origins, community-based environmental justice, and the role of our transportation system in environmental justice.
4. ***How does transportation affect the environment?***
    - Students learn about cars and carbon emissions through the impacts of traditional gas-burning vehicles and newer technology of electric vehicles on the environment, the relationship between greenhouse gases and transportation, and analyzing transportation options and solutions.
5. ***How do electric vehicle batteries impact our world?***
    - Students build their understanding of battery basics and lithium-ion batteries that power electric vehicles (EVs). Learn about the sources and environmental impacts of lithium used to power electronics, such as cell phones, computers, and Eversion, and explore solutions to advance a more sustainable battery-powered future.

The piloting teachers provided input on and confirmed the suggested order of the StoryMap collection. Teachers chose to implement the entire collection in a one-week mini-unit or one map per week over several weeks based on their instructional preferences. Completion of the EJ StoryMaps is not an essential requirement for students to complete the final EV Design Challenge project; however, social and technical aspects are integrated into the final project as students have the opportunity to incorporate in the summative Design Expo their response to the question “What aspects of the Environmental Justice StoryMaps resonated most with your team about EVs (air quality, health, community and environmental impacts, transportation connections)?”.

During the CED pilot, a cross-classroom collaboration was coordinated between teachers and students from El Paso Leadership Academy (EPLA) and InTech Collegiate Academy (InTech) where classes shared real-time air quality conditions from their local community, and compared air quality between El Paso, TX and Logan, UT. The EPLA students explored the impacts of the largest thoroughfare in their community, Interstate-10, and local air quality. Their teacher shared an anecdote that their students initially thought the air quality in El Paso was always good, but after completing the StoryMap investigations the students realized the correlation between traffic proximity and particulate matter pollution on air quality. At InTech, the students in Logan were very engaged in checking the AirNow.gov website to keep track of their local air quality. Their teacher shared the story that one winter day Logan had the worst air quality in the nation, and after that realization, the students continued to check their city’s air quality each morning even when their CED pilot was over.

Skill-Building Workshops
Student motivation and achievement increase when they have opportunities and exposure to engage with technology in STEM education [9]. Another core aspect of CED is the inclusion of introductory engineering skills workshops on CAD and electronics. Developing engineering skills in K-12 enhances their problem-solving and design skills, regardless of whether they choose to pursue a degree in engineering or simply build and create for their enjoyment. CAD and electronics are foundational to many engineering disciplines. CED includes two, guided Tinkercad web-based workshops—Introduction to CAD and Introduction to Circuits & Motors—that are free and compatible with the Google Classroom format. The workshop goals center on providing teachers and students with limited or no experience in these essential skills with accessible classroom-ready resources. These workshops actively build design and electrical skills in a self-paced, step-by-step guided format that acts as a launch pad into advanced skills development and application.

Assessments
Active assessment is embedded throughout the CED modules. Formative assessments include rapid prototype design challenges, CAD and Circuits & Motors workshops, and the EJ StoryMap worksheets. Summative assessments include the individual/partner introductory mousetrap car design project and the final team-based EV design project and presentation. For the purpose of the pilot, the CED assessments were not analyzed due to time constraints and each teacher adapting the course resources for their respective classroom setting.

Training Teachers
Educators often struggle to effectively teach engineering curricula due to the lack of insufficient background knowledge and limited training [16, 17]. To raise teachers' awareness of and interest in bringing CED into their classrooms, five CED teacher professional development workshops were implemented that engaged 83 educator participants. The workshop formats included: one virtual, nationwide, after-school training series of four, weekly 2-hour sessions in 2023; four in-person 60-minute trainings at the 2024 NSTA national conference; a workshop at the 2024 ASEE P-12 national pre-conference; a workshop at the 2024 ASEE Rocky Mountain Section regional conference; and the 2024 Colorado Science Conference. In addition to CED professional development workshops, the CED EJ StoryMaps were shared at the 2022 ASEE Resource Exchange, the 2023 ASEE RMS conference poster session, the 2024 GIS in the Rockies conference poster session, and presentations on the CED EJ StoryMaps were given at each of the annual Esri Education Summits in 2023 and 2024.

CED professional development workshops utilized three teacher-as-student interactive sections:

- Introduction to CED including an overview of the ASPIRE ERC and exploration of CED on TeachEngineering.
- Environmental Justice: Introduction to EJ and exploration of the EJ StoryMap collection. Teachers were given time to explore one of the CED EJ StoryMaps and become familiar with the format and ArcGIS content. Next, teachers participated in a jigsaw share out where participants gave feedback and asked questions about each of the EJ StoryMaps.
- Engineering Skills Workshops: Teachers were introduced to the free, web-based Tinkercad software including the 3D Design simulator, and built a simple motor circuit as

part of the Circuits & EV Motor skills workshop. Each participant was provided with a classroom kit of ten EV model motor kits to support their students in doing the CED final Electric Vehicle Design Challenge.

Sharing the Curriculum

The CED modular curriculum is published on the TeachEngineering digital library under the ASPIRE K-12 resources landing page to facilitate free and widespread adoption [18]. Each module activity is NGSS standards-aligned and provides instructional support through the provided activity summary, engineering connections, learning objectives, materials list, slides and worksheets, activity introduction and procedure, vocabulary, and assessment options.

Methods

Participants

Recruitment for the CED pilot teachers was coordinated through existing K-12 partnerships between ASPIRE institutions at the University of Colorado Boulder (UCB), Purdue University, University of Texas at El Paso, and Utah State University. With UCB leading the CED initiative, the first iteration of CED was developed, implemented, and revised with UCB's partner high schools before expanding to high schools in other states. A total of 1,199 students piloted CED over three academic years, as noted in the following tables for each of the three pilot years.

Table 2. 2021-22 CED Pilot Schools - Year 1 (including DSST Elevate Y2 and Y3 pilots)

Schools	DSST Elevate Y1-3	DSST College View
Region	Mountain	Mountain
Location	Large City	Large City
Category	Public Charter	Public Charter
Total Students	447	562
% Minority Students	94.18	91.46
% Free & Reduced Lunch	79.2	70.3
# Piloting Teachers	2	1
Grade Levels	9-10	9-10
# Piloting Classes	16	11
# Piloting Students	537	215

Table 3. 2022-23 CED Pilot Schools - Year 2 (excluding DSST Elevate)

Schools	DSST Byers (Cedar)	InTech Collegiate Academy	El Paso Leadership Academy
Region	Mountain	Mountain	Southwest
Location	Large City	Small Suburb	Large City
Category	Public Charter	Independent Charter	Public Charter
Total Students	548	155	226
% Minority Students	67.52	22.9	97.6
% Free & Reduced Lunch	54.6	21	81
# Piloting Teachers	1	1	1
Grade Levels	11	8	10-12
# Piloting Classes	1	2	3
# Piloting Students	25	29	50

Table 4. 2023-24 CED Pilot Schools - Year 3 (excluding DSST Elevate)

Schools	PPHS Englewood	PPHS North	Cathedral High School	Loretto Academy	Logan High School
Region	Midwest	Midwest	Southwest	Southwest	Mountain
Location	Large City	Large City	Large City	Large City	Small Suburb
Category	Public Charter	Public Charter	Private	Private	Public
Total Students	567	283	383	556	1456
% Minority Students	68.4	54.4	93.5	92.6	44
% Free & Reduced Lunch	69	48	n/a	n/a	46
# Piloting Teachers	3	2	1	1	2
Grade Levels	9-11	9-12	11-12	10-12	9
# Piloting Classes	3	6	2	1	2
# Piloting Students	75	150	32	20	66

Student Demographics

Because gender and racial/ethnic representation have been at the forefront of the decades-long push to diversify the engineering profession, we decided to focus on these two variables for this initial analysis.

Across all piloting schools, the gender and race/ethnicity makeup of students who experienced CED was based on self-reported data from students' pre-course surveys as noted in the tables below:

Table 5. Creative Engineering Design Pilot Students' Gender

Student Gender	Percent Total
Female	34.1
Male	46.3
Non-Binary	4.4
Unknown (missing data), prefer not to say	15.2

Table 6. Creative Engineering Design Pilot Students' Race and Ethnicity

Student Race/Ethnicity	Percent Total
American Indian or Alaska Native	4.3
Asian	4.8
Black or African American	16.4
Latina, Latino, Latinx, Hispanic or Spanish Origin	43.3
Middle Eastern or North African	1.5
Native Hawaiian or other Pacific Islander	1.1
White	21.9
Other	2.7
Prefer not to answer.	4

Teacher Demographics
Fifteen teachers piloted CED, including one teacher who piloted CED for the entire 3-year pilot. The demographic composition by gender and race/ethnicity for the combined pilot teacher cohorts is:

- 2 Hispanic/Latina women
- 1 White woman
- 1 Hispanic/Latino man
- 11 White men

Demographic data was not collected for the 83 teachers who participated in the CED professional development workshops.

Data Sources
Students
Because the scope of the multi-year pilot was large-scale, involving a range of classroom environments in multiple states, plus the navigation of the COVID-19 pandemic and post-pandemic challenges at the time, we did not formally outline a research study for the CED pilot and we did not seek IRB approval. Thus, all data collected from students and teachers served for program evaluation, not research. Data were collected via optional, anonymous pre- and post-course surveys administered via Qualtrics.

The student pre- and post-course surveys included 16 demographic questions and 84 questions about their attitudes and beliefs toward engineering. The following lists the survey question categories:

- Course preparedness self-rating and rating to fellow students
- Why enroll in the engineering course and ranking reasons for enrolling
- Reasons for studying engineering
- Beliefs about engineering
- Agreement statements about engineering
- Environmental justice beliefs
- Engineering skills rating
- Student demographics

To administer an inclusive survey, we asked students to type in their gender identity (i.e., gender was an open-response question) and offered nine racial/ethnic identity options. We then manually recoded the gender responses into four categories: male, female, non-binary, and unknown (data was missing)/prefer not to report. We acknowledge that these gender categories are a simplification of the gender spectrum and that some categories use language of sex; federal guidelines influenced the categories we chose to utilize. The nine categories for race/ethnicity were:

1. American Indian or Alaska Native
2. Asian
3. Black or African American
4. Latina, Latino, Latinx, Hispanic or Spanish origin
5. Middle Eastern or North African
6. Native Hawaiian or Pacific Islander

7. White
8. Another race or ethnicity not listed (please specify)
9. Prefer not to answer

Because the survey data was anonymous, we did not have paired data. Thus, we could not employ student-centric analysis methods (e.g., multiple linear regression [19]) and instead had to rely on group-comparison methods. As mentioned previously, gender and race/ethnicity were key demographic characteristics for this analysis, so we used a X^2 test to ensure that the gender and race/ethnicity characteristics of the pre- and post-survey samples were similar. The X^2 test for gender ($X^2 = 4.05$, df = 3, p = .256) and race/ethnicity ($X^2 = 7.83$, df = 8, p = .450) suggested that the pre- and post-survey samples had statistically similar demographic characteristics. These results enabled us to assume that any differences we saw in the pre- and post-survey results were *not* likely due to bias in the samples relative to their gender and race/ethnicity profiles.

For this paper, we concentrate on the results of only a few survey questions:
- Q1: Rate how prepared do you feel now to do the following: Engineering Design Process
- Q2: Rate how prepared do you feel now to do the following: Incorporate Environmental Justice Concepts in Design Solutions
- Q3: Why study engineering? I want to make a difference in my local community
- Q4: I can understand concepts in engineering
- Q5: I can see myself becoming an engineer
- Q6: I can easily explain engineering to another person
- Q7: I understand the impacts of engineering design on my local community
- Q8: Women should consider a career in engineering

We chose the eight questions above for this initial analysis because the questions align with the gender and racial/ethnicity focus of this paper and broadening participation efforts in engineering for decades.

Teachers

Throughout the 3-year CED pilot, each year's pilot-teacher cohort participated in weekly check-ins. The purpose of these check-ins was to provide teachers with instructional support and record teacher feedback that informed revisions of the CED curriculum. An end-of-semester (or year) meeting was also held with teachers during which we asked them reflective questions about how the course went overall and suggestions for improvement.

The participants in professional development workshops had the opportunity to take the optional pre- and post-workshop surveys via Google Forms, which asked them to rate their confidence and interest in teaching engineering plus EJ- and EV-related topics. The survey administered to teachers who attended the virtual PD was more in-depth (17 pre-survey and 16 post-survey questions) than that administered to participants at national or regional conferences (six pre-survey and six post-survey questions) because of the time constraints participants faced between conference sessions. For the virtual PD, we had 26 teachers fill out the pre-workshop survey, and 23 completed the post-workshop survey. For the conference survey, 25 filled out the pre-survey and 20 completed the post-survey.

Data Analysis
As mentioned previously, we made the decision early in this project to collect data for program evaluation, not research. Therefore, we did not seek IRB approval, and we only collected anonymous, voluntary information from student and teacher participants. The consequence of this decision was that we did not have paired pre- and post-survey data, which meant that we could not employ student-centric methods for exploring the results across different gender and racial/ethnicity groups. This also meant that investigating the results with respect to intersecting identities was not possible. We rely instead on non-parametric statistical methods for group comparisons of ordinal data.

Students
For the student survey data, we conducted three different analyses for eight survey questions of interest. In all cases, we used a family-wise alpha of 0.05, and when statistical differences were identified, we calculated the Area Under the Receiver Operating Characteristic (AUROC) curve [20, 21] as a non-parametric effect size that ranges between 0 and 1. The AUROC is a measure of the stochastic dominance of one group (pre-survey data) over another group (post-survey data). It can be interpreted as the probability that a randomly selected sample (a single datum point) from the pre-survey data is larger in value than a randomly selected sample from the post-survey data. For example, two groups with equal distributions would yield an AUROC of 0.50 (i.e., a 50% chance of a single, random sample from the first group being larger than a single, random sample from the second group).

Our three analyses for each question were:

- *Overall*: With aggregated data, we utilized a Mann-Whitney U test to investigate differences in the pre- and post-survey data.
- *By Gender*: With disaggregated data by gender, we utilized four Mann-Whitney U tests to investigate pre/post differences for each category of gender. We used Bonferroni adjustments of the p-values to ensure our family-wise alpha remained 0.05.
- *By Race/Ethnicity*: Similar to our gender analysis, we used disaggregated data and nine Mann-Whitney U tests to explore pre/post differences for each race/ethnicity category and used a Bonferroni adjustment to control our Type I error. Students could select multiple racial/ethnic identities, so a single student could have been included in more than one group comparison.

We report statistically significant differences in the data; however, because our data is not paired and our power (i.e., the ability to detect a true difference) is limited, we also highlight trends in the data that may be significant if we had more data or were able to employ other (student-centric) statistical methods with more power. The trends we note reflect the inferential statistical tests that had a p-value less than 0.05 before the Bonferroni adjustment but had a p-value greater than 0.05 after the adjustment.

Teachers
We used descriptive statistics to investigate the quantitative survey responses we collected from teachers at professional development workshops. The feedback collected from piloting teachers

throughout the semester/year was used to inform improvements to the curriculum in real time, and no formal research method was used to collect or analyze this data. We provide direct quotes from teachers to reflect the themes we identified across different modules of the CED curriculum to exemplify the feedback we received. Throughout the three-year CED pilot, teachers learned about, contributed to, and provided advice on the curriculum, plus they gave and received instructional guidance related to CED. Cooperating teachers had access to the full CED pilot curriculum on a shared Google Drive and were provided with a copy of the source CED curriculum spreadsheet. The spreadsheet provided a suggested scope and sequence for instructing CED, links to all CED curriculum resources, and a section to record comments and suggestions. Teachers could download all instructional resources and add their comments and suggestions on copies of the content materials to contribute to CED curriculum revisions. Though teachers received materials and instructional stipends, there was no incentive for teachers to only be positive in their CED piloting experience.

Results

Students' Survey Results

A comprehensive report of descriptive and inferential statistical results for the eight questions from the CED student pre- and post-course surveys over the three-year pilot period is found in the appendix. Table 2 is a summary of the inferential statistics and notable trends (as defined in the Data Analysis section) when comparing pre- and post-survey data. A statistically significant difference in the distribution of the ordinal data between pre- and post-survey data is indicated by the p-value of the Mann-Whitney U test and the AUROC effect size (ES). In all cases of statistical difference, the post-survey data distribution shifted higher along the Likert scale. Arrows indicate a trend (not statistically significant after the Bonferroni adjustment) in the data with regard to the post-survey data shifting up or down relative to the pre-survey data. The full text for each survey question is found in the Data Sources section.

Table 7. A summary of the group comparison statistical results for the eight survey questions of interest.

	Q1 (EDP)	Q2 (EJ)	Q3 (interest: community)	Q4 (understand concepts)	Q5 (see myself)	Q6 (able to explain)	Q7 (impacts on community)	Q8 (women careers)
Overall	$p < .001$ ES = 0.39	$p < .001$ ES = 0.39		$p = .010$ ES = 0.40	$p = .020$ ES = 0.39	$p < .001$ ES = 0.32	$p < .001$ ES = 0.37	
Gender:								
Female	$p = .028$ ES = 0.41	↑		↑		$p < .001$ ES = 0.33	$p < .001$ ES = 0.40	
Male	$p = .001$ ES = 0.38	$p < .001$ ES = 0.38				$p < .001$ ES = 0.41		
Non-binary	↑	↑						
Unknow/ Prefer not to say	$p = .004$ ES = 0.35	$p < .001$ ES = 0.35						
Race/Ethnicity:								
American Indian or Alaska Native								
Asian	↑					↑		
Black or African American					↑	↑		
Hispanic, Latinx, or Spanish origin	$p < .001$ ES = 0.41	$p < .001$ ES = 0.41				$p < .001$ ES = 0.38	↑	
Middle Eastern or North African			↓			↑	↑	
Native Hawaiian or Pacific Islander								
White	$p = .028$ ES = 0.41	$p = .022$ ES = 0.42		↑		$p < .001$ ES = 0.37		
Another race or ethnicity not listed			↓					

Notes. 1) Statistically significant results are indicated with the Mann-Whitney U test's p-value and the AUROC effect size (ES); 2) trends that were not statistically significant after Bonferroni adjustment are indicated with an arrow in the direction of the post-survey distribution shift relative to the pre-survey.

Teachers' Feedback

The survey results from all professional development indicating teacher responses of "strongly agree"or "agree" across five questions asked show: a) 86% said the PD was valuable to their STEM teaching, b) 98% said the PD increased their interest to incorporate EV topics in their STEM curriculum, c) 91% said the PD increased their confidence in teaching EV topics, d) 93% said the PD increased their interest to incorporate environmental justice in their STEM curriculum, and e) 93% said the PD increased their confidence in teaching EJ topics.

A primary goal for teacher participation in the CED pilot was to nurture a culture of collaboration and continuous improvement in secondary engineering education. The piloting teachers did not participate in pre- and post-instruction surveys like their students. Instead, teachers participated in weekly 30-minute check-ins to ask questions, share ideas, and get and give support regarding CED instruction and student learning. This format was the primary source of feedback, and some check-ins had a couple of teachers meeting synchronously from the same or different schools, which created an informal professional learning community. These regular check-ins helped inform curriculum revisions based on pilot teacher feedback. In addition, post-instruction written reflections and post-pilot interviews were fundamental in synthesizing final CED curriculum revisions. The following quotes are a few examples from teachers' written reflections after teaching their students CED:

- Introductory Design Challenges
    - *I really liked the quick challenges that got at the core of the engineering processes. They were fun and had the students working quickly in teams and trying new things. The supporting documents were helpful and the low-pressure atmosphere allowed them to have creative confidence.*
    - *All introductory activities worked very well. Students were engaged with the Paper Tower activity and the Straw Bridge activity particularly. Overall the first module was well suited for introducing students to the types of activities, routines, and assignments that the class will require. Integrating the robotics curriculum was easy for this module. The timing and sequence of this module was appropriate as well.*

- Engineering Design Process
    - *I really liked the activity that had the students put the steps of the design process in order. This helped them to think critically and invited discussions that led us to discussing the cyclical nature of the design process.*
    - *This module was successful in introducing the Creative Engineering Design Process to the students. The worksheets and presentations worked well and it set the foundation for students to utilize the engineering process for the rest of the course.*

- Introductory Design Project
    - *This activity worked very well. As we progressed through the projects I started seeing better applications of the Engineering Design Process. This module is where I started seeing better products, both in the engineering notebooks and their mousetrap cars. Students were placed in pairs for this project. The pairs had to individually brainstorm and design before they came together on a final design and receive the materials to build. Students were not given materials until a consensus was provided on their mousetrap car design.*
    - *I used Tinkercad along with safety so that the students could use the equipment in the shop while building their mousetrap car. Each student built their own car and also had to draw a design in the engineering notebook along with drawing it in*

Tinkercad and make a materials list for me before I handed out the materials to the students to build with.

- Environmental Justice StoryMaps
  - *EJ storymaps began in this module and were well received by students. The fuel debates also elicit lively and meaningful discussions.*
  - *EJ story maps continued to be engaging for the students and contributed to student buy-in.*

- Engineering Skills Workshops:
  - *Students learned Tinkercad at a faster rate with the (CED) tutorials that were provided compared to the previous tutorials I was using.*
  - *The students enjoyed the circuit simulation. Students thoroughly enjoyed the small circuit project and demonstrated learning the different circuit components and apparati. This module and building circuits had the best student feedback.*

- Model Electric Vehicle Final Team Design Project
  - *I really liked how this final project felt like a combination of the skills learned and some different types of engineering. I kept emphasizing that they needed to have a good chassis and structure (structural engineering and materials), a reliable drivetrain (mechanical engineering), and functioning electronics (electrical engineering). This allowed the groups to operate as a team with each student representing a part of the project.*
  - *This project worked well in the sense that it engaged a majority of my students, incorporated a novel and unique challenge, and provided a suitable opportunity to discuss issues of environmental justice, energy policy, society, and climate change. Specifically, the balancing of "build time" (where students actively work in a group to design and build a car) and "academic time" (where they investigate the societal issues listed above) made this a project in which there are ample opportunities to learn in the many different ways that a group of 20-30 students prefer.*

Discussion

When analyzing the data in aggregate, the distribution of student responses had a statistically significant shift upward for six of the eight questions we analyzed. This shift for Q1 highlights that after experiencing the CED course students felt more prepared to employ engineering methods to solve problems, and the shift of Q2 responses implies that students recognize that engineering problems are not just technical in nature--they have social components too, like environmental justice. The survey data from the teacher PD workshops showed similar trends, with teachers becoming more interested and more confident in teaching STEM, EJ, and EV topics. These results are encouraging because teachers are more likely to implement content and activities that they are interested in and are confident in teaching, and the shift upward for Q1 and Q2 responses suggest that the emphasis on the EDP and EJ in the CED curriculum positively impacted student outcomes in this area.

Of the six questions from the students' survey that had statistically significant shifts upward, four (Q1, Q2, Q4 and Q6) related to the students' understanding and skills of engineering as a profession, and two questions (Q5 and Q7) highlight how students perceive engineering or its impacts in their community; i.e., Q1, Q2, Q4 and Q6 speak to students knowledge of engineering concepts, and Q5 and Q7 speak to the affective, personal connection they had with engineering. The data suggest that students, on average, not only learned more about engineering through their experiences in CED, but they also recognized the value and impact engineers have on their local communities and even became more open to the idea of themselves becoming engineers.

The implications of these results cannot be overstated because the engineering community has been trying for decades to broaden participation in engineering, specifically among communities that are underrepresented in engineering. However, unlike other professions like teachers, doctors, and lawyers, the general public does not have a good understanding of what engineering is or what engineers do. Our results suggest that exposing students from marginalized communities to engineering courses like CED can develop their engineering skills, while also advancing their understanding of the profession and the impact engineers have on their daily lives. We can only hope that these students then share this knowledge and insight with their friends and family so that eventually the public develops a better understanding of engineering and more people—from all communities—choose to pursue engineering as a career.

When the student data is disaggregated across gender categories, two interesting results emerge. First, there is no statistical difference in pre- and post-survey data regarding: a) whether girls see themselves as engineers, or b) whether girls feel women should pursue engineering as a career. This is a discouraging result because women are underrepresented in engineering, so we had hoped that girls' experience in CED would cultivate interest in pursuing engineering as a career. However, this result could indicate that many of these girls have already self-selected in—or out, as is more often the case for girls, unfortunately—of engineering by the time they take a high-school engineering course [22]. Future work should explore if there was any difference in the responses from the girls in the middle school pilot course versus the responses from the girls who were in high school courses.

Second, after taking CED, girls felt more prepared to employ the engineering design cycle, and they could more strongly see the impact of engineering on their local community. However, as previously discussed, their interest in engineering did not increase, their perceptions of seeing themselves as engineers did not increase, and they did not shift their thoughts regarding women seeking engineering as a career. Together, these results might suggest that after experiencing CED the girls more clearly see the value and impact of engineering in their lives and that they are capable of doing engineering, but they do not see women—including their future selves—as part of that impact. Future work could explore if these results are reflective of the lack of women representation (and thus role models) in engineering, which then inhibits girls' ability to see (or visualize) the contributions that women engineers have (and could have) in the girls' lives and communities. Additionally, prior research has suggested that traditionally masculine content--such as car-related problems--can negatively impact women's sense of belonging in engineering [23, 24]. While we have not seen any data--empirical or anecdotal--that suggest the electric vehicle content of CED discouraged the girls, this is an area we can further investigate as an explanation for some of our other gender-specific results.

With so many categories for race/ethnicity, the sample sizes within a given category were decreased, which affected our ability to detect statistically significant shifts in the data. Three questions had statistically significant results, and they were all cognitive-related questions (Q1, Q2, and Q6). Future work could dig deeper into why we did not see more trends or significant shifts in the questions related to students' non-cognitive attitudes and beliefs. This work may lead to insights about what changes could be made to the curriculum to nurture students' engineering interest and identity among all racial/ethnic groups, especially students who identify as a race/ethnicity that has historically been underrepresented in engineering.

Limitations and future work
As previously mentioned, our data were collected anonymously and for the primary purpose of program evaluation; therefore, we could not utilize paired-data, student-centric analysis methods. We also did not perform a rigorous research design for understanding the teacher experience, instead, we focused on general trends and feedback on how we can improve the CED curriculum. If we choose to further study implementations of this course and its impacts on students and teachers, we would likely request IRB approval for our data collection tools and methods so that we could collect identified data that would enable disaggregation and analyses across intersecting demographic identities.

We piloted CED for three years and engaged about 1,200 students. However, we acknowledge that these students were from four regions in the US and taught by fewer than 20 teachers in total. Thus, our sample is relatively small compared to the wide-scale, nationwide adoption that we would love to see for CED. Thus, while our pilot data stems from a diverse population of students and teachers, our data still may not be representative of future students and teachers who adopt CED.

We have only presented an initial analysis of eight survey questions; we collected data for 100 pre-survey and 74 post-survey questions. Thus, there is a chance that we have zoomed in on a few items and missed larger trends and insights that will only be evident when we complete a comprehensive analysis of all survey questions. Also, future analyses should investigate if any of our data includes responses from students who filled out the survey for completion, without regard to actually reading or answering the questions thoughtfully (e.g., eliminate any responses from students who answered the same Likert scale option for all questions of the survey and completed the survey much faster than all other students).

Lastly, we plan to continue promoting CED and training teachers. We are currently exploring virtual teacher professional development opportunities, including those through our partners at NCWIT, the parent organization for TeachEngineering.

Conclusion

The ultimate goal of this work was to develop a free, comprehensive, project-based curriculum for a high-school engineering course. We labeled this curriculum Creative Engineering Design (CED). CED empowers students to build engineering and problem-solving skills through hands-on learning, and we specifically designed the curriculum to reach students new to engineering. We embedded environmental justice topics, tools, and activities into the core modules of the course, which leverage and honor students' lived experiences to understand engineering and its connection to their communities and lives. Initial results indicate that CED students—as a whole and within some subgroups—learned what engineering is, how to employ engineering methods to find socially-responsible solutions, how to explain engineering to others, how engineering impacts the world and community around them, and how they see themselves as engineers. These results are encouraging because the general public lacks a clear understanding of the engineering profession, which hinders efforts to broaden participation in engineering. Opportunities for students to experience engineering in courses like CED are critical for democratizing engineering education.

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Appendix

Statistics for Q1: Rate how prepared do you feel now to do the following: Engineering Design Process

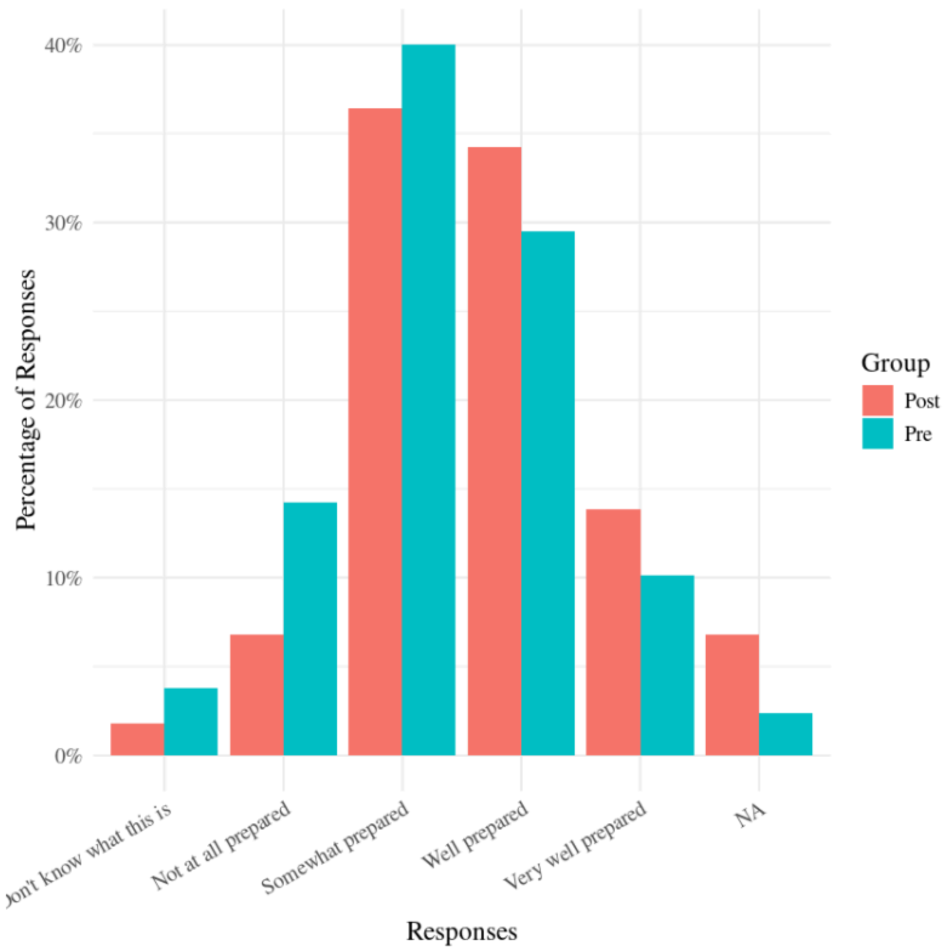

Figure A1. Distribution of aggregated (overall) responses for Q1: Rate how prepared do you feel now to do the following: Engineering Design Process.

Table A1. Descriptive statistics for Q1: Rate how prepared do you feel now to do the following: Engineering Design Process.

Category	Time	Median	IQR	Mean	StdDev	Min	Max
Overall	Pre	3	1	3.29	0.97	1	5
Overall	Post	4	1	3.55	0.90	1	5
By Gender:							
Female	Pre	3.5	1	3.45	0.95	1	5
Female	Post	4	1	3.68	0.80	1	5
Male	Pre	3	1	3.22	1.00	1	5
Male	Post	3	1	3.46	0.92	1	5
Non-binary	Pre	3	1	3.20	0.94	1	5
Non-binary	Post	4	1	3.68	0.82	2	5
Unknown/Prefer not to say	Pre	3	1	3.15	0.89	1	5
Unknown/Prefer not to say	Post	3	1	3.54	0.99	1	5
By Race/Ethnicity:							
American Indian or Alaska Native	Pre	3	1	3.22	1.12	1	5
American Indian or Alaska Native	Post	3.5	1.25	3.54	1.10	2	5
Asian	Pre	3	1	3.32	1.03	1	5
Asian	Post	4	2	3.81	1.00	1	5
Black or African American	Pre	3	1	3.28	1.03	1	5
Black or African American	Post	3	1	3.40	1.03	1	5
Hispanic, Latinx, or Spanish origin	Pre	3	1	3.27	0.98	1	5
Hispanic, Latinx, or Spanish origin	Post	4	1	3.55	0.87	1	5
Middle Eastern or North African	Pre	3	2	2.88	1.11	1	5
Middle Eastern or North African	Post	4	2	3.75	1.14	2	5
Other	Pre	3	2	3.12	1.13	1	5
Other	Post	3	1	3.39	1.12	1	5
Pacific Islander and Native Hawaiian	Pre	3	2	3.08	1.32	1	5
Pacific Islander and Native Hawaiian	Post	4.5	2.75	3.70	1.57	1	5
Prefer not to answer	Pre	3	1	3.09	1.17	1	5
Prefer not to answer	Post	3	1	3.47	0.91	2	5
White	Pre	3	1	3.36	0.99	1	5
White	Post	4	1	3.64	0.93	1	5

Note. 1: Don't know what this is, 2: Not at all prepared, 3: Somewhat prepared, 4: Well prepared, 5: Very well prepared.

Table A2. Inferential statistics for Q1: Rate how prepared do you feel now to do the following: Engineering Design Process.

Category	W	p-value	Adj. p-value	AUROC Effect Size
Overall	317136.0	<.001		0.39
By Gender				
Female	46457.0	0.007	0.028	0.41
Male	89887.0	<.001	0.001	0.38
Non-binary	812.5	0.028	0.110	
Unknown/Prefer not to say	12576.5	0.001	0.004	0.35
By Race/Ethnicity				
American Indian or Alaska Native	667.0	0.336	1.000	
Asian	1691.5	0.018	0.164	
Black or African American	10379.5	0.327	1.000	
Hispanic, Latinx, or Spanish origin	103804.0	<.001	<.001	0.41
Middle Eastern or North African	143.0	0.065	0.583	
Other	418.0	0.383	1.000	
Pacific Islander and Native Hawaiian	82.5	0.280	1.000	
Prefer not to answer	977.5	0.144	1.000	
White	28282.0	0.003	0.028	0.41

Statistics for Q2: Rate how prepared do you feel now to do the following: Incorporate Environmental

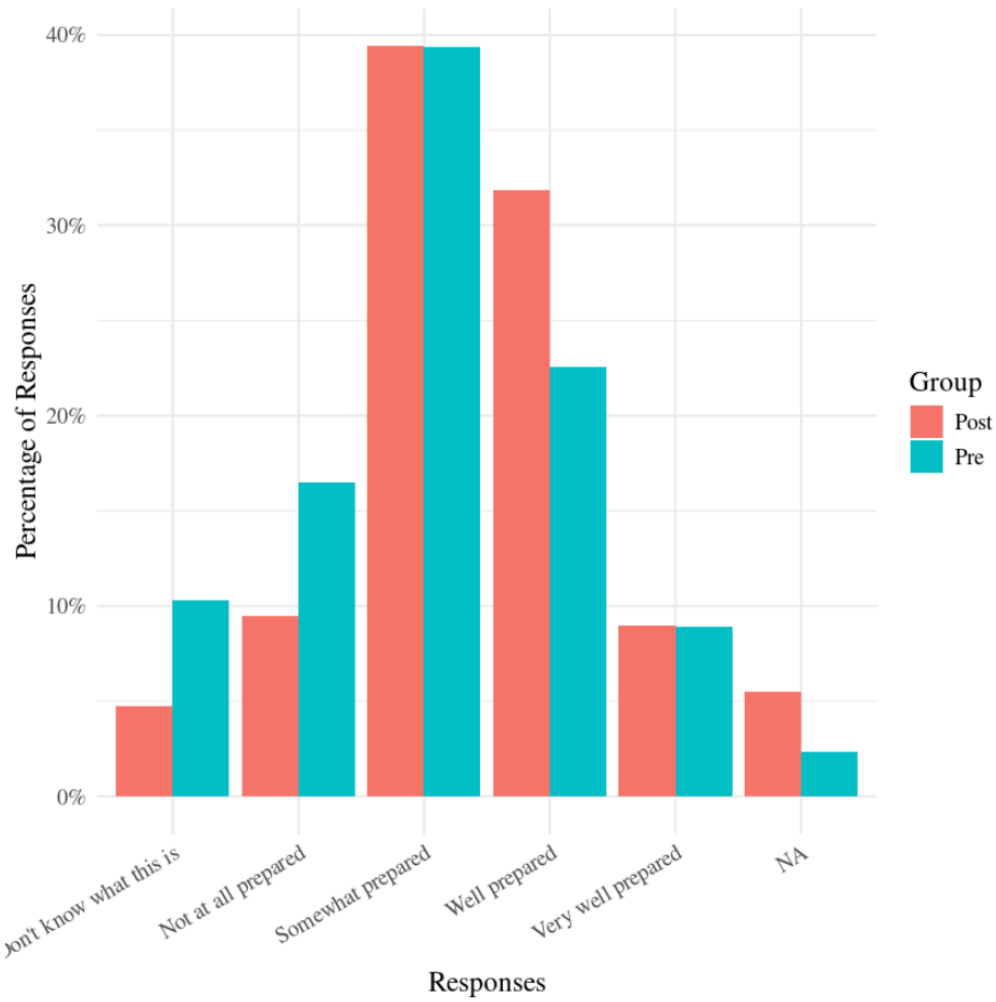

Figure A2. Distribution of aggregated (overall) responses for Q2: Rate how prepared do you feel now to do the following: Incorporate Environmental.

Table A3. Descriptive statistics for Q2: Rate how prepared do you feel now to do the following: Incorporate Environmental.

Category	Time	Median	IQR	Mean	StdDev	Min	Max
Overall	Pre	3	2	3.03	1.09	1	5
Overall	Post	3	1	3.33	0.96	1	5
By Gender:							
Female	Pre	3	1	3.24	1.05	1	5
Female	Post	3	1	3.44	0.85	1	5
Male	Pre	3	2	2.96	1.09	1	5
Male	Post	3	1	3.27	0.99	1	5
Non-binary	Pre	3	1	2.76	1.00	1	5
Non-binary	Post	3	1	3.29	0.94	1	5
Unknown/Prefer not to say	Pre	3	1	2.87	1.12	1	5
Unknown/Prefer not to say	Post	3	1	3.28	1.04	1	5
By Race/Ethnicity:							
American Indian or Alaska Native	Pre	3	1	2.71	1.21	1	5
American Indian or Alaska Native	Post	3	1	3.28	1.24	1	5
Asian	Pre	3	1	3.31	1.26	1	5
Asian	Post	3	1	3.46	1.03	1	5
Black or African American	Pre	3	2	2.97	1.13	1	5
Black or African American	Post	3	1	3.22	1.00	1	5
Hispanic, Latinx, or Spanish origin	Pre	3	2	3.05	1.08	1	5
Hispanic, Latinx, or Spanish origin	Post	3	1	3.36	0.87	1	5
Middle Eastern or North African	Pre	3	2	3.00	1.37	1	5
Middle Eastern or North African	Post	3	2	3.54	1.20	2	5
Other	Pre	3	2	2.91	1.25	1	5
Other	Post	3	2	3.25	1.26	1	5
Pacific Islander and Native Hawaiian	Pre	3	1	2.69	1.25	1	5
Pacific Islander and Native Hawaiian	Post	3	2	3.45	1.21	2	5
Prefer not to answer	Pre	3	2	2.98	1.13	1	5
Prefer not to answer	Post	3	1	3.03	1.01	1	5
White	Pre	3	2	3.04	1.16	1	5
White	Post	3	1	3.35	1.02	1	5

Note. 1: Don't know what this is, 2: Not at all prepared, 3: Somewhat prepared, 4: Well prepared, 5: Very well prepared.

Table A4.Inferential statistics for Q2: Rate how prepared do you feel now to do the following: Incorporate Environmental

Category	W	p-value	Adj. p-value	AUROC Effect Size
Overall	319550.0	<.001		0.39
By Gender				
Female	45421.0	0.027	0.110	
Male	94230.0	<.001	<.001	0.38
Non-binary	832.5	0.016	0.064	
Unknown/Prefer not to say	12818.5	0.001	0.003	0.35
By Race/Ethnicity				
American Indian or Alaska Native	755.5	0.090	0.806	
Asian	1429.5	0.720	1.000	
Black or African American	11184.5	0.071	0.635	
Hispanic, Latinx, or Spanish origin	104499.5	<.001	<.001	0.41
Middle Eastern or North African	134.5	0.312	1.000	
Other	439.0	0.352	1.000	
Pacific Islander and Native Hawaiian	94.0	0.190	1.000	
Prefer not to answer	877.0	0.805	1.000	
White	28801.0	0.002	0.022	0.42

Statistics for Q3: Why study engineering? I want to make a difference in my local community

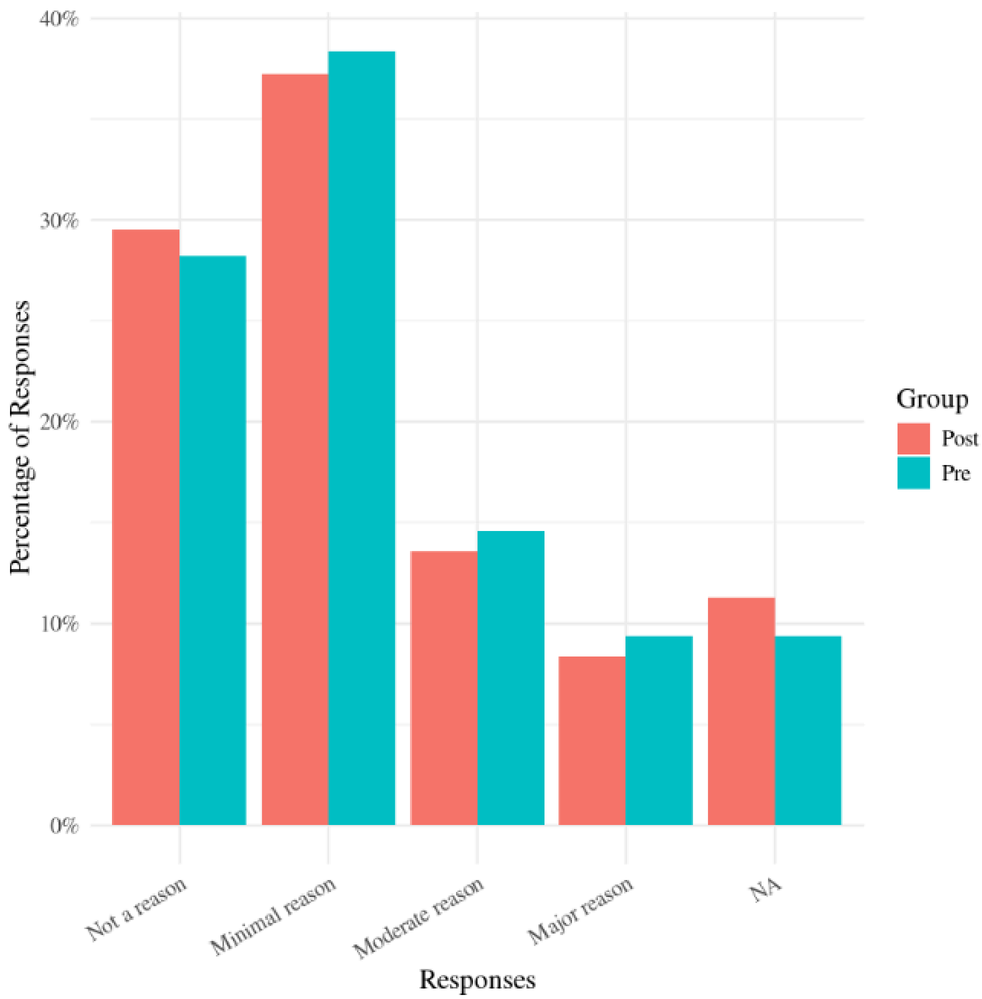

Figure A3. Distribution of aggregated (overall) responses for Q3: Why study engineering? I want to make a difference in my local community

Table A5. Descriptive statistics for Q3: Why study engineering? I want to make a difference in my local community.

Category	Time	Median	IQR	Mean	StdDev	Min	Max
Overall	Pre	2	2	2.06	0.94	1	4
Overall	Post	2	1	2.01	0.93	1	4
By Gender:							
Female	Pre	2	2	2.17	1.00	1	4
Female	Post	2	2	2.02	0.94	1	4
Male	Pre	2	1	1.93	0.88	1	4
Male	Post	2	1	1.96	0.90	1	4
Non-binary	Pre	2	1	2.17	0.87	1	4
Non-binary	Post	2	1	2.24	0.99	1	4
Unknown/Prefer not to say	Pre	2	2	2.21	0.97	1	4
Unknown/Prefer not to say	Post	2	2	2.11	0.99	1	4
By Race/Ethnicity:							
American Indian or Alaska Native	Pre	2	2	2.16	0.98	1	4
American Indian or Alaska Native	Post	2	2	2.25	1.07	1	4
Asian	Pre	2	1	1.92	0.84	1	4
Asian	Post	2	1	1.78	0.76	1	4
Black or African American	Pre	2	2	2.17	0.99	1	4
Black or African American	Post	2	2	2.12	0.92	1	4
Hispanic, Latinx, or Spanish origin	Pre	2	1	1.99	0.91	1	4
Hispanic, Latinx, or Spanish origin	Post	2	1	1.91	0.89	1	4
Middle Eastern or North African	Pre	2	1	2.50	0.89	1	4
Middle Eastern or North African	Post	1	1	1.64	0.81	1	3
Other	Pre	2	1	2.26	0.96	1	4
Other	Post	2	1	1.74	0.69	1	3
Pacific Islander and Native Hawaiian	Pre	2.5	1.5	2.50	1.17	1	4
Pacific Islander and Native Hawaiian	Post	2	1	1.56	0.53	1	2
Prefer not to answer	Pre	2	2	2.28	1.11	1	4
Prefer not to answer	Post	2	2	2.22	1.15	1	4
White	Pre	2	2	2.17	0.95	1	4
White	Post	2	2	2.12	1.02	1	4

Note. 1: Not a reason, 2: Minimal reason, 3: Moderate reason, 4: Major reason.

Table A6. Inferential statistics for Q3: Why study engineering? I want to make a difference in my local community.

Category	W	p-value	Adj. p-value
Overall	339578.0	0.301	
By Gender			
Female	32776.5	0.092	0.369
Male	69066.5	0.729	1.000
Non-binary	681.0	0.369	1.000
Unknown/Prefer not to say	8668.5	0.439	1.000
By Race/Ethnicity			
American Indian or Alaska Native	560.5	0.793	1.000
Asian	1096.0	0.442	1.000
Black or African American	8773.5	0.773	1.000
Hispanic, Latinx, or Spanish origin	81280.0	0.226	1.000
Middle Eastern or North African	42.5	0.019	0.166
Other	250.5	0.049	0.442
Pacific Islander and Native Hawaiian	28.5	0.062	0.555
Prefer not to answer	698.0	0.816	1.000
White	21784.5	0.469	1.000

Statistics for Q4: I can understand concepts in engineering

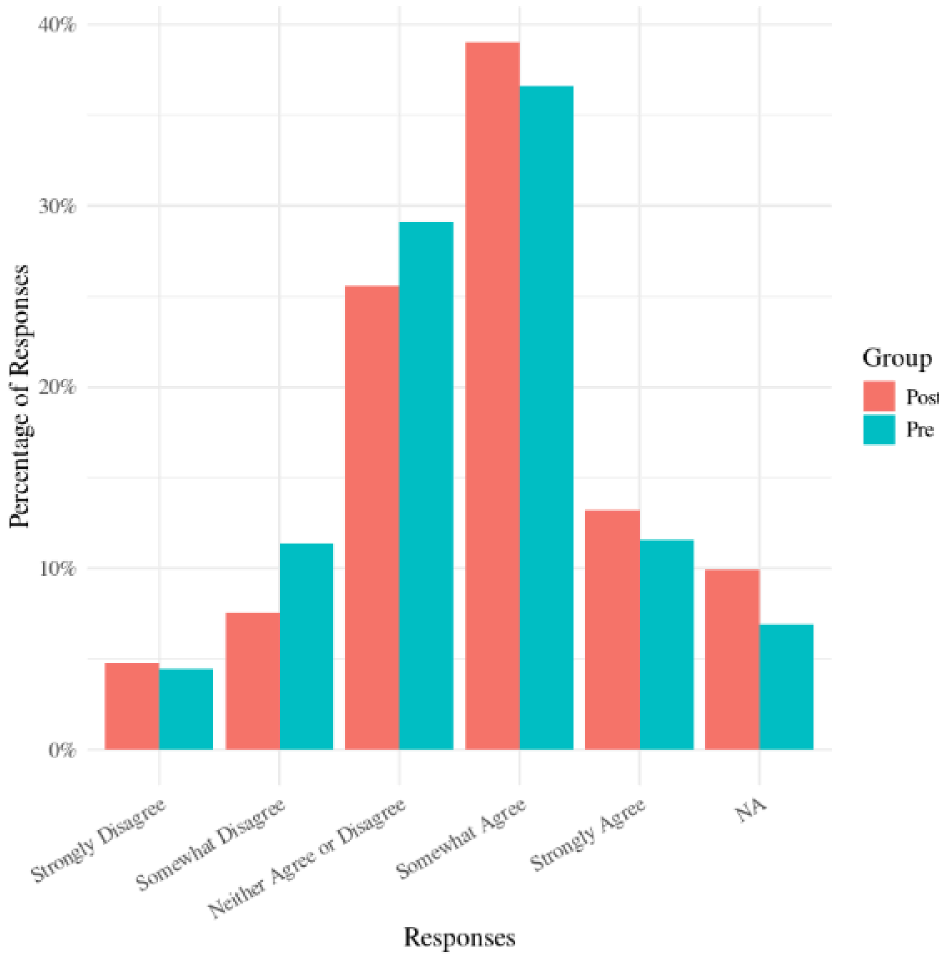

Figure A4. Distribution of aggregated (overall) responses for Q4: I can understand concepts in engineering.

Table A7. Descriptive statistics for Q4: I can understand concepts in engineering.

Category	Time	Median	IQR	Mean	StdDev	Min	Max
Overall	Pre	4	1	3.42	1.01	1	5
Overall	Post	4	1	3.54	1.01	1	5
By Gender:							
Female	Pre	4	1	3.62	0.93	1	5
Female	Post	4	1	3.75	0.85	1	5
Male	Pre	3	1	3.36	1.03	1	5
Male	Post	4	1	3.47	1.05	1	5
Non-binary	Pre	3	2	3.11	1.21	1	5
Non-binary	Post	3	1	3.43	0.79	2	5
Unknown/Prefer not to say	Pre	3	1	3.23	1.01	1	5
Unknown/Prefer not to say	Post	3	1	3.38	1.15	1	5
By Race/Ethnicity:							
American Indian or Alaska Native	Pre	4	1	3.49	1.14	1	5
American Indian or Alaska Native	Post	3.5	3	3.31	1.49	1	5
Asian	Pre	4	1	3.56	0.88	1	5
Asian	Post	4	1.25	3.81	1.02	1	5
Black or African American	Pre	3	1	3.34	1.00	1	5
Black or African American	Post	3	1	3.38	1.13	1	5
Hispanic, Latinx, or Spanish origin	Pre	4	1	3.43	1.04	1	5
Hispanic, Latinx, or Spanish origin	Post	4	1	3.55	0.98	1	5
Middle Eastern or North African	Pre	4	1	3.41	1.33	1	5
Middle Eastern or North African	Post	4.5	1.25	3.92	1.51	1	5
Other	Pre	4	1	3.56	1.05	1	5
Other	Post	3	1.25	3.46	1.22	1	5
Pacific Islander and Native Hawaiian	Pre	4	1	3.62	1.33	1	5
Pacific Islander and Native Hawaiian	Post	4	2	3.55	1.51	1	5
Prefer not to answer	Pre	3.5	1	3.39	1.22	1	5
Prefer not to answer	Post	3	1	3.15	0.87	1	4
White	Pre	4	1	3.49	1.00	1	5
White	Post	4	1	3.66	1.02	1	5

Note. 1: Strongly disagree, 2: Somewhat disagree, 3: Neither agree or disagree, 4: Somewhat agree, 5: Strongly agree.

Table A8. Inferential statistics for Q4: I can understand concepts in engineering.

Category	W	p-value	Adj. p-value	AUROC Effect Size
Overall	320771.0	0.010		0.39
By Gender				
Female	39727.0	0.170	0.680	
Male	78323.5	0.067	0.269	
Non-binary	719.5	0.291	1.000	
Unknown/Prefer not to say	10362.5	0.166	0.666	
By Race/Ethnicity				
American Indian or Alaska Native	613.0	0.786	1.000	
Asian	1551.0	0.101	0.913	
Black or African American	9997.5	0.631	1.000	
Hispanic, Latinx, or Spanish origin	94651.0	0.137	1.000	
Middle Eastern or North African	132.5	0.166	1.000	
Other	361.5	0.704	1.000	
Pacific Islander and Native Hawaiian	71.0	1.000	1.000	
Prefer not to answer	742.0	0.272	1.000	
White	27006.0	0.048	0.435	

Statistics for Q5: I can see myself becoming an engineer

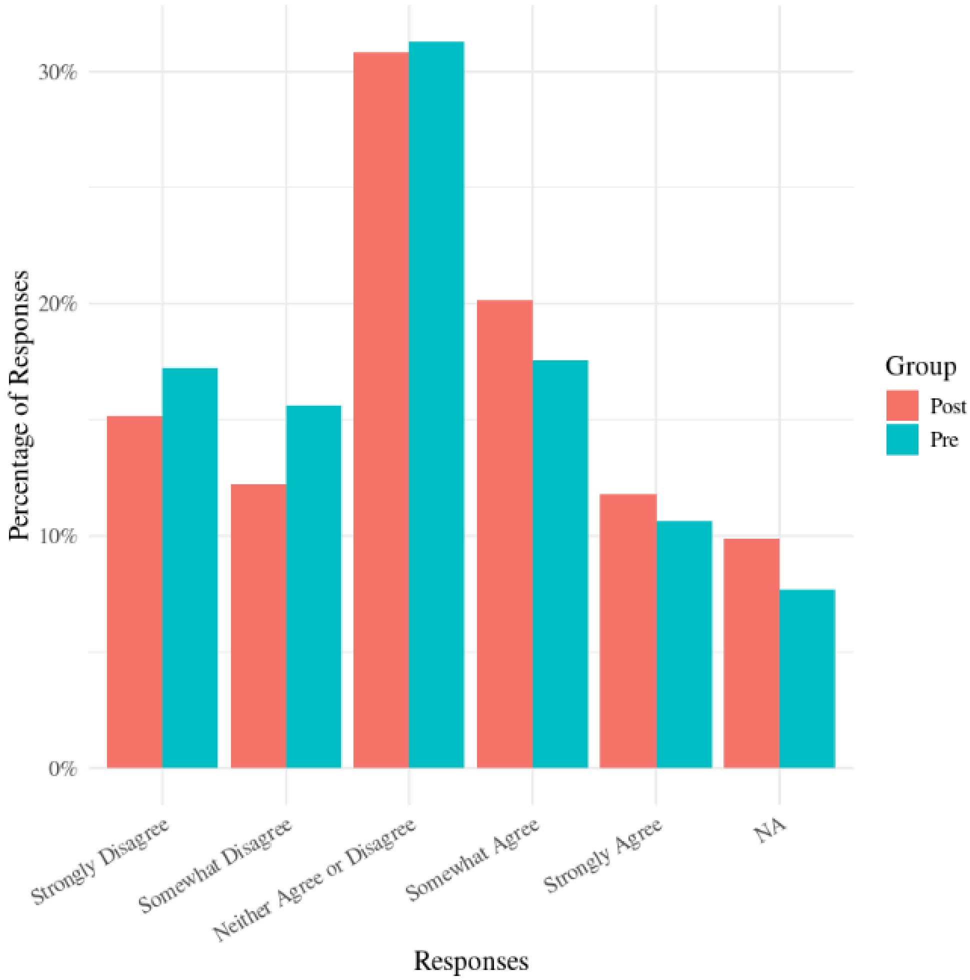

Figure A5. Distribution of aggregated (overall) responses for Q5: I can understand concepts in engineering.

Table A9. Descriptive statistics for Q5: I can understand concepts in engineering.

Category	Time	Median	IQR	Mean	StdDev	Min	Max
Overall	Pre	3	2	2.88	1.25	1	5
Overall	Post	3	2	3.01	1.25	1	5
By Gender:							
Female	Pre	3	2	2.89	1.22	1	5
Female	Post	3	2	3.07	1.21	1	5
Male	Pre	3	2	2.91	1.24	1	5
Male	Post	3	2	3.00	1.23	1	5
Non-binary	Pre	3	3	2.73	1.40	1	5
Non-binary	Post	3	1	3.17	1.04	1	5
Unknown/Prefer not to say	Pre	3	2	2.78	1.27	1	5
Unknown/Prefer not to say	Post	3	3	2.91	1.39	1	5
By Race/Ethnicity:							
American Indian or Alaska Native	Pre	3	2	2.96	1.43	1	5
American Indian or Alaska Native	Post	3	2.25	2.92	1.47	1	5
Asian	Pre	3	1	3.20	1.24	1	5
Asian	Post	3	1.25	3.42	1.18	1	5
Black or African American	Pre	3	2	2.79	1.23	1	5
Black or African American	Post	3	1	3.12	1.24	1	5
Hispanic, Latinx, or Spanish origin	Pre	3	2	2.87	1.23	1	5
Hispanic, Latinx, or Spanish origin	Post	3	2	2.96	1.23	1	5
Middle Eastern or North African	Pre	3	2	2.94	1.30	1	5
Middle Eastern or North African	Post	3	2	3.42	1.44	1	5
Other	Pre	3	1.5	2.55	1.23	1	5
Other	Post	3.5	3.25	3.21	1.59	1	5
Pacific Islander and Native Hawaiian	Pre	3	4	3.08	1.71	1	5
Pacific Islander and Native Hawaiian	Post	3	2.5	3.30	1.42	1	5
Prefer not to answer	Pre	3	3	2.61	1.33	1	5
Prefer not to answer	Post	3	2.75	2.66	1.34	1	5
White	Pre	3	2	2.92	1.32	1	5
White	Post	3	2	3.09	1.20	1	5

Note. 1: Strongly disagree, 2: Somewhat disagree, 3: Neither agree or disagree, 4: Somewhat agree, 5: Strongly agree.

Table A10. Inferential statistics for Q5: I can understand concepts in engineering.

Category	W	p-value	Adj. p-value	AUROC Effect Size
Overall	319735.0	0.020		0.39
By Gender				
Female	40949.0	0.060	0.240	
Male	74725.0	0.344	1.000	
Non-binary	771.5	0.173	0.691	
Unknown/Prefer not to say	9792.5	0.359	1.000	
By Race/Ethnicity				
American Indian or Alaska Native	565.5	0.903	1.000	
Asian	1421.5	0.487	1.000	
Black or African American	11218.5	0.024	0.214	
Hispanic, Latinx, or Spanish origin	92943.5	0.254	1.000	
Middle Eastern or North African	122.5	0.361	1.000	
Other	467.5	0.099	0.892	
Pacific Islander and Native Hawaiian	70.0	0.775	1.000	
Prefer not to answer	850.0	0.897	1.000	
White	26444.5	0.188	1.000	

Statistics for Q6: I can easily explain engineering to another person

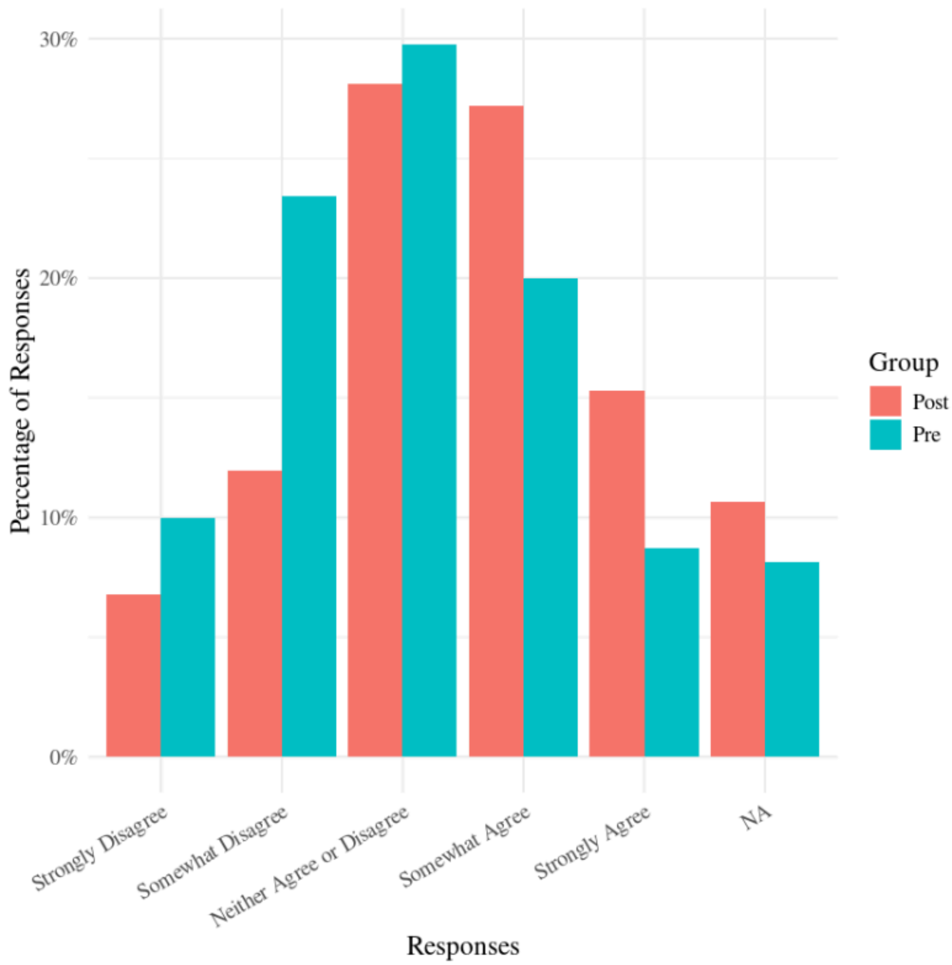

Figure A6. Distribution of aggregated (overall) responses for Q6: I can easily explain engineering to another person.

Table A11. Descriptive statistics for Q6: I can easily explain engineering to another person.

Category	Time	Median	IQR	Mean	StdDev	Min	Max
Overall	Pre	3	2	2.94	1.13	1	5
Overall	Post	3	1	3.36	1.14	1	5
By Gender:							
Female	Pre	3	2	3.10	1.11	1	5
Female	Post	4	1	3.54	1.09	1	5
Male	Pre	3	2	2.89	1.11	1	5
Male	Post	3	1	3.30	1.15	1	5
Non-binary	Pre	3	3	2.62	1.35	1	5
Non-binary	Post	3	1	3.31	1.04	1	5
Unknown/Prefer not to say	Pre	3	1.75	2.76	1.13	1	5
Unknown/Prefer not to say	Post	3	2	3.23	1.19	1	5
By Race/Ethnicity:							
American Indian or Alaska Native	Pre	3	2	3.04	1.23	1	5
American Indian or Alaska Native	Post	3	2.25	3.38	1.31	1	5
Asian	Pre	3	1	3.14	1.09	1	5
Asian	Post	4	2	3.71	1.06	1	5
Black or African American	Pre	3	2	2.97	1.20	1	5
Black or African American	Post	3	1	3.21	1.13	1	5
Hispanic, Latinx, or Spanish origin	Pre	3	2	2.89	1.12	1	5
Hispanic, Latinx, or Spanish origin	Post	3	1	3.37	1.08	1	5
Middle Eastern or North African	Pre	3	1	3.29	1.10	1	5
Middle Eastern or North African	Post	5	1	4.23	1.17	2	5
Other	Pre	3	2	3.06	1.09	1	5
Other	Post	4	2	3.50	1.41	1	5
Pacific Islander and Native Hawaiian	Pre	3	1	3.15	1.28	1	5
Pacific Islander and Native Hawaiian	Post	3.5	2	3.70	1.25	2	5
Prefer not to answer	Pre	3	1	2.74	1.14	1	5
Prefer not to answer	Post	3	2	2.95	1.29	1	5
White	Pre	3	2	2.94	1.15	1	5
White	Post	4	1	3.47	1.15	1	5

Note. 1: Strongly disagree, 2: Somewhat disagree, 3: Neither agree or disagree, 4: Somewhat agree, 5: Strongly agree.

Table A12. Inferential statistics for Q6: I can easily explain engineering to another person.

Category	W	p-value	Adj. p-value	AUROC Effect Size
Overall	319735.0	0.020		0.39
By Gender				
Female	45043.0	<.001	<.001	0.32
Male	85314.0	<.001	<.001	0.32
Non-binary	856.5	0.020	0.081	
Unknown/Prefer not to say	11292.0	0.001	0.003	0.30
By Race/Ethnicity				
American Indian or Alaska Native	639.5	0.348	1.000	
Asian	1765.5	0.009	0.078	
Black or African American	11219.0	0.049	0.445	
Hispanic, Latinx, or Spanish origin	111863.5	<.001	<.001	0.38
Middle Eastern or North African	163.0	0.024	0.212	
Other	416.5	0.165	1.000	
Pacific Islander and Native Hawaiian	79.0	0.386	1.000	
Prefer not to answer	902.0	0.406	1.000	
White	31052.5	<.001	<.001	0.37

Statistics for Q7: I understand the impacts of engineering design on my local community

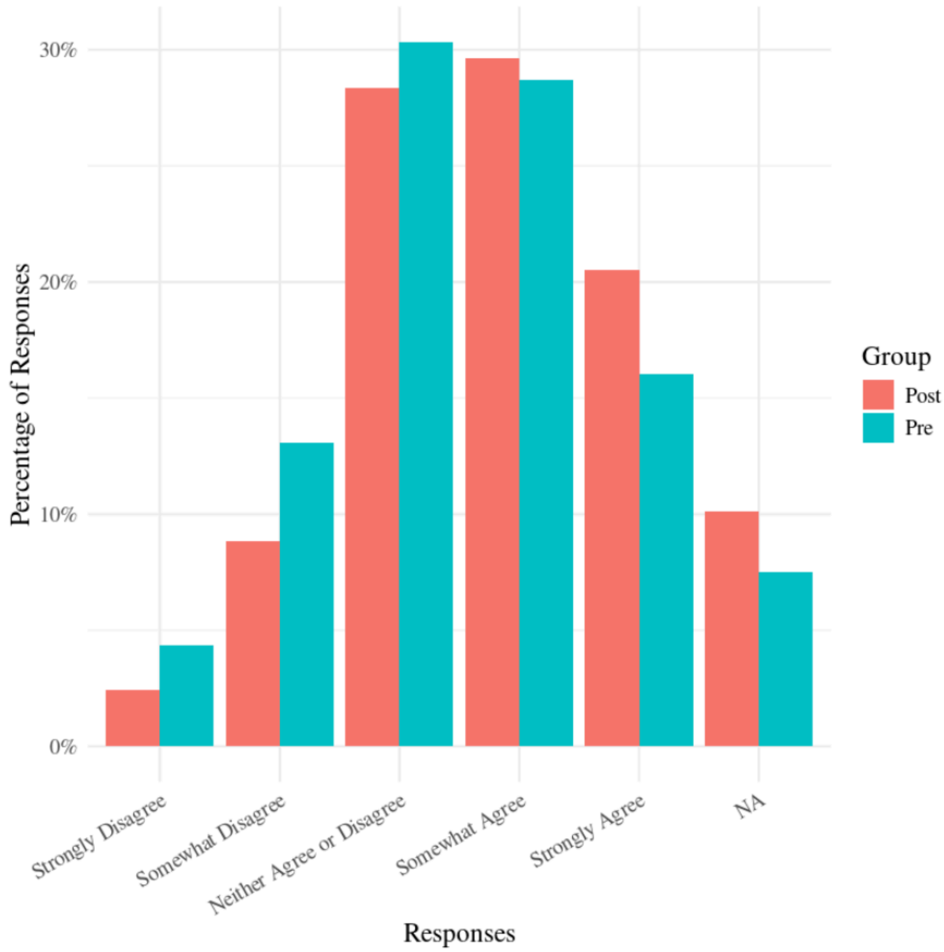

Figure A7. Distribution of aggregated (overall) responses for Q7: I understand the impacts of engineering design on my local community.

Table A13. Descriptive statistics for Q7: I understand the impacts of engineering design on my local community.

Category	Time	Median	IQR	Mean	StdDev	Min	Max
Overall	Pre	3	1	3.42	1.08	1	5
Overall	Post	4	1	3.63	1.02	1	5
By Gender:							
Female	Pre	4	1	3.58	1.03	1	5
Female	Post	4	2	3.83	0.92	1	5
Male	Pre	3	1	3.39	1.08	1	5
Male	Post	4	1	3.59	1.07	1	5
Non-binary	Pre	3	2	3.00	1.23	1	5
Non-binary	Post	3	1	3.48	0.95	1	5
Unknown/Prefer not to say	Pre	3	1	3.28	1.05	1	5
Unknown/Prefer not to say	Post	3	1	3.47	1.06	1	5
By Race/Ethnicity:							
American Indian or Alaska Native	Pre	4	1	3.40	1.20	1	5
American Indian or Alaska Native	Post	4	2	3.73	1.25	2	5
Asian	Pre	4	1.25	3.48	1.22	1	5
Asian	Post	4	2	3.88	0.93	1	5
Black or African American	Pre	3	1	3.35	1.05	1	5
Black or African American	Post	3	1	3.50	1.04	1	5
Hispanic, Latinx, or Spanish origin	Pre	3	1	3.42	1.08	1	5
Hispanic, Latinx, or Spanish origin	Post	4	1	3.60	1.03	1	5
Middle Eastern or North African	Pre	3	1	3.29	1.16	1	5
Middle Eastern or North African	Post	5	1	4.38	0.77	3	5
Other	Pre	4	1.25	3.41	1.10	1	5
Other	Post	4	2	3.79	1.10	2	5
Pacific Islander and Native Hawaiian	Pre	4	2	3.23	1.54	1	5
Pacific Islander and Native Hawaiian	Post	4.5	2	3.80	1.48	1	5
Prefer not to answer	Pre	3	1.25	3.20	1.15	1	5
Prefer not to answer	Post	3	1.75	3.61	1.00	2	5
White	Pre	4	1	3.47	1.07	1	5
White	Post	4	1	3.61	1.06	1	5

Note. 1: Strongly disagree, 2: Somewhat disagree, 3: Neither agree or disagree, 4: Somewhat agree, 5: Strongly agree.

Table A14. Inferential statistics for Q7: I understand the impacts of engineering design on my local community.

Category	W	p-value	Adj. p-value	AUROC Effect Size
Overall	304744.0	<.001		0.37
By Gender				
Female	41597.0	0.008	0.031	0.36
Male	79949.5	0.009	0.035	0.37
Non-binary	823.0	0.080	0.319	
Unknown/Prefer not to say	10092.0	0.198	0.792	
By Race/Ethnicity				
American Indian or Alaska Native	718.5	0.273	1.000	
Asian	1613.5	0.108	0.967	
Black or African American	10778.5	0.256	1.000	
Hispanic, Latinx, or Spanish origin	99291.0	0.019	0.167	
Middle Eastern or North African	172.0	0.008	0.069	
Other	458.5	0.204	1.000	
Pacific Islander and Native Hawaiian	80.5	0.337	1.000	
Prefer not to answer	978.5	0.168	1.000	
White	26632.0	0.187	1.000	

Statistics for Q8: Women should consider a career in engineering

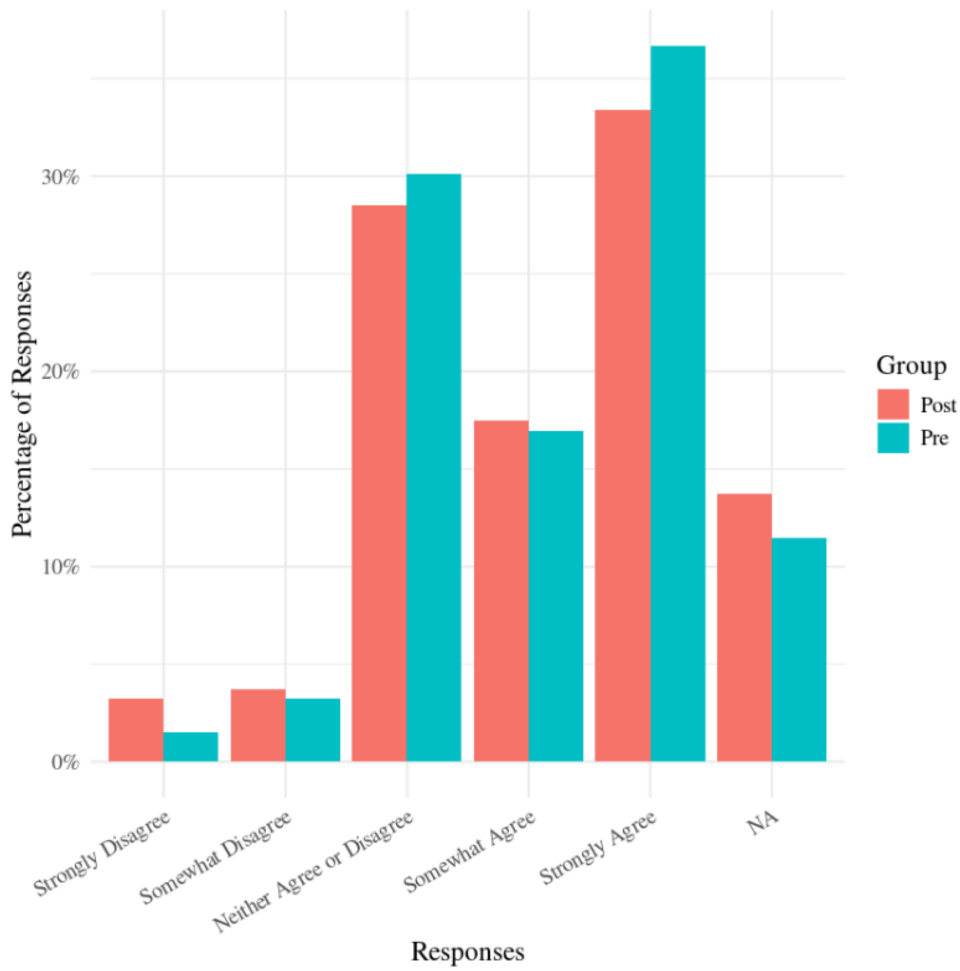

Figure A8. Distribution of aggregated (overall) responses for Q8: Women should consider a career in engineering.

Table A15. Descriptive statistics for Q8: Women should consider a career in engineering.

Category	Time	Median	IQR	Mean	StdDev	Min	Max
Overall	Pre	4	2	3.95	1.03	1	5
Overall	Post	4	2	3.86	1.10	1	5
By Gender:							
Female	Pre	4	2	4.10	1.02	1	5
Female	Post	4	2	4.03	1.08	1	5
Male	Pre	4	2	3.95	0.99	1	5
Male	Post	4	2	3.81	1.12	1	5
Non-binary	Pre	3	2	3.56	1.06	1	5
Non-binary	Post	4	2	3.90	0.94	2	5
Unknown/Prefer not to say	Pre	3	2	3.71	1.07	1	5
Unknown/Prefer not to say	Post	4	2	3.71	1.09	1	5
By Race/Ethnicity:							
American Indian or Alaska Native	Pre	4	2	3.84	1.12	1	5
American Indian or Alaska Native	Post	4	2	3.78	1.37	1	5
Asian	Pre	5	2	4.07	1.09	1	5
Asian	Post	4.5	2	3.88	1.33	1	5
Black or African American	Pre	3	2	3.63	1.08	1	5
Black or African American	Post	3	2	3.65	1.08	1	5
Hispanic, Latinx, or Spanish origin	Pre	4	2	4.04	0.99	1	5
Hispanic, Latinx, or Spanish origin	Post	4	2	3.90	1.08	1	5
Middle Eastern or North African	Pre	3	1	3.59	0.80	3	5
Middle Eastern or North African	Post	4	2	3.86	1.17	2	5
Other	Pre	4	2	3.88	1.10	1	5
Other	Post	3	2	3.75	1.26	1	5
Pacific Islander and Native Hawaiian	Pre	3	1	3.69	0.85	3	5
Pacific Islander and Native Hawaiian	Post	5	2	3.91	1.30	2	5
Prefer not to answer	Pre	3	1	3.59	0.93	2	5
Prefer not to answer	Post	4	2	3.87	0.95	2	5
White	Pre	4	2	4.06	1.00	1	5
White	Post	4	2	3.89	1.12	1	5

Note. 1: Strongly disagree, 2: Somewhat disagree, 3: Neither agree or disagree, 4: Somewhat agree, 5: Strongly agree.

Table A16. Inferential statistics for Q8: Women should consider a career in engineering.

Category	W	p-value	Adj. p-value
Overall	325343.0	0.183	
By Gender			
Female	32104.5	0.479	1.000
Male	63110.0	0.195	0.781
Non-binary	770.0	0.169	0.675
Unknown/Prefer not to say	8595.0	0.963	1.000
By Race/Ethnicity			
American Indian or Alaska Native	663.0	0.991	1.000
Asian	1322.5	0.597	1.000
Black or African American	10387.0	0.851	1.000
Hispanic, Latinx, or Spanish origin	85270.5	0.109	0.984
Middle Eastern or North African	137.0	0.458	1.000
Other	364.0	0.728	1.000
Pacific Islander and Native Hawaiian	79.5	0.642	1.000
Prefer not to answer	1049.5	0.153	1.000
White	23129.0	0.168	1.000