The Role of Community in Promoting Engineering Identity Formation in Historically Marginalized Communities

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***Abstract*— This Innovative Practice Full Paper presents findings on the impact of framing Engineering as a prosocial career on high school students' engineering identity formation. Engineers are often stereotyped as people who work alone and are primarily motivated by financial rewards. This stereotype may deter students who value altruism from pursuing engineering career pathways. In reality, many engineers work in collaborative, creative, interdisciplinary fields on problems that positively affect society. This work examined the impacts of framing engineering as altruistic on the engineering identity development of low socioeconomic status, predominantly Black high school students in an urban region of the Southern United States. The program consisted of a summer camp and academic year activities that included mentoring from underrepresented minority undergraduate engineering students. The program content was aligned to the US National Academy of Engineering's Grand Challenges for Engineering (GCEs), a list of 14 critical challenges that society faces that will require engineering solutions to address. Each of these challenges highlights the exciting ways that a career in engineering allows students to serve their communities and improve the lives of others. A convergent, mixed-methods approach was used to understand how this program affected students' perceptions of and interest in engineering. These results were compared to those for a traditional STEM Saturday informal education program with participants from the same demographic group. The altruistic framing resulted in students' having a broader definition of engineering as well as increased interest in engineering as a potential career.**

Keywords—diversity, altruism, grand challenges

I. Introduction

Researchers have demonstrated widespread misconceptions about engineering as a career among teachers, students, and the broader community. Capobianco et al. utilized the *Draw an Engineer Test (DAET)* with young students and found that many students illustrated engineers as car mechanics, repairing electrical systems, or working directly on mechanical devices, including vehicles and engines [1]. Teachers as well hold vague definitions of engineers as designers or technicians. Lambert et al. (2007) analyzed teachers' responses to the DAET after a training program [2]. The results suggested that teachers were likely to describe that engineers design or build/construct things, but that they rarely mentioned that the products of engineering are all around or the impact of engineering on everyday lives. Creativity and collaboration were rarely depicted. In their quantitative survey, Cunningham et al. (2006) reported that teachers were more likely to believe engineers construct buildings themselves and drive machinery, rather than planning and supervising these tasks [3]. Sadly, engineering is also often portrayed as a field for those who value individual accomplishment, working with complex math, and who prefer isolation and have few interests outside math and science [3, 4].

The reality is that engineers work collaboratively to solve complex, interdisciplinary problems that directly impact our everyday lives [5]. Definitions from professional organizations in engineering provide insight into the importance of collaboration and cultural awareness in engineering. Both the U.S.'s Accreditation Board for Engineering and Technology [6] and the European-Accredited Engineer (EUR-ACE) Framework Standards and Guidelines [7] include standards around traditional technical aspects of engineering knowledge, analysis, design, and practices. However, both sets of standards also emphasize the importance of social awareness and interpersonal communication to the modern practice of engineering [8]. The ABET standards include "an ability to apply engineering design to produce solutions that meet specified needs with consideration of factors". EUR-ACE similarly emphasizes the importance of the non-technical aspects of engineering, including "societal, health and safety, environmental, economic and industrial – considerations" in engineering problem solving, design, and practice. Both sets of standards emphasize societal and ethical considerations in engineering as well as the importance of communication and teamwork.

These accreditation organizations' definitions of the field stand in stark contrast to students' and teachers' perceptions of engineering, which focus very much on the technical aspects of the field [3, 9]. K-12 students' and teachers' misconceptions about engineering may discourage students from forming interests in engineering, especially if they value working

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collaboratively and helping others with their careers. For those with altruistic values, these misconceptions about engineering have the potential to signal a mismatch between personal values and career affordances. Holding altruistic values (including wanting to work collaboratively or to help others in one's career) may be a negative force pulling students away from engineering [10]. Furthermore, research strongly suggests that some underrepresented groups are more likely to hold altruistic values negatively impacting their interest in engineering as a career [11].

A. *The Current Study*

Given these common misconceptions, the goal of this research was to create learning experiences that gave students broader and more accurate understandings of the field of engineering to promote perceptions of goal congruity (i.e., greater alignment of engineering to one's own career values) [12, 13].

The approach taken in this work draws on several initiatives led by the National Academy of Engineering [14, 15] to design our interventions to reframe engineering as altruistic. One of their campaigns to change perceptions is the *Grand Challenges for Engineering* (GCEs)*,* fourteen challenges facing modern society that reinforce the message that engineers use their creative problem-solving skills to improve our world and shape the future, Table I [15]. Each of these challenges impacts people around the world and using these challenges as framing for engineering projects and lessons can engage students who are interested in having a career that helps others or solves problems they observe in their everyday life. We expected that building engineering lessons and challenges around themes from the GCEs would highlight the altruistic opportunities for engineering to address societal challenges that students find motivating.

Most of the previous work evaluating the impact of the Grand Challenges has focused on undergraduate engineering majors and their perceptions of lessons based on Grand Challenges [16]. For example, Corneal (2014) found that students responded positively to a group project organized around their choice of a Grand Challenge [17]. Previous work by the authors of the present study looked at the impacts of Grand Challenges as part of a freshman engineering course and found positive gains in their knowledge on module-specific content tests [18]. In addition, much of the previous work on congruity theory has focused on women and college students. Limited attention has been paid to education interventions to leverage goal congruity to increase the participation of marginalized races or ethnicities in engineering. This study extends the literature by 1) exploring the impacts of framing engineering through the Grand Challenges for engineering on high-school-aged students who are not already committed to engineering college programs and 2) exploring how framing engineering as an altruistic profession affects the development of career interests of low-SES, Black 8th – 10th-grade students from an urban area in a predominantly rural Southern state. The research examined two types of programs a Saturday Academy called Raise the Bar (RTB) and a new program called Tomorrow's Community Innovators (TCI). Research questions included:

- How did the RTB Academy and TCI summer camp experience influence students' interest in and self-efficacy for engineering as a career field?
- Did the altruistic focus of the TCI camp experience lead to different impacts on students in terms of interest, self-efficacy, definitions, or perceptions of engineering?
- How did each experience influence students' definitions or perceptions of engineering as a career field? Did different programs appear to change students' perceptions differently?

TABLE I NATIONAL ACADEMY OF ENGINEERING "GRAND CHALLENGES FOR ENGINEERING"

Challenge
Make solar energy economical
Provide energy from fusion
Develop carbon sequestration methods
Manage the nitrogen cycle
Provide access to clean water
Restore and improve urban infrastructure
Advance health informatics
Engineer better medicines
Reverse-engineer the brain
Prevent nuclear terror
Secure cyberspace
Enhance virtual reality
Advance personalized learning
Engineer the tools of scientific discovery

II. INTERVENTIONS

An existing high-quality STEM educational program, Raise the Bar (RTB), was evaluated in 2019. This evaluation provided data that allowed a comparison in student perceptions of engineering between a program that focuses on STEM learning and interventions that specifically highlight the altruistic nature of engineering careers. The intervention created around GCEs took the form of summer camps, called Tomorrow's Community Innovators (TCI). The camps were designed to provide similar learning opportunities but specifically framed engineering as a pro-social career path. One of the two camps, the 2020 TCI camp was virtual due to the COVID-19 pandemic.

A. *Raise the Bar (RTB)*

The RTB Saturday Academy is a 10-week program that consists of weekly themes around STEM domains, including mechanical engineering, aerospace engineering, biomedical research, and other engaging topics. The learning opportunities include hands-on activities, guest speakers from local universities, and museum visits such as to the local aviation museum. The program makes no specific effort to highlight how any of the STEM careers discussed met altruistic goals or help the local community. Based on our evaluation of multiple sessions of RTB, we found the activities are typically engaging and well-designed. Students in the program showed increased attitudes towards engineering as a pro-social career path. Observations using the Dimensions of Success rubric suggested that the program met informal STEM goals including building positive rapport between facilitators and students with a clear focus on the youth and their potential. Interviews with students indicated that they were engaged in STEM ideas, learned new things about engineering, and enjoyed the program [19]. The participants are typically low-income students from groups underrepresented in STEM that live in the Bessemer or Birmingham, AL area.

B. Tomorrow's Community Innovators (TCI 2019)

In contrast, the TCI camps developed were designed to focus on how engineering addresses important societal challenges. Topics were selected from the Grand Challenges for Engineering (GCEs). The TCI leadership team included faculty from the departments of Chemical Engineering, Materials Engineering, and Computer Engineering. Students were recruited through a partnership with a nonprofit in based in Bessemer Alabama with connections to the area's schools. The nonprofit organization was supplied with recruitment flyers containing contact information for the program director and a link to the application. The goal of the work was to understand how pro-social framing could impact positive perceptions of engineering, particularly in students that were not considering engineering as a career path. To attract these students the engineering focus of the camp was minimized in publicity and recruiting. For example, the camp's name was designed to attract students interested in solving problems in their community and avoided the mention of engineering. The recruitment information stated:

> *Do you want to make life better for your family and community? Do you have ideas for how to help your community right now? Do you want skills for the future? Then this is the program for you! We will learn about new inventions and ideas that can make lives better for the people around us and create solutions that you can implement right now and in your future career.*

The residential camp took place over the summer and students attended free of charge. This enabled students from low-income families to participate. Transportation to and from the camp, held in Auburn, was provided by the RTB organization eliminating this cost as well. Auburn engineering students from URM's in engineering were recruited as camp counselors. These counselors helped campers navigate the campus, encouraged participation in social activities, and acted as near-peer mentors.

The days were divided with the morning session focusing on a hands-on laboratory activity and the afternoon session focused on the creation and building of apps using App Inventor [20]. During the camp, role models met with students over lunch, including representatives from industry, Engineers without Borders, and the Auburn University's Black Student Union. Campers also participated in social activities including icebreakers, kickball, a tour of the football stadium, and a movie night. participated in lunches with role models from industry, Engineers without Borders, and the Auburn University's Black Student Union. They also participated in fun activities such as icebreakers, kickball, a football stadium tour, and a movie night.

The first day of the camp, Monday, was used for setting the stage for the rest of the weeks' activities. A brainstorming session was held where students identified problems in their communities and collectively identified what they considered the most important issues they felt society needed to solve, "What's the Challenge" [21]. After this activity students were introduced to the Grand Challenges for Engineering. In the afternoon, students learned the essentials of App Inventor and modified a simple game interface to learn block coding. Days two to four of the camp each focused on a specific Grand Challenge for Engineering: providing access to clean water, making solar energy economical, and restoring urban infrastructure.

On Tuesday, the morning activity focused on the challenge of providing access to clean water and involved building a water filtration system to remove large particulates from contaminated water. Students then used filters with silver nanoparticles to further filter the water and test the quality of the filtered water using test strips and a multi-day test of bacterial content with petri dish cultures. In the afternoon, a Computer and Software Engineering graduate student demonstrated an app she had built where users could map the location of water leaks and contamination. Students then built a game in App Inventor to demonstrate water clean-up projects (specifically, collecting trash from the ocean).

On Wednesday, students tested commercial solar panels, Fig. 1, to learn about the impacts of direct and indirect sunlight on output. They then built their own solar panels to learn about the challenges of economical solar energy [21]. Correspondingly, in the afternoon, they built an app that tracked solar panel efficiency. Students then created a simple app to convert energy data for record-keeping purposes (e.g., converting Fahrenheit to Celsius).

On Thursday, students learned about urban infrastructure by working as a team to gather information from community stakeholders (mentors acting assigned roles such as town mayor or economic developer) and then planning a city block and using their limited budget to place necessary buildings and roads. This activity was developed from an outreach-focused lesson plan [22]. In the afternoon, a graduate student in Computer and Software Engineering demonstrated a self-driving robot, Fig. 2, that used color sensors to detect and follow a pre-determined

Fig. 1. Students test commercial solar panels at TCI 2019.

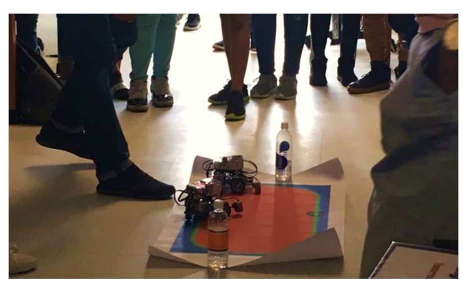

Fig. 2 Students observe a self-driving robot prior to programing.

Fig. 3. Students constructing and testing a water filtration system online.

path. After the demonstration, students programmed the self-driving robot to avoid obstacles on a course.

On Friday morning, a graduation ceremony was held to celebrate the students' accomplishments and inform them about future opportunities to be involved with the project and institution.

C. TCI 2020:

Due to COVID-19, the second TCI camp was delivered virtually. A variety of activities were planned including discussions, hands-on activities, and guest speakers. One week before the camp, students were mailed a kit of camp supplies. Students logged into the same Zoom meeting room each day and a simple website to organize all camp materials, including artifacts that we created as a group (https://sites.google.com/view/tci2020) was created.

The week was framed as "career exploration" and opportunities were provided for students to collect data before learning anything directly about engineering. On the first day, the discussion of engineering was minimized, and the Shark Tank Inventors activity was used to practice brainstorming skills. In this activity, unusual household items (e.g., pacifier straps, canvas bags, chip clips) were supplied and participants were challenged to use SCAMPER brainstorming techniques to come up with at least 10 inventions using these items. The rest of the first day focused on data collection, including a series of surveys on their interest and self-efficacy in engineering and science, their career interests, and their career values. These surveys allowed for the collection of data research but are also commonly used to help high school students reflect on their career paths and plan for their future education. Therefore, after completion the students discussed their results with mentors in small groups. Links to career exploration websites (such as https://www.mynextmove.org/explore/ip) based on the same survey tools were provided.

On day two, as with TCI 2019, students engaged with the "What's the Challenge?" activity, previously developed by the PI team. Students were eager to think through the possibilities of this challenge. Students were engaged throughout the process and seemed eager to share ideas and think about societal challenges. The facilitator then introduced the 14 GCEs and described how they were compiled in a similar fashion to our activities that day. The overlap between the challenges they identified and the GCE was highlighted. Students were then encouraged to watch (after the camp) a series of videos that would let them explore these challenges and learn more.

"Access to Clean Water" was the focus of days three and four. One of the mentors (undergraduate engineering students) led a lab activity on testing water quality with the provided kits, Fig. 3. The kits allowed evaluation of several water quality characteristics including pH, various types of hard metals, chlorine, lead, and bacteria. All students evaluated their home water and several collected additional samples for characterization. Discussion included the impacts of each water quality characteristic such as how high pH can lead to pipe erosion and the negative effect of bacteria and pesticides on health. Students were engaged and excited throughout the lab.

On day four a water filtration lab similar to that used in TCI 2019 was conducted, Figure 6. The activity was based on the LaMotte Water Treatment and Filtration lab kit which involved building water filters in plastic cups consisting of coarse and fine sand and gravel. Students also used activated charcoal to filter the water. The "dirty" water contained leaf debris, vinegar, fine clay, and blue food dye. By the end of the lab, students created water that was visibly cleaner (though still warned not to drink it!) Throughout the lab, students answered questions about how water quality is improved by water treatment plants and the issues that lack of treatment causes to human and environmental health.

The focus of the last day of the camp was a student discussion of what they had learned during the week and what they enjoyed. Part of the day was also used to check on the 48-hour bacteria contamination test that was started on day three. One student obtained a sample of pond water from farmland and had a clear positive result for bacteria. (Thankfully, the water samples from treated water were negative).

D. TCI 2021:

In the most recent year of the program, an effort was made to bring back some of the original 2019 TCI participants. To do so partnerships were created with other summer camps that students would find interesting and that provided altruistic framing opportunities. ASE was utilized to connect to families with eligible students and place them in camps organized by other Auburn faculty, but with a congruent focus on STEM and community-focused solutions. In total, 27 students applied to participate in the summer camps. Due to COVID resulting in restricted camp sizes, only 15 students were ultimately able to register for the three camps that were held. All of these students were from the focal community (Bessemer, AL, region) and were Black. Many attended low-performing schools, including Bessemer City and Jefferson County school districts.

One of the camps was the Industrial Design program, hosted by the School of Industrial and Graphic Design, which was held in a residential format at Auburn University. They are designed to be flexible and responsive to student interests and include a week-long design challenge. The camps had a significant focus on both engineering and altruistic concepts. They included defining and caring about others' needs, the engineering design process, creative problem solving, communication, and drawing

TABLE II CAMP PARTICIPANTS AND DATA COLLECTION

	Total participants	Completed interviews	Completed survey
RTB 2019	13	7	8
TCI 2019	20	8	7
TCI 2020	13	5	7
TCI 2021	12	0	7

and modeling skills. The directors of the Industrial Design Camps were able to provide opportunities for data collection and observations during the programs. In 2021, the camp focused on designing bicycles for specific avatars (archetypal end users) with different needs such as electrical assistance, speed, and durability. All students in the camp (whether recruited by TCI or not) participated in the TCI-provided project-related activities and data collection in addition to camp activities.

III. METHODS

A mixed methods approach to evaluating the interventions was utilized to allow findings to be triangulated across different analytical approaches. Specifically, a congruent methodology was utilized in which both quantitative data (including pre/post-camp surveys) and qualitative data (interviews, reflection essays, and artifacts) were collected to triangulate our findings regrading students' perceptions of engineering and their interest in an engineering career [23]. Survey design and analytical methods are described in the sections that follow.

***Limitations to Data*:** This research study was as implemented as a program evaluation. While specific research questions motivated the camp program, the project leadership and researchers were conscious that the primary goal was to create a powerful learning opportunity for the students, with data collection as a secondary concern. Therefore, data collection was designed to be as unobtrusive as possible. This led to the decision to only collect as many interviews as could be managed within planned camp activities.

A. Participants:

All of the samples consisted of grades 8-10 and predominantly Black students. The RTB participants were students from low-income families in the Bessemer Alabama Area. Recruitment for the TCI 2019 camp focused on this area and all participants came from this single low-income community. In 2020, due to COVID-related cancellations, we revised our summer plans to offer a virtual camp experience instead of in-person camps that were scheduled to be on-campus. We reached out to our returning TCI 2019 students, but just a handful expressed interest in a virtual summer camp. We recruited from this group, the broader community, and additional rural sites that we worked with in order to provide the camp for as many students as wanted the experience. We recruited thirteen virtual participants who attended at least one day of camp. This included two returning students from TCI 2019, three other students from our target urban region, and eight who came from rural areas outside of our target region. During the course of the camp, only 2 did not return for at least 3 days of camp.

The number of participants that attended, completed surveys, and were interviewed for each intervention is provided in Table II. Thirteen students participated in the RTB session that was formally evaluated. Three previous 10-week sessions were observed while learning about the program and evolving the evaluation process. Only data from the formal evaluation are reported here. Pre- and post-program interviews with seven participants were conducted and complete pre and post-surveys for eight students were obtained. Five students completed both the pre- and post-camp interviews. In the TCI 2019 camp, all twenty participating students came from one low-income urban community. We interviewed 12 students at the start of camp, but only 8 completed post-camp interviews due to time constraints. In addition, some students did not complete the full pre-camp surveys because they did not notice the double-sided pages while completing surveys (and socializing) in the communal area of their dorm on the first day of TCI 2019. Seven students provided complete pre- and post-camp surveys. For TCI 2020 students were provided links to the surveys and asked to log into zoom meetings at set times for interviews. Five completed both interviews and seven students provided complete survey data.

B. Pre- and Post-Camp Surveys:

The quantitative surveys included measures of science and engineering interest and self-efficacy developed for the age group [24]. Example items are provided in Table III. The scale for each ranged from 1 (not at all true) to 3 (somewhat true) to 5 (very true).

Because of the casual context of data collection in 2019, most seemed not to notice that the surveys were printed the front and back which resulted in 9 of 20 students providing usable pre- and post-camp quantitative surveys. Given the limited sample, the Wilcoxon signed-rank test for a paired sample comparison was used for analysis [25]. This nonparametric test compares the magnitude of pre-to-post changes across participants to determine if the positive changes are consistently larger than any negative changes.

At the beginning of camp, students also rated their career and life values on a survey instrument commonly used for career planning [26]. Examples are included in Table III . Nineteen of the students completed this survey (located on the front page of the instrument). The scale ranged from 1 to 4: 1= Not important, 2=Somewhat important, 3=Important, and 4=Extremely important. Items included an example to explain the value. The scale included 11 items that could be classified as individualistic, 5 that were altruistic, and 4 that were relative to creativity.

C. Pre- and Post-Camp Interviews:

At each program, the same set of interview questions guided the semi-structured interviews. The interviewers asked students about career values and their perceptions of engineering.

- Think about your life and future career. Have you thought about what you would major in at college? What are your goals for your adult life?
- Do you know any engineers? Scientists?
- What is engineering? What does an engineer do?
- What kinds of engineering or science things do you find interesting?

TABLE III SURVEY SCALES AND EXAMPLE ITEMS

Scale	Items
Interest in Science (n=5)	I like science. I would like to work in science someday.
Interest in Engineering (n =5)	I would like to study engineering in college. I want to learn more about engineering.
Self-efficacy for Science (n=5)	I am good at science. I believe I will receive a good grade in science class.
Self-efficacy for Engineering (n=5)	I believe I can do well in an engineering club or camp. Even if the work in an engineering club or camp is hard, I can learn it.
Career values (n= 11 individualistic, 5 altruistic, 4 creative)	Make decisions: Have the power to decide what I want to do and manage others. Help society: Do something which contributes to improving the world we live in. Aesthetics: Studying or appreciating the beauty of things, ideas, etc.

- Have you considered engineering or a field of science as a future career? What do you think that career would be like?

Interviews were transcribed verbatim and reviewed for accuracy by the researchers. The transcripts were analyzed by using the *Sort and Sift, Think and Shift* approach [27]. This approach encouraged engagement with the data and reflection on findings that emerged in an iterative process with attention to findings that were warranted by the data. Given the explanatory nature of this case study, the analysis was focused within each participant (threading), comparing their responses at pre- and post-camp.

The process began with individual assessors familiarizing themselves with the data, highlighting key quotations, and constructing memos that captured the key elements and storyline for each transcript. These memos, a mechanism to document emerging thoughts and ideas about the data, served to capture the essence of interviewee responses and capture their voice. Simultaneously, the researchers engaged in ongoing written reflections to document what was already known, how this data contributes to the project aims, and to acknowledge what is new. Next, a consensus around strong quotations and key elements of the data was reached.

After preliminary quotations and topics were identified, the other authors (all experts in engineering disciplines) were engaged in reading and reflecting on the selected quotations organized by student. A group consensus was reached on meaning and consistent topics and patterns. The results and discussion presented here reflect both this shared consensus as well as the discipline-specific implications that these co-authors identified.

IV. RESULTS AND DISSCUSSION

A. *How did the RTB Academy and TCI summer camp experience influence students' interest in and self-efficacy for engineering as a career field?*

Thirty students completed usable pre- and post-camp surveys on their science and engineering interest and self-efficacy. The non-parametric Wilcoxon paired-samples t-test, as implemented in JASP v0.14, was used to analyze the changes in students' attitudes [28]. Initial tests for the impact of the camp type (TCI 2019 or 2020) on the dependent variables as an interaction term with time were conducted, but was found to be non-significant. Therefore, the TCI camp data was collapsed into a single sample for analysis. Only one attitude scale increased significantly, engineering self-efficacy, which rose by a moderate amount (0.3 scale points or 0.48SD), Table IV. Changes in engineering self-efficacy but not science self-efficacy is consistent with expectations given the focus of the camps. It was anticipated that interest in engineering to also increase, but this effect was not observed.

Because the 2021 camps were organized by other programs, there was no opportunity to conduct interviews only surveys were collected. Therefore, the surveys were adapted to inquire about STEM more broadly, instead of just engineering, so the data could not be combined with that reported previously. In these analyses, there was a clear increasing trend in student endorsement of STEM career interest and altruistic beliefs about engineering, Table V. There was no change in individualistic beliefs about engineering, which is consistent with expectations.

B. *How did each experience influence students' definitions or perceptions of engineering as a career field?*

A priori codes based on prior literature such as those used by Villanueva & Nadelson [9] were not found to fit the data adequately, because many students had misconceptions about engineering (such as equating an engineer to a car mechanic) or limited definitions of engineering (such as naming types of engineers). Therefore, based on repeated reading of the data, two categorization schemes were developed: one based on the initial definition's accuracy and breadth and a second scheme based on the amount of growth observed from pre- to post-camp.

A "broad and encompassing definition" was defined similarly to Villanueva and Nadelson's conception of "21st-century interdisciplinary problem-solvers with a social impact" and informed by prior work with engineering freshmen [29, 30]. A key consideration was if students mentioned multiple elements of this definition: works collaboratively, helps others or solves problems for others, uses math and science, uses the engineering design process, and solves problems based on creativity or efficiency. Some students provided definitions including several elements of this definition. More students gave definitions falling in this category, but some students persisted with misconceptions about engineering (particularly whether they worked on cars or only "fixed" tech.), Table VI and VII.

The second categorization was based on the amount of growth observed. While not strictly based on moving between categories for definitions, student definitions were evaluated for an increase in breadth. Essentially, students were sorted from least to most growth in definitions to organize students into three clusters. See Table VII which shows examples growth from each initial definition category (no students fit both "level 2" and "little growth"). For space not all levels of growth are shown.

TABLE IV WILCOXON PAIRED-SAMPLES T TEST OF SURVEY DATA

Scale	Pre *M* (*SD*)	Post *M* (*SD*)	W statistic	df	P	Cohen's d effect size
Science interest	3.22 (0.80)	3.17 (0.83)	88.5	24	0.28	0.16
Engineering interest	3.48 (1.25)	3.76 (1.15)	94.5	22	0.35	0.10
Science self-efficacy	3.98 (0.65)	4.11 (0.48)	63.0	22	0.17	0.26
Engineering self-efficacy	3.48 (1.06)	3.80 (1.15)	60.0	22	0.03	0.48

C. Did the altruistic focus of the TCI camps lead to different impacts on students in terms of definitions and perceptions of engineering?

Patterns emerged in how students' definitions of engineering changed across the different types of camps. With RTB, that students who came in with strong definitions of engineering tended to leave with even more accurate or broad definitions. Students who started with limited or inaccurate definitions showed no change or improvement. While at least two students started and ended the RTB program thinking that engineers work on cars, students in the TCI camps who held this misconception addressed how they recognized it was a misperception and then offered more detailed and accurate definitions of engineering after the camp (see Wanda in Table VII for an example). The overall impression is that TCI 2019 had the most transformative impact on students' definitions.

D. Changes in interests between 2019 and 2020 TCI camps

Students participating in camps were also asked questions about their potential career interest in the field at the beginning and end of the camp program. At the first, on-campus TCI camp, students fell into one of four categories comparing their pre- and post-camp interests; "same career, new interests", "connected engineering to existing interests", "new interests for career", and "no change". At TCI 2019, just one student fell into the "no change" category. Pseudonyms were assigned to all students for reporting purposes.

Among those students in TCI 2019 who said at the outset they were not interested in science or engineering careers, three reported in post-camp interviews that they would consider engineering as a career. For instance, Hailey stated:

> *"…but now that I've came to this camp, I've become more interested in engineering. So, I think I might be looking into engineering now".*

She later went on to express:

> *"…now that I hear about different parts of the world not having clean water and water being contaminated and everything, it makes we wanna go out and help people with dirty water get clean water."*

TABLE V SURVEY RESULTS OF PRE/POST CAMP INTERESTS AND BELIEFS ABOUT ENGINEERING

Scale	Pre-camp	Post-camp	Cohen's d
STEM career interest	3.3 (0.2)	3.5 (0.4)	0.59a
Altruistic beliefs	3.6 (0.3)	3.8 (0.4)	0.74a
Individualistic beliefs	3.1(0.3)	3.2 (0.6)	0.21

[a.] Significant, $p < .05$, n=7

Hailey also noted how much she enjoyed the solar panel lab activity and thought there might be a connection to her future career.

Kiara and David indicated that they found new science and engineering interests, although it did not affect their career goals. Other students integrated engineering into their existing interests. For example, Jaylen noted that computer science could be an avenue to film production. Chloe recognized that biomedical engineering could provide another pathway to helping others through medical treatments. Just one student did not identify any potential links between engineering and his career interests (Malik).

In the second TCI camp, there was less clear evidence of students finding new interests or connecting previous interests to engineering. Rather, students in this camp either had no change in interest (two students) or could be best described as having a "halfway" change in interest (one student). An example of this result is drawn from an interview with Jada, who, when asked if she had an interest in engineering as a career, stated:

> *"I would like to, like halfway. [what kind] oh, chemical engineer. I'm because … sometimes I'd be curious about, like, like how things are gonna be, that I put together. So, yes."*

These students in TCI 2020 did not express specific new interests or career pathways open to them. Rather, they noticed activities they enjoyed and speculated that they might be clues to other career interests. Sylvie stated, when asked if she thought about her future career during the camp:

> *"I thought about if I could see myself continuing doing like experiments and testing different stuff. I thought about if I enjoyed it."*

Across camps, interviews suggested that that the TCI camps led to meaningful changes in students' appreciation of engineering and, in some cases, new interests in pursuing engineering as a career. Many students noted how broadly engineering affects our everyday lives and how it helps others.

TABLE VI THEMES AMONG DEFINITIONS FOR ENGINEERING DURING PRE- AND POST-CAMP INTERVIEWS

Level of definition	Pre-camp	Post-camp
Broad, encompassing definition (helps others, uses math and science)	3	11
Able to name specific types and their work or one aspect of the broad definition	8	5
Limited, inaccurate or no definition	10	5

TABLE VII EXAMPLES OF DEFINITIONS AT SELECT LEVELS OF ACCURACY AND GROWTH

Pre-camp	Growth	Alias	Pre-camp definitions	Post-camp definitions
Started with weak or inaccurate definition	Showed little growth	Malik	There's different types of engineers. They can work on computers, rebuild things and maybe painting. Pretty sure painting. … Building a house from the ground.	I would say it takes like time management and creativity you have to like ask for help if you don't know what you're doing and keep asking until you understand because there's lots to take in at one time to be like you're doing something
	Showed greater growth	Aliyah	Engineering is like building stuff, putting stuff together in different ways. … Like there need to be an automotive engineer which means like working on cars. Could be like tech or a computer engineering that work on technology and stuff. It can be people that like build stuff like architectures, buildings. And I guess they can just be like someone like an engineer in science.	I think engineering is like building things to help out your like community. … People that build like buildings help somebody start a business which helps the city grow ... So, I think engineering is like helping somebody else out. So, engineers, I respect them because they do all the hard work with stuff like that…. I think of creative. You gotta be creative to build something. Gotta be organized and then you gotta work…it's just like stay on like you can't be lazy… " "hardworking".
Started with accurate though limited definition	Showed moderate growth	Brianna	So, like um, build the roads and make the bridges and they do the…the…they make power, yeah. They, they work out of some of them work out of power plants and some of them like I said they build streets and figure out what to do when like [inaudible] aren't like as levels as others and things like that, so, I feel like they just are like some of the main people who make what we have today. Um, without some engineers I don't think we would have like some of the things we have today	Engineering, I feel like, now that I've just been through this week, earlier it was such a just broad term because like engineering can be like so many different things. It can be like uh uh finding a way to give someone a heart…finding a way to make artificial organs or like building bridges or things like that. So, I feel like engineering is just people helping their community, people helping other people and just… just help, I guess, that's…they help in different ways but they're helping
	Showed greater growth	Oscar	I'd define it like building things and trying to come up with things that help a problem, or make it more efficient. // I'm thinking the one who builds things, designs things, and comes out with a plan to making it, like why would it work, how it would. // Working in teams, and really makin' somethin' to benefit the community or somebody. More like, yeah, they work in teams where they could help build somethin' to help the community or help somebody.	I'd say engineering is coming up with ideas to build something to benefit a problem or to fix a problem. // When you think about somebody, somebody who's creative, and has a plan, and a team because it takes an effort. Well, one engineer can build somethin', but if it's startin' to be somethin' real big, it takes a team. // They have to be creative and be good at brainstormin' 'cause they gotta think of stuff.
Started with broad, accurate definition	Showed little growth	Sylvie	I just think about like creating things or innovation, trying to make things better. // Like computer programs … 3D printer.// They probably go through the design process if they're just starting a project like with brainstorming like we did earlier. … Work on whatever project or innovation. They're trying to work on, make it better, make it work better. // They're on site working if they're like a civil engineer, they go to the site or they're doing experiments with their prototypes.	Engineering someone uses math and science to find a better solution to a problem. They design different things to help you. // Working with machines, brainstorming // Go through the steps of the engineering design process like if they just got just got started on a on a project that they would like to brainstorm and stuff. So if they were closer to the know the project they would make some prototypes for they would be getting their prototype to work better and quantify the product.
	Showed greater growth	Wanda	To me engineering is using your past knowledge to solve problems to help people and help create a better future. // Mechanics, computers, building // I think engineer first thing that comes to my mind is like someone who works with gears or Vehicles or things like that. But as I grew up. I learned that it's not just geared theaters and everything. It's also working with science mainly just working at science. I don't know too much to the details.	I have to say that before I started camp…. but like now I've actually met some engineers. And it's like, something else. It's something else about not just solving problems and things like that. It's like they want to make the world a better place. I don't know how to explain it. …I think, um, they persevere. A lot. They don't give up easily… but they also not only try and solve problems. They do it they try to do it in the best way possible, whether it's making it more cost efficient. …I think it's interesting that, you know, it's amazing that a lot of engineers, you know, like I said before they persevere and everything, but don't give up easily.

For students in the traditional STEM program, students also increased their interest in engineering, but their definitions of the field did not broaden appreciably. Some found new interests, but they did not have the same type of transformative experience as those that participated in the GCE and altruistic engineering focused TCI camps.

V. CONCLUSIONS

Overall, framing engineering as an altruistic career path appeared to lead to meaningful changes in students' definitions of engineering and their connection of engineering to their career interests. TCI 2019 seemed to have the most profound effects. Over the students interviewed and surveyed over the three iterations of the camp only one student did not find a way their career interests were broadened. Many gains in definitions were profound and clearly reflected the learning experience. Further work is needed to understand if these gains in understanding translate to increased pursuit of engineering as a career path for these students.

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