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Framing Engineering as Community Activism for Values-Driven Engineering (RFE Design and Development - Year 2)

Dr. Joni M. Lakin, University of Alabama

Joni M. Lakin (Ph.D. , The University of Iowa) is Associate Professor of Educational Research at the University of Alabama. Her research interests include educational assessment, educational evaluation methods, and increasing diversity in STEM fields.

Dr. Daniela Marghitu, Auburn University

Dr. Daniela Marghitu is a faculty member in the Computer Science and Software Engineering Department at Auburn University, where she has worked since 1996. She has published seven Information Technology textbooks, over 100 peer reviewed journal articles and conference papers, and she gave numerous presentations at national and international professional events in USA, Canada, England, France, Italy, Portugal, Spain, Germany and Romania. She is the founder director of the Auburn University Educational and Assistive Technology Laboratory (LEAT), Co-PI of NSF EEC "RFE Design and Development: Framing Engineering as Community Activism for Values-Driven Engineeringan", Co-PI of NSF CISE "EAGER: An Accessible Coding Curriculum for Engaging Underserved Students with Special Needs in Afterschool Programs", institutional partner of AccessComputing (http://www.washington.edu/accesscomputing/), AccessCS10k and AccessEngineering NSF funded Alliances, CO-PI of NSF INCLUDES: South East Alliance for Persons with Disabilities in STEM (https://cws.auburn.edu/apspi/pm/includes), CO-PI and Technology Coordinator of the NSF Alabama Alliance for Students with Disabilities in STEM (https://cws.auburn.edu/apspi/pm/ste the PI of NSF Computer Science for All (http://cs4all.eng.auburn.edu),. She is the recipient of the 2011 AccessComputing Capacity Building Award, the 2012 Auburn University Access award, the 2012 SDPS Outstanding Achievement Award, the 2013 Microsoft Fuse Research award, the 2015 DO-IT Trailblazer award, the 2017 IARIA Fellowship, the 2017 SDPS Fellowship, and the 2019 Samuel Ginn College of Engineering 100+ Women Strong Leadership in Diversity Faculty Award.

Dr. Edward W. Davis, Auburn University

Edward W. Davis received his PhD from the University of Akron in 1996. He worked in the commercial plastics industry for 11 years, including positions with Shell Chemicals in Louvain-la-Nueve Belgium and EVALCA in Houston TX. He joined the faculty at Auburn University in the fall of 2007. In 2014 he was promoted to Senior Lecturer. He has regularly taught courses in three different engineering departments. In 2015 he began his current position as an Assistant Professor in the Materials Engineering Program.

Prof. Virginia A. Davis, Auburn University

Dr. Virginia A. Davis' research is primarily focused on using fluid phase processing to assemble cylindrical nanomaterials into larger functional materials. Targeted applications include optical coatings, 3D printed structures, light-weight composites, and antimicrobial surfaces. Her national awards include selection for the Fulbright Specialist Roster (2015), the American Institute of Chemical Engineers Nanoscale Science and Engineering Forum's Young Investigator Award (2012), the Presidential Early Career Award for Scientists and Engineers (2010), and a National Science Foundation CAREER Award (2009). Her Auburn University awards include the Excellence in Faculty Outreach (2015), an Auburn University Alumni Professorship (2014), the Auburn Engineering Alumni Council Awards for Senior (2013) and Junior (2009) Faculty Research, the Faculty Women of Distinction Award (2012), and the Mark A. Spencer Creative Mentorship Award (2011). Dr. Davis is the past chair of Auburn's Women in Science and Engineering Steering Committee (WISE) and the faculty liaison to the College of Engineering's 100 Women Strong Alumnae organization which is focused on recruiting, retaining and rewarding women in engineering. She was also the founding advisor for Auburn's SHPE chapter. Dr. Davis earned her Ph.D. from Rice University in 2006 under the guidance of Professor Matteo Pasquali and the late Nobel Laureate Richard E. Smalley. Prior to attending Rice, Dr. Davis worked for eleven years in Shell Chemicals'

polymer businesses in the US and Europe. Her industrial assignments included manufacturing, technical service, research, and global marketing management; all of these assignments were focused on enabling new polymer formulations to become useful consumer products.

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Abstract

Researchers theorize that identification with a career field is achieved when there is alignment between student values and their perceptions of the values a career field meets. Stereotypically, engineering is perceived to align with status values, such as high pay, but the reality is that engineering is a collaborative enterprise that solves important social challenges. The goal of this study was to understand how highlighting this broader review of engineering (i.e., *altruistic framing*) affected students' interest in the field. We evaluated a traditional Saturday STEM program for Southern, urban African American youth that did not include a significant altruism component. In parallel, we designed a program for this same demographic group that used *Grand Challenges for Engineering* to create altruistic framing that highlights the impacts of engineering on society and our everyday lives. Students from the same region as the traditional STEM program were recruited for this new summer camp program called *Tomorrow's Community Innovators*. We compared the impacts of the traditional STEM program to the camp with altruistic framing to explore how they impacted students' attitudes towards engineering and perceptions of the field.

Engineering is a widely misunderstood field. It is often perceived as a field for those who prefer isolation, value individual accomplishments, and have little interest outside of math and science. [1] [2] The reality is that engineers work collaboratively to solve complex, interdisciplinary problems that directly impact our everyday lives. [3] This common misconception is concerning not only because it is inaccurate, but because research strongly suggests that some underrepresented groups are more likely to hold altruistic values, including women, first-generation college students, and underrepresented racial minority students. [4] [5] [6] 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. [7] [8] The goal of this research was to create learning experiences that gave students broader and more accurate understandings of the field of engineering in order to promote perceptions of *goal congruity* (i.e., greater alignment of engineering to one's own career values). [9] [10]

Defining "Engineering"

Researchers have demonstrated widespread misconceptions of engineering. Using the *Draw an Engineer Test (DAET)* with young students, Capobianco et al. found that many students illustrated engineers as car mechanics, repairing electrical systems, or working directly on mechanical devices, including vehicles and engines. [11] Even teachers hold vague definitions of engineers as designers and technicians. In their analysis of teachers' responses to the DAET after a training program, Lambert et al. found 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 impacts our everyday lives. [12] Even less common were details about how engineers work collaboratively or that they have to be creative in their work. In their quantitative survey, Cunningham et al. reported that teachers were more likely to believe engineers construct buildings themselves and drive machinery, rather than planning and supervising these tasks. [1] Given this lack of awareness of the field, it is no wonder that many students have inaccurate perceptions of the potential to meet altruistic values in engineering because they do not appreciate the breadth of its impact or the importance of engineering in our everyday lives.

Other researchers have uncovered a range of definitions that students hold that are accurate but limited to different extents. Villanueva and Nadelson explored student perceptions of engineering within a framework of historical definitions. [13] They found students hold one of three impressions of engineers: tinkerers (pre-industrial view); those who apply science to practical problems (industrial view); and 21st century interdisciplinary problem-solvers with a social impact (modern view). They argued that the last, most modern, and inclusive conception of engineering was most likely to support students' development of an engineering identity that would be productive for the current engineering field. This effect was expected to be greater for traditionally underrepresented groups such as women and racial/ethnic minorities.

Of course, the professional field of engineering provides its own formal definitions, including via accreditation standards for higher education, including the U.S.'s Accreditation Board for Engineering and Technology [14]. Unsurprisingly, the first student outcome for ABET accredited engineering programs is "an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics (p. 5). [14] However, other standards emphasize the importance of social awareness and interpersonal communication to the modern practice of engineering. [15] For example, the 2019 ABET student outcomes include

> 2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
>
> 3. an ability to communicate effectively with a range of audiences
>
> 4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
>
> 5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives (pp.5-6)

The outcomes specifically address the need for interpersonal skills and a nuanced understanding of social and global context that may not be reflected in students' or teachers' understanding of the field.

Grand Challenges for Engineering

In response to widespread misunderstandings of the field, as well as low enrollment numbers of U.S. students in engineering programs [16], the National Academy of Engineering (NAE) has introduced a series of marketing campaigns to counter these common misperceptions of engineering and the number and diversity of students entering engineering career fields. [16] [17] [18] One of their campaigns to change perceptions is *Grand Challenges for Engineering,* 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. [17] [18] See Table 1 for a list of the Grand Challenges. Each of these challenges impact 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.

Most of the work evaluating the impact of the Grand Challenges has focused on undergraduate engineering majors and their perceptions of lessons based on Grand Challenges. [19] For example, Corneal found that students responded positively to a group project organized around their choice of a Grand Challenge. [20] Our own work 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. [6] [21] [22] This study extends the literature by exploring the impacts of Grand Challenges on high-school aged students who are not already committed to college programs in engineering.

Table 1

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

Interventions to change perceptions of engineering

Goal congruity theory predicts that students will be motivated to pursue a career field if they feel they are likely to obtain valued outcomes from a learning experience. [9] [10] [11] It builds from expectancy-value theory, which emphasizes the roles of values and self-efficacy in predicting learner engagement. [23] Therefore, we were interested in changes to students' perceptions of the value affordances, their self-efficacy, and their interest in engineering topics or a career.

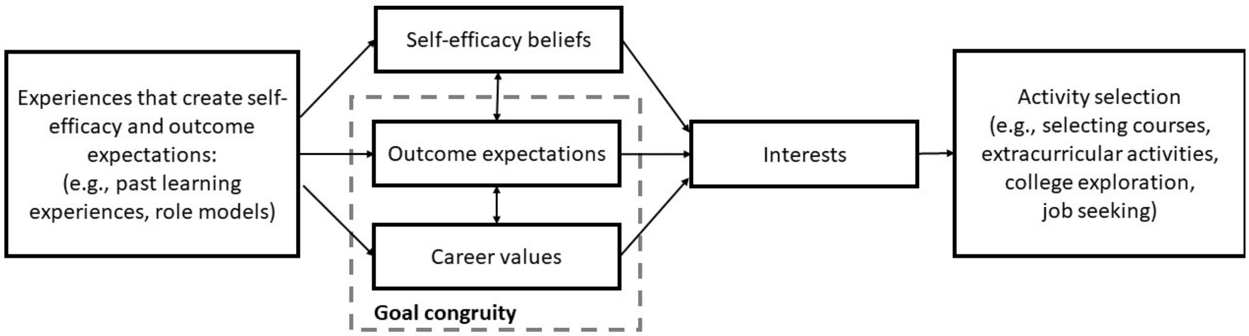


Figure 1. Expectancy-Value Theory overlaid with Goal Congruity Theory

Much of the work on goal congruity focuses on STEM in general or specific domains of science. The field of engineering has not received as much direct attention, possibly because it is even more misunderstood as only meeting individualistic values. In addition, much of the previous work on congruity theory has focused on women and college students, with limited attention paid to educational interventions to leverage goal congruity to broaden participation in engineering among students from marginalized races or ethnicities. [24]

Extensive work has focused on interventions to promote engagement of Black, low-income, and/or urban students in STEM college programs, with an emphasis on building skills essential for college success or creating a sense of belonging among historically marginalized groups of students. [25] [26] [27] The goal of this project was to explore the potential of a values intervention to make such progams even more effective in recruiting, not just retaining, student interest in STEM. Research suggests that Black students may be more likely than white students in general to value social and collaborative features of careers. [4] Low-income and first-generation students are also more like to value helping others through their chosen careers. [7] Therefore, goal congruity interventions, specifically an altruistic framing strategy, may be especially effective at engaging the interest of students who are Black, low-income, or potential first-generation college students.

Research Focus

This study specifically recruited students from our intended demographic groups by working with an organization deeply connected to a low-income, predominantly Black community in our state. By supporting this organization and connecting to students in the community, we had a more informed and connected understanding of our population of students from that community.

This research aimed to understand how framing engineering as an altruistic profession affects the development of career interests of low-SES, African American 8th – 10th grade students from an urban area in a predominantly rural Southern state. Our research examined two types of programs: a Saturday academy with a traditional STEM curriculum, called Raise the Bar (RTB), and a new summer camp program focused on the *Grand Challenges* called Tomorrow's Community Innovators (TCI). Our research questions were:

1. How did the RTB Academy and the TCI summer camp experiences influence students' interest in and self-efficacy for engineering as a career field?
2. 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?
3. How did each experience influence students' definitions or perceptions of engineering as a career field? Did different programs appear to change students' perceptions differently?

Interventions

Evaluation of a high-quality STEM educational program, Raise the Bar (RTB), in 2019 was conducted to provide comparison data to evaluate changes in students' attitudes and definitions of engineering. Two camps, called Tomorrow's Community Innovators (TCI), were designed to provide similar quality learning opportunities while framing engineering explicitly as a pro-social career path. The 2020 TCI camp was virtual due to the COVID-19 pandemic.

Our project followed the Design-Based Research Process (DBRP) shown in Figure 2**.** [28] DBRP is an iterative process that informs our knowledge of the learning sciences through the design and evaluation of curriculum, educational tools, and interventions. The iterative design process and corresponding research questions will be addressed with mixed methods data collection, specifically a concurrent triangulation design.

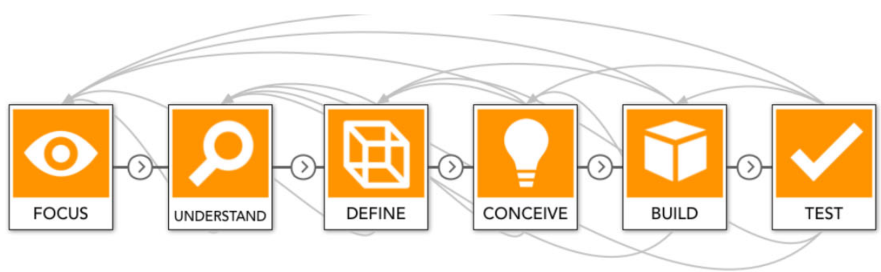


Figure 2. Iterative phases of Design-Based Research Process [27]

An important component of the Design-Based Research Process is to Focus and Understand, which includes defining the context and people of interest and reviewing existing research and practice regarding learners, contexts, and existing effective solutions. Our ***focus*** was enhancing our knowledge of students who are URM, low SES, and from an urban area in the Deep South. To enhance our ***understanding*** of these students and their context(s), we initially focused on evaluating the experiences of our target population as they engaged with a high-quality STEM educational program, Raise the Bar (RTB), which provides a traditional view of engineering. Particular attention was given to understanding students' attitudes and definitions of engineering to provide comparison data for alternative methods of framing engineering. Two camps, called Tomorrow's Community Innovators (TCI), were designed to provide similar quality learning opportunities while framing engineering explicitly as a pro-social career path. The 2020 TCI camp was virtual due to the COVID-19 pandemic. Because the camp experiences providing the altruistic framing intervention, the programs are described in depth in the sections that follow.

Raise the Bar (RTB)

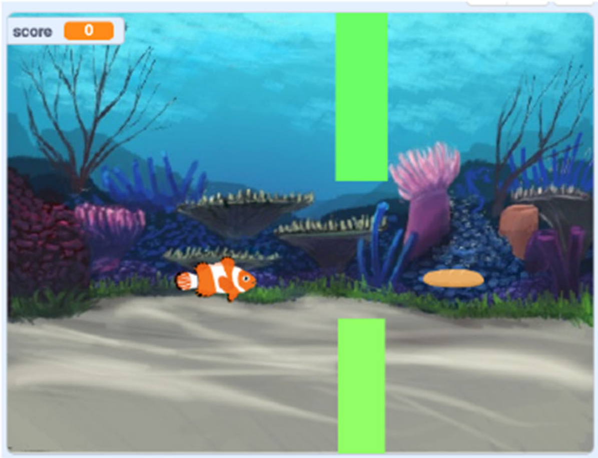
The RTB Saturday Academy is a 10-week program that consists of weekly themes around STEM domains, including mechanical engineering, aerospace engineering, biomedical research, and other engaging topics. The learning opportunities include hands-on activities, guest speakers from local universities, and museum visits such as to the local aviation museum. The program participants consist of low-income students from underrepresented groups in STEM disciplines who live in Bessemer or Birmingham, AL. There was no significant effort in this program to highlight how STEM careers met altruistic goals or helped the local community, but activities were typically engaging and well-designed.

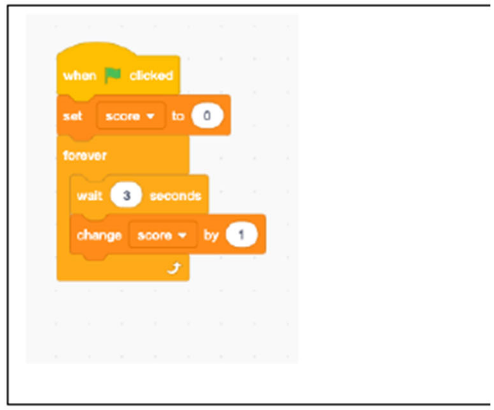
Tomorrow's Community Innovators (TCI 2019)

A a week-long summer camp that framed engineering as an altruistic endeavor and demonstrated how the field of engineering addresses important societal challenges was organized around the Grand Challenges for Engineering. The leadership team included chemical, materials, and computer engineering faculty. We titled the camp *Tomorrow's Community Innovators* to minimize the focus on engineering and highlight that we were recruiting students interested in solving problems in their community. 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.

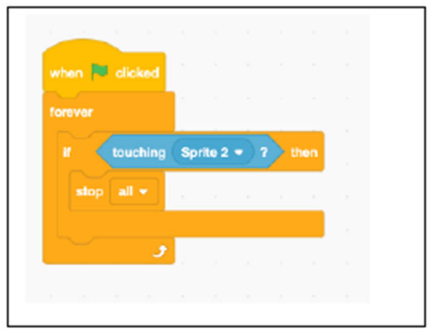
Each day of the camp had a specific engineering theme that incorporated the Grand Challenges for Engineering: providing access to clean water, making solar energy economical, and restoring urban infrastructure. Each morning focused on a hands-on laboratory activity, and each afternoon focused on using App Inventor to build apps related to the daily theme. [29] On Monday, the morning activity focused on a brainstorming session where students identified problems in the community and collectively identified the most important problems they felt society needed to solve. [30] In the afternoon, students learned the essentials of App Inventor and modified a simple game interface to learn block coding. [31]





1- Setting the variables

2- Controlling the fish with mouse.



3- Interating with obstacles using controls.

Figure 3. MIT App Inventor uses block coding

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 created a game in App Inventor to demonstrate water clean-up projects (specifically, collecting trash from the ocean).

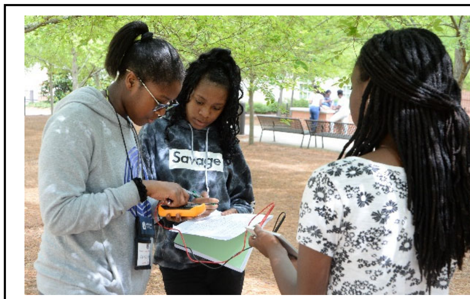


Figure 4. Students test commercial solar panels

On Wednesday, students tested commercial solar panels 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. [30] Correspondingly, in the afternoon, they built an app that tracked solar panel efficiency. Students then create a simple app to convert energy data for record-keeping purposes (e.g., converting Fahrenheit to Celsius).

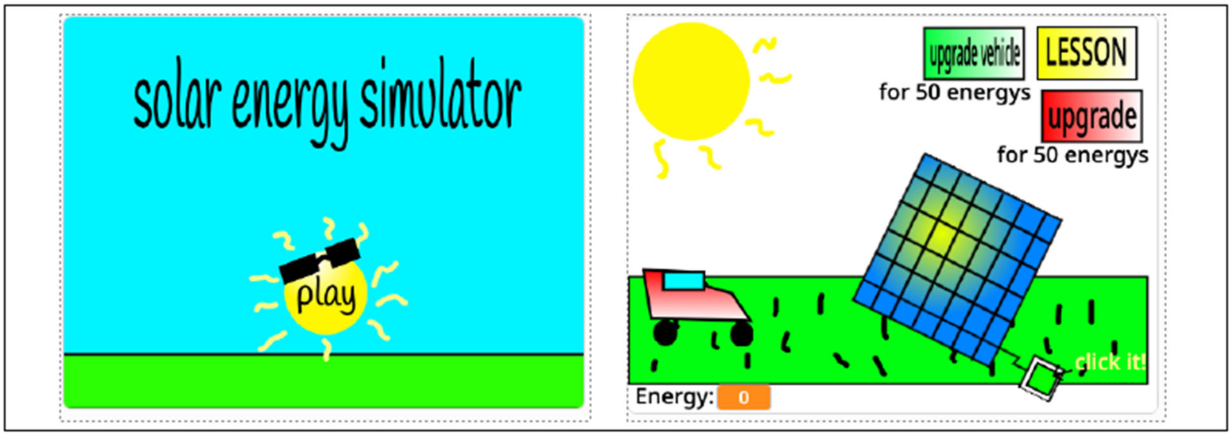


Figure 5. A simple app for students to modify to estimate optimal angles for solar energy

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. [32] In the afternoon, a graduate student in Computer and Software Engineering demonstrated a self-driving Lego EV3 robot that used color, infrared, ultrasonic, and touch sensors to detect a pre-determined path indicated by color, and to avoid obstacles. After the demonstration, students programmed the self-driving robot to avoid obstacles on a course.

Figure 6. A mentor consults with students as a city developer for the "design a city block" activity

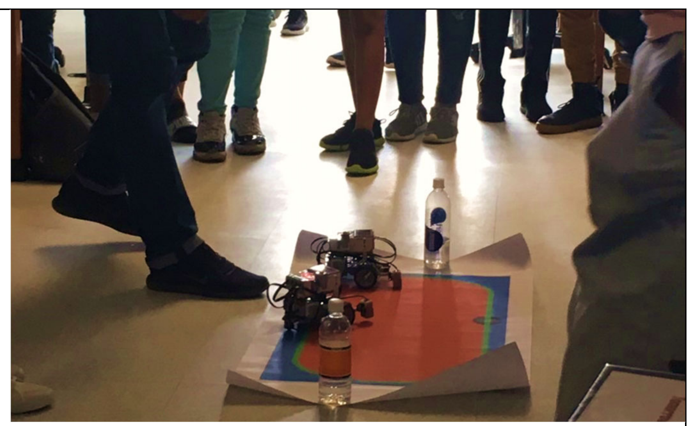


Figure 7. Students observe a self-driving robot prior to programming it

In addition to the formal content, students 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. 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. Note that the summer camp was followed up with events for students during the school year, but our data collection primarily focused on the camp.

TCI 2020

We planned a variety of activities for students 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. We used a simple website to organize all camp materials, including artifacts that we created as a group.

We wanted to frame the week as "career exploration" opportunities and provide an opportunity to collect data before students learned anything directly about engineering. Therefore, on day one we minimized our discussion of engineering and focused on practicing brainstorming skills through the Shark Tank Inventors activity. In "Shark Tank Inventor," students are given unusual household items (e.g., pacifier straps, canvas bags, chip clips) and challenged to use SCAMPER brainstorming techniques to come up with at least ten inventions using their item. The rest of the first day focused on data collection, including a series of surveys on their interest and self-efficacy for engineering and science, their career interests, and their career values. These surveys allowed us to collect this data for our research but are also commonly used to help high school students reflect on their career paths and plan for their future education. Therefore, we had students complete the surveys then discuss their results with mentors in small groups. We also provided links to career exploration websites (such as https://www.mynextmove.org/explore/ip) based on the same survey tools.

On day two, as with TCI 2019, we engaged students in TCI 2020 in 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 anxious to share ideas and think about societal challenges. The facilitator then introduced the 14 Grand Challenges for Engineering and described how they were compiled similarly to our activities that day. We pointed out the overlap of their challenges and the 14 GCE. Students were then encouraged to watch (after the camp) a series of videos that would let them explore these challenges and learn more.

Figure 8. A mentor demonstrates water testing steps

The focus of days 3 and 4 was the GCE: "Access to Clean Water". On day 3, one of our mentors (undergraduate engineering majors) led a lab activity on testing water quality with provided kits. Students tested their home water and several gathered an additional sample to test for characteristics such as pH, various types of hard metals, chlorine, lead, and bacteria. For each test, we discussed what implications it would have for water safety. For example, high pH can erode pipes and cause heavy metal contamination. Bacteria, pesticides, and lead have well known impacts on human health. Students were engaged and excited throughout the lab.

The activities for day 4 were similar to those on water filtration in TCI 2019. The water filtration lab 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 visibly cleaner water (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.

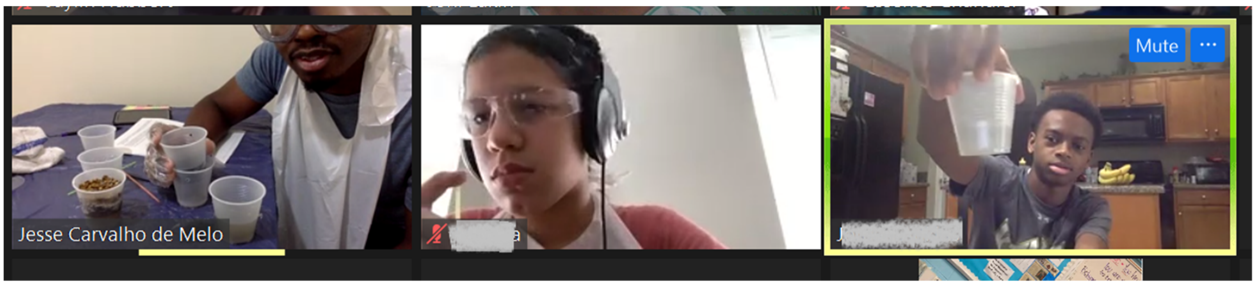


Figure 9. A mentor and two students filter their "contaminated" water

On the final day of camp, we discussed what we had learned during the week and what students enjoyed. We also checked back on our water testing results when the 48-hour bacteria contamination test was ready. One student had obtained a sample of pond water from farmland and had a clear positive result for bacteria. (Thankfully, our water samples from treated water were negative).

Limitations to Data

This research study was conducted as part of a program evaluation. While our 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 our decision to only collect as many interviews as could be managed within planned camp activities. We also had some students who 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.

Methods

The TCI program (now entering its third year) includes university-run summer camps, events for parents and students coordinated with our regional STEM Education partner, and an on-campus engineering open house event. One camp was held on campus in 2019 while the camp in 2020 was moved to a virtual format. At both TCI camps and the Saturday program, students completed pre- and post-camp interviews and surveys about their experiences and how they perceive engineers or define engineering.

Participants

All of our samples consisted of grade 8-10 and African American students. Thirteen students participated in the RTB session we evaluated formally. We observed three previous 10-week sessions while learning about the program and evolving our evaluation process. Only data from our formal evaluation are reported here. We conducted pre- and post-program interviews with seven participants and obtained complete pre and post surveys for eight students. Five students completed both the pre- and post-camp interviews.

In the TCI 2019 camp, all twenty participating students came from the low-income urban community as RTB. We interviewed 12 students at the start of camp, but only 8 completed post-camp interviews due to time constraints. Seven students provided complete pre- and post-camp surveys.

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 sites that we worked with in order to provide the camp to 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 this region. During the camp, only 2 did not return for at least 3 days of camp. Students were provided links to surveys and asked to log into zoom meetings at set times for interviews. Five completed both interviews and seven students provided complete survey data. See Table 2 for a summary of data.

Data Collection and Analysis

We used a mixed methods approach to evaluating the programs, which allowed us to triangulate findings across different analytical approaches. We used two main methods: (1) pre/post survey design and (2) emergent, qualitative discourse analysis of pre- and post-camp one-on-one interviews inductive cycles of coding using constant comparison approach. The methods are described in the sections that follow.

Table 2

Participation in programs and data collection

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

Pre- and Post-Camp Surveys. The quantitative surveys included measures of science and engineering interest and self-efficacy developed for this age group. [33] [34] Example items are provided in Table 3. The scale for each ranged from 1 (not at all true) to 3 (somewhat true) to 5 (very true). Given the limited sample, we used the Wilcoxon signed-rank test for a paired sample comparison. [35] 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. [36] Examples are included in Table 3. 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 related to creativity. We used average ratings for indididualistic and altruistic values in exploring interactions of student experiences and values.

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?
- 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 the two lead authors using the *Sort and Sift, Think and Shift* approach to discourse analysis. [37] This approach encouraged us to engage with the data and reflect on findings that emerged in an iterative process with attention to findings that were warranted by the data. We also reflected on coding schemes from previous work, using a priori codes where appropriate. [22] [13] Given the explanatory nature of this case study, we focused our analysis within each participant (threading), comparing their responses at pre- and post-camp.

Table 3

Scales and example items

Scale	**Items**
Interest in Science (n=5)	I like science. I would like to work in science someday.

Scale	Items
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.

The analysis process began with the lead authors individually 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, 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 discipline-specific implications that these co-authors identified. A visual representation of our process is shown in Figure 10.

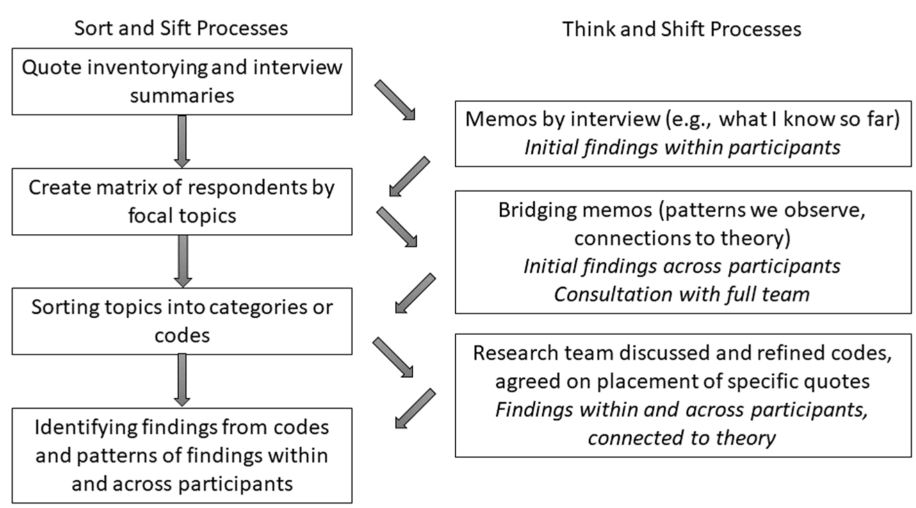


Figure 10. Sort and Sift, Think and Shift approach adapted to our research context

Results

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 was used (as implemented in JASP v0.14) to analyze the changes in students' attitudes (See Table 4). [38] We found that only one attitude scale increased significantly, engineering self-efficacy, which rose by a moderate amount (0.3 scale points or 0.48SD) but was observed to consistently increase for students at each of the three camps. Changes in engineering self-efficacy but not science self-efficacy is consistent with our expectations given the focus of the programs. We expected interest for engineering to increase, but did not observe that change. When camp type was included as an independent variable, there was no interaction by camp type.

Table 4

Wilcoxon Paired-Samples T-test

	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

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

A priori codes based on prior literature [13] [22] were not found to fit our data adequately, because many students had misconceptions (such as equating an engineer to a car mechanic) or limited definitions of engineering (such as just naming a few types of engineers). Based on our repeated reading of the data, we created two categorizations schemes based on the initial definition's accuracy and breadth as well as a scheme based on the amount of growth observed from pre- to post-camp. Our idea of a "broad and encompassing definition" was similar to Villanueva and Nadelson's conception of "21st century interdisciplinary problem-solvers with a social impact" and informed by our prior work with engineering freshmen. [22] [21] We looked for students to mention multiple elements of this definition: uses math and science, uses the engineering design process, works collaboratively, helps others or solves problems for others, and solves problems based on creativity or efficiency. Some students provided definitions including several elements of this definition. At the end of the programs, 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" technology). See Table 5 and 6.

Our second categorization was based on the amount of growth observed. While not strictly based on moving between categories for definitions, we did look for students to add more breadth to their definitions. Essentially, we sorted students from least to most growth in definitions to organize students into three clusters. See Table 6 which shows examples of each level of growth from each initial definition category (no students fit both “level 2” and “little growth”).

Table 5

Themes among definitions at pre- and post-camp

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

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

We noticed patterns in how students’ definitions of engineering changed across the different types of camps. With RTB, we noted 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. The program’s traditional focus could be effective for some, but did not overcome students’ initial conceptions of engineering. We noticed a more consistent growth in definitions for the TCI camps.[1]

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 corrected it or even discussed how they recognized it was a misperception and then offered more detailed and accurate definitions of engineering after the camp (see Toni in Table 5 for an example). Our impression is that TCI 2019 had the most transformative impact on students’ definitions, leading to much broader and modern definitions of engineering at the end of camp.

Changes in interests between 2019 and 2020 TCI camps

We asked participating students 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, we found students fell into one of four categories comparing their pre- and post-camp interests. One was “same career, new interests”, “connected engineering to existing interests”, “new interests for career”,

[1] We made efforts not to look at the data based on the program, but were somewhat able to mask the interviews in making these comparisons.

Table 6

Examples of definitions at each level of accuracy and growth

Definition pre-camp	Level of growth		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. Painting maybe? Let's see. 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 moderate growth	Nathan	"Technology…because…technology is just interesting because it functions and thinks…well it doesn't think…it functions off of a program…and I want to understand how the program works. // I think there are like engineers that work on holding devices, not devices, but cars, buses and stuff like that. And also they work on buildings.	Mechanical engineering because I like to build. It's something that you can do to help out the world. Some build, some just assist or work on something that's already been built. They find technology interesting.
	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. That's what I think it is. 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…. They have to, first they had to like come up with something. And then they have to go over it before they just started building it. … 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… They 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 moderate growth	Tiana	They identify a problem. And then they come up with ways to fix the problem and then They, you know, they have to test it out to see but work. And if it works, and there's a problem like there's a flaw with it, they would go back to the problem is fix it and if it they fix it and it's right then. The different types of engineers love computers, mechanical, Civil Engineers. So they do a lot to contribute to the world. … They design will construct different like different machinery and things to help society. … The things we need if there's a problem. They will figure out what the problem… brainstorm what the problem is.	It's…engineering is a lot of different things that contributes to the world they design, build, help society and others. So there's an. There's a lot of different types. … they come up with ideas stuff that needs to be needs to be done to the world they communicate with each other … like brainstorm ideas what nice like how to help, They build a design it, they tested, see how everything works and if it's good, then they do the same thing process over again, or that that and if it's bad. And so Choose a different way to approach it and keep testing to see whatever works for their problem say… Everybody will come with different ideas of what needs to be done depends on who's all contributing to the problem. And they would all get together and communicate their ideas to each other. And if they would come… They would see. Which sounds the best or they will test all of them and see what they can agree on sounds the best and they'll go, and they'll do that. And then if that doesn't work, they go back and go try another way
Showed greater growth	Toni	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.

and “no change”. At the first camp, just one student fell into the “no change” category. When students in RTB were asked about new interest, the answers were vague and mainly focused on specific activities at the program, rather than reflections on career possibilities.

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.” 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, Malik did not identify any potential links between engineering and his career interests.

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. This code was drawn from an interview with Jada, who, when asked if she had interest in engineering as a career, stated:

> I would like to, like halfway. [what kind?] oh, chemical engineer. … 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.

Three students in the second camp were classified in this “halfway” mentality.

Values interaction

Prior research suggests that women are more likely to have high value for altruism while men are more likely to value individualistic career outcomes. We ran Welch’s t-test for the two summer camps and found no gender differences in either altruistic or individualistic values. This may again be a function of statistical power, as when we sorted interviews by relatively high or low altruism, all of the low-altruism interviews were boys and the interviews with high-altruism scores were all girls.

Notably, students grouped by growth and quality of definitions spanned the levels of altruism. In other words, students with any values orientation seem open to perceiving engineering as a broad, collaborative career with impacts on daily life. We also found students with both high and low altruism values found new interests in engineering and grew in their understanding of the field. Overall, our hypothesis that students wih greater expressed altruistic values would be more impacted by the camp was not supported. Students with a wide variety of career values found the TCI camps engaging and gained new interests.

Discussion

Across both camps, through interviews, we found that 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. For students in the traditional STEM program, students also increased their interest in engineering, but their definitions of the field did not broaden appreciably or become more accurate if they began with misconceptions. Some found new interests, but they did not have the same type of transformative experience as a result of STEM programming without the Grand Challenges or altruistic engineering framing. The on-campus experience, which also included close relationships with undergraduate mentors from their community, seemed to be most effective for students' engaging and attitude changes.

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 and 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 because students highlighted the way engineering affects their everyday lives or how engineers want to help others. While altruistic framing may not be specifically effective for students with altruistic career values, we found the framing was broadly motivating for the students who attended our camp. One limitation is that we used a broad definition of communal or altruistic values as framing, which includes both service to others and anting to work collaboratively or having opportunities to interact with others. [37] Future research should explore the effects of framing when it is general ("help the world!"), community-centered ("help your community"), or focused on communal, team-based work ("engineers work in teams").

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