

## **Broadening the Contexts of Engineering to Broaden Participation: A Multi-method Study of an Interest-based Engineering Challenges Framework**

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I am currently a sophomore in Electrical Engineering. I grew up in Dhaka, Bangladesh; one of the most densely populated cities in the world and capital of a third world country. Growing up we had a lot of trouble with power and electricity; never enough. I wanted to solve these problems, find a way to make our system better and more efficient. So I picked electrical engineering. After coming to college, I realized the backbone of engineering was problem-solving but this message was not being clearly passed along. Many students still consider engineering to be just about math and science and don't consider it as a field that works to solve problems and make life easier and efficient, I wanted to know more about engineering education myself as I realized most of us only have a vague idea about what this vast field is.

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# **Broadening the contexts of engineering to broaden participation: A multi-method study of an interest-based engineering challenges framework (RTP)**

## Introduction

Engineering benefits from people with diverse backgrounds to push existing boundaries and stereotypical perceptions. Irrespective of the social, economic, racial, ethnic, or gender group an individual belongs to, he or she can make valuable contributions to and can benefit from engineering. Also, every individual should have an opportunity to engage in engineering in ways they find meaningful.

Our work in this paper is encouraged by these ideals related to diversity and inclusion, and a conceptual framework that supports the use of an interest-based framework for engineering challenges to broaden participation in engineering. Curricular activities based on this framework provide opportunities for students to engage in engineering by solving problems they find interesting, thus making the activities more inclusive for people with myriad interests. In this paper, we present findings from an activity based in the interest-based framework for engineering challenges. The participants of our activity were between 9-14 years of age and qualified for free or reduced lunch. We recruited them to engage in our engineering activity from a 5-week summer camp focused on positive youth development by engaging students in a number of physical (i.e., swimming, judo, and basketball) and learning (i.e., videography, financial literacy) activities.

The research questions for this study relate to how engagement in these interest-based engineering challenges: (1) influence students' perceptions of engineering; (2) appeal to students' diverse interests; and (3) meet intended learning outcomes related to the engineering design process.

## Conceptual Framework

The activities administered as part of this research study are informed by two perspectives. The first is related to the humanistic nature of engineering where engineering necessarily takes place in social contexts. The second perspective relates to the role students' interests play in their motivation and persistence as related to their learning and development. The following sections detail these perspectives.

### Humanistic engineering

The humanistic framework for engineering proposes that engineering is practiced for people, with people, and as people<sup>1</sup>. Engineers solve problems for people, they work with other engineers and professional, and bring their personal beliefs and experiences as people to their work. Also, the social sciences play an integral role in engineering and introducing engineering to P-12 students<sup>2</sup>. This humanistic nature of engineering is also important for engineering to be more appealing to students who are more interested in social pursuits<sup>3</sup>. We use this framework extensively in the design of the activities that constitute the interest-based engineering challenges framework.

### Role of students' interests in learning

Students' interests play a crucial positive role in learning and development<sup>4</sup>. Several researchers have reported the rich connections between learning activities being interesting for learners and high levels of engagement, learning, and achievement<sup>5-8</sup>. Voss and Schauble<sup>9</sup> propose that learning is achieved by the interplay of value-based "equipment" and intellectual "equipment" within an individual. The intellectual "equipment" is comprised of the learner's knowledge and beliefs, whereas the value-based equipment are solely driven by the learners' personal goals and interests. Also, Deci<sup>10</sup> proposes that learners' interests motivate them to participate in learning activities. According to Atkinson and Wickens<sup>11</sup> this motivation to engage in learning is a function of learners selecting activities that pique their interests, and also persisting and making efforts to accomplish goals they find interesting. Further, activities that cater to students' interests have also been claimed to be related with self-efficacy, educational choices, and career outcomes<sup>12-14</sup>.

### The role of interests and the humanistic nature of engineering for underrepresented populations

In addition to the humanistic nature of engineering and role of interests in learning and development, our work is also motivated by students from underrepresented populations' interest in pursuing humanistic education majors and professions. Several studies report interest as an important factor for students from underrepresented minority groups to pursue engineering and science, motivated by their humanistic aspects. Lewis and Collins<sup>15</sup> report on African American students' inclinations to pursue careers in science to contribute to their ethnic communities. Doughtie, Chang, Alston, Wakefield, & Yom<sup>16</sup> reported the higher preference of black students as compared to white students for pursuing professions with a strong social impact. Davison Avilés & Spokane<sup>17</sup> from their study on 570 students from an urban middle school, reported Hispanic students to be more interested in social and enterprising themes as compare to White students. Also, female students were more interested in artistic and social themes than male students. Thus, an interest-based framework that upholds the humanistic aspects of engineering can cater to the interests of students form underrepresented populations and motivate them to pursue engineering.

## Methodology

### Context and participants

This study is part of a larger design-based research study aimed at broadening participation in engineering by broadening the contexts in which it is practiced. As part of this study we use a variety of qualitative analysis methods to answer questions that contribute to the ongoing research and development of the project. This paper reports on an engineering activity designed using the aforementioned interest-based framework. The participants of this activity were recruited from a 5-week summer camp focused on positive youth development by engaging students in a number of physical (i.e., swimming, judo, and basketball) and learning (i.e., videography, financial literacy) activities. This study reports on 40 students who consented to be a part of the study, all of whom were between 9-14 years of age and qualified for free or reduced lunch. The students participated in an engineering activity designed and delivered by the research

team for 40 minutes per day for 9 days. We collected survey, interview, and observation data before, during, and after the activity.

Our research questions for this study are:

How does participation in interest-based engineering challenges: (1) influence students' perceptions of engineering; (2) appeal to students' diverse interests; and (3) meet intended learning outcomes related to the engineering design process.

#### The curriculum

The students participated in a 9-day curriculum where they were teamed up in groups of 3-5 and guided through the engineering design process to create a solution for an open-ended problem. The specific learning objectives for the curriculum related to the students' being able to carry out various engineering design practices related to the engineering design process. Namely, through the activity students should be able to:

- Identify a problem that could be solved using the engineering design process;
- Identify who (various stakeholders) is effected by the problem and its potential solution
- Brainstorm multiple solutions to a problem;
- Evaluate potential solutions using a pros and cons framework;
- Create a functional prototype that highlights key feature of their solution idea;
- Test and evaluate a functional prototype; and
- Communicate the final product by describing the design decisions and process.

Figure 1 depicts the prompt used to help the student teams formulate a clear, specific problem that they would solve. It also helped them identify the person or group of people the solution would be serving. Further worksheets were used to help students document their brainstorming results, the pros and cons of various solutions, feedback from other students or workshop facilitators, and a template for their final presentations.

**Problem Statement**

How can we help \_\_\_\_\_  
person/group of people

\_\_\_\_\_

do, be, or have something

\_\_\_\_\_

in some improved way (safer, more fun, easier)

**Figure 1: Problem statement prompt presented to the students**

The student teams were guided to identify a problem that they or others may have encountered at the camp they were attending. For example, students identified that it was tiring walking from station to station at the camp, or that the scooters used for one of the activities sometimes ran

over fingers or got people's long hair stuck in them, or that some people did not know how to swim making the swimming station less fun. The student teams then developed solutions using various craft materials, 3-D printers, a laser cutter, and electronics.

#### Data and analysis

Various types of data were collected to serve the goals of the larger research project. The data analyzed in this paper include: semi-structured pre/post interviews of students, a pre/post attitudes and interest survey, videotaped observations of students, results from the person-thing orientation instrument developed by Graziano, Habashi, Evangelou, & Ngambeki<sup>18</sup>, and final worksheets and artifacts created by the student teams.

The semi-structured interviews were conducted on the first day of the workshop during a period when the facilitators were forming teams, establishing norms for behavior and participation, and introducing the activity. For this paper, analysis focused on the questions, "what do you think engineering is?", "how would you explain engineering or what engineers do to someone who hasn't heard of it before?", "what kind of people become engineers?" and "do you think you would like to be an engineer?"

The person-thing orientation instrument<sup>18</sup> measures an individual's tendency to prefer person-oriented environments (e.g., social environments) or thing-oriented environments (e.g., physical environments). Research shows that a person's orientation along this scale can be a strong predictor for interest in engineering where engineers are predominantly thing-oriented<sup>19</sup>. Su, Rounds, and Armstrong<sup>20</sup> found that women were more often person-oriented whereas men were more often thing-oriented, which also plays out with respect the demographics in the engineering profession.

To answer the first research question we analyzed student interviews from before and after the engineering challenge where they were asked to share what they thought engineering was. We also observed the participants' people or thing-orientation, and its relation with their perception of engineering. For understanding students' affinities towards social scenarios and man-made objects, we employ the person-thing orientation instrument.

For the second research question, we conducted a content analysis of the prototypes the students developed during the activity. The prototypes were analyzed with respect to the contexts in which the problems the students chose to solve are situated. This would provide evidence for whether the interest-based framework for engineering challenges supports the diverse interests of the students. We then analyzed student worksheets and video observations of the students working through the activities to identify the engineering design process practices they were engaging in. This analysis supports students successfully engaging in the engineering challenges and achieving the intended learning outcomes.

## Findings and Discussions

### Research Question 1

How does an interest-based engineering challenges framework affect students' perceptions of engineering?

Based on the participants' perceptions of engineering from their interviews and the attitudes and interests survey, four categories of participant emerged: students who were highly interested in engineering (responded that they wanted to become engineers), students who were moderately interested in engineering (expressed that they were unsure, but might consider engineering), students who knew about engineering but were not interested (expressed knowledge of engineering, but were clear that they were not interested), and students who did not know about engineering (were not able to express what engineering was). In this section, we discuss four participants that are representative of these four categories to be able to show depth with respect to how individual students' perceptions and interests with respect to engineering and the interest-based activity. The takeaways for the students in the first two categories relate to the social aspect of engineering. The students in the third and the fourth categories, who either were either not interested in engineering, or were not interested enough to know what engineers do, started thinking of engineering as fun after the activity.

For participants like Frank, the activities they enjoyed outside of school correlated with the conventional perceptions of engineering as a thing-oriented pursuit. These activities include robotics, playing with Legos, and taking apart objects and putting them back together. Frank scored high on both person-orientation (5/5) and thing-orientation (4.857/5). Frank came into the camp having a conception of engineering, and was interested in pursuing engineering as a profession. He described engineers as people who "fixed things". His idea of an engineer was very thing-oriented. When asked what he thought engineering was, he responded, "engineering to me is like solving problems that have to do with building stuff or fixing things that are broken or repairing things that could be broken or damaged." After participating in the activity, Frank still desired to become an engineer in the future. However, his perception of what an engineer does was altered. When asked again about what engineers do, he maintained his earlier conception of engineers fixing things, but added that they solve problems to make the world an easier and better place. When asked again after the camp, "what is engineering to you?" he responded, "engineering to me is, I guess like the subject of solving problems in our everyday lives and creating things that will help solve those problems." When asked "what kind of people become engineers?" he responded, "people who want to solve problems I guess, and make the world a better place and easier." Thus, after being a part of our interest-based engineering challenges activity, a people-oriented attribute was added to his conception of engineering.

Another group of students showed middle to high thing-orientation, had some grasp on the concept of engineering, and thought of engineering as a possible career choice. A participant that shared these results was Kyle. After completing the survey prior to the camp he received a thing-orientation of a 5/5 and a person-orientation of a 3/5. During his interview prior to starting the camp Kyle answered the question "how would you explain engineering or what engineers do to someone who hasn't heard of it before?" by saying "the things that I describe them is like they make a bunch of stuff so that people can use them and they build very good stuff...". Kyle displayed interest in thing-oriented activities although he did not lack all social queues indicated by his person and thing-orientation scores. He also described engineering to some extent in his own words, which surpasses many students' response to this question. Kyle lacked knowledge of

the communication and collaborative work that engineers establish. Once completing the camp Kyle became aware of how collaboration could be a useful tool in the field of engineering. During an interview after the camp Kyle explained how they had to change their idea along the way. He said, “yeah we shared how to make the automatic project.” He was then asked if the consulting from the people around him was helpful for this situation, he answered yes. From his responses and our observations, we see that Kyle broadened his definition of engineering to include collaboration and group efforts.

The previous two students had a conception of engineering that they found interesting, however there was also a group of students who had a conception of what engineering is, but did not find it interesting. These students had middle-ranged scores on both thing and person-orientation, and the activities they pursued outside of school could not be related to the conventional perceptions of thing-oriented engineering like the first group. One example of such participants is Fatima. Fatima had a thing-orientation of 2.857 and a person-orientation of a 2. Although her thing-orientation is higher, both were middle-range scores. In the interview prior to the camp, Fatima was asked about the kind of hobbies she was interested in outside of school, to which she responded saying, “I like sports and I like drawing and I like playing and I like exercising.” None of these activities ascribe to the conventional perceptions of what engineers do. When asked, “what do you think engineering is?”, she responded saying “building something to help other people, like maybe someone’s car breaks down and you’re building it to help them.” After completing the camp, she was asked what surprised her about engineering to which she responded “how fun it was!”. She was then asked if she found engineering interesting, and she said, “yeah a little bit more than last time... because well it’s a lot more fun and a little complicated so I like that”. After completing the activity Fatima considered engineering to be fun, which she did not originally relate with engineering, and also considered pursuing it in the future.

All the participants we write about so far had some conception of engineering, irrespective of whether they thought it was for them or not. Our final group knew little to nothing about what engineering is and what engineers do. They scored low on both person and thing-orientation, and showed interest in very few topics. One example of this type of student was David. David scored a thing-orientation of 2/5 and a person-orientation of 1.125/5. Although his thing-orientation is higher than his person-orientation, they are both much lower than most of our other participants. In the interview prior to the camp he was asked if he had heard of engineering, to which he responded, “no”. His interests included “playing outside and playing soccer.” It is apparent that David had absolutely no knowledge or interest in engineering prior to the camp. On being asked “what is engineering to you” after the camp, David who showed little interest in any of our interview and survey questions before the activity, thought engineering was fun. With no previous knowledge of engineering, it is exciting to see that after participating in the activity, the first word that David related to engineering was fun.

The descriptions above uncover interesting preliminary results of the power of our short engineering activity which was framed on the theories of the humanistic aspects of engineering and the role that interests play in learning and development. Students who were not interested in engineering started thinking of it as fun, and the others realized the important social aspects of engineering. Thus, providing strong initial evidence of the power of our intervention for students

from the breadth of the spectrum, those who knew little to nothing about engineering to those who already knew they wanted to become engineers in the future. Also, the students successfully participated in human-centered design activities where they were solving real problems that related directly to their experiences at the camp they were a part of.

Name	Thing-orientation score (out of 5)	Person-orientation score (out of 5)
Frank	4.857	5
Kyle	5	5
Fatima	2.857	2
David	2	1.125

**Table 1.** Participants’ thing and person-orientation

### Research Question 2

How does participation in interest-based engineering challenges appeal to students’ diverse interests?

To answer this question, we first present the prototypes student teams made during the activity. The different teams of students solved problems in varied contexts. Some of these contexts are, swimming, transportation, helping people with disabilities, personal accessories, and making sports safer. Below, we provide details on the problems the students solved in these contexts to show the variety and opportunity for student teams to choose problems that most appealed to them.

Figure 2 depicts the prototype developed by **Team 03 “ship sinkers”** who were interested in helping the campers afraid of swimming to get into the pool and enjoy without necessarily having to swim. As a solution for their problem statement, they designed an underwater dome with a slide used to enter it from the top of the pool.

**Team 26 “sailor scouts”** and **team 36 “white tigers”** had similar interests. Figure 3 shows their prototypes. They brainstormed to find solutions to get from one station to another without having to walk. **Team 26** made an inflatable trampoline cart with rails that would be pulled by their team leader, while **team 36’s** cart would be driven by motors and power. **Team 26** also added rails for safety of the passengers; they also made the cart soft so it would go through narrow spaces, and made it inflatable so it could be portable.

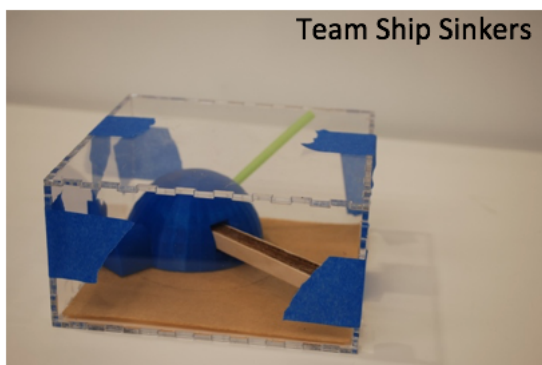
**Teams 11 and 09** as seen in figure 4, decided to help people with disabilities at the camp. Their humanistic interests to help people in need made them tackle this problem. **Team 11 “tech crew”** settles helped blind people and designed glasses to make them see by tactile senses. The glasses were designed by inspiration from virtual reality glasses. On the other hand **team 09 “majestic empire”** designed a solution to help people in wheelchairs to get to places without being pushed. They designed an electrical cart to transport them.

**Team 41 “masters of engineering”** wanted to make playing judo easy by modifying the belts that they thought were hard to tie. They brainstormed to design an auto-adjustable belt so there would be no risk of it opening and it would be easy to wear. This would also make putting belts

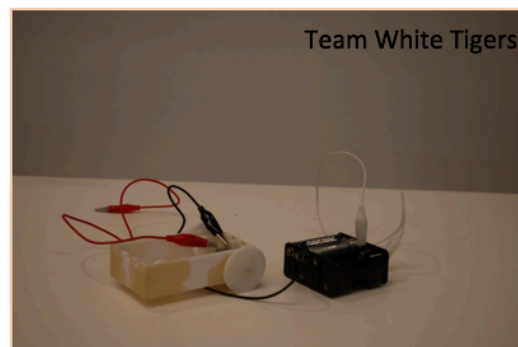


on easier. **Team 47 “awesome”** went on a completely different path compared to the other teams and decided that people asking for other people’s food was a problem. Instead of saying no to share food, they built a prototype that would store food and have a light attached to the lid; which if lit would mean the owner was ready to share food and if turned off would mean that the owner did not want to share food. **Team Galaxy Unicorns** tried to solve the problem of having less energy at the soccer stations. They devised a prototype which was a fanny pack that had a water bottle and a long straw so they could “drink while on the go”. All three prototypes can be seen in figure 5.

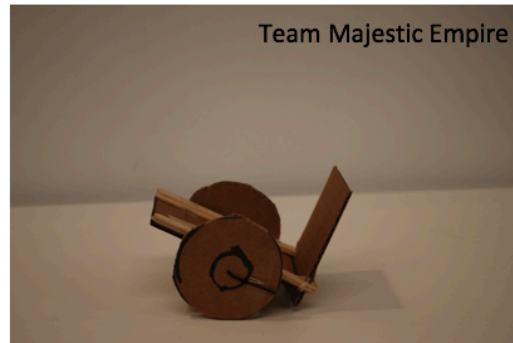
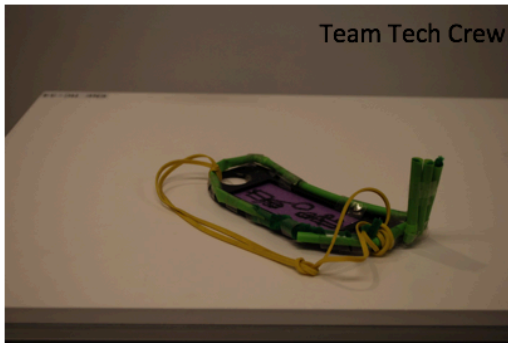
**Team 25 “cavaliers”** and **team 01 “awesome”** solved problems to make the game ‘sharbade’ safer for the students. They both designed gloves that would protect their hands while playing game. The material and structure of the gloves would be made of a hard and thick material to prevent injury. **Team 31 “fantastic four”** also made a prototype that made playing games safer. They designed a prototype to prevent injury when a basketball hits the players’ heads. They made a trampoline helmet that would bounce the ball back from the players’ heads. Their prototypes can be seen in figure 6.



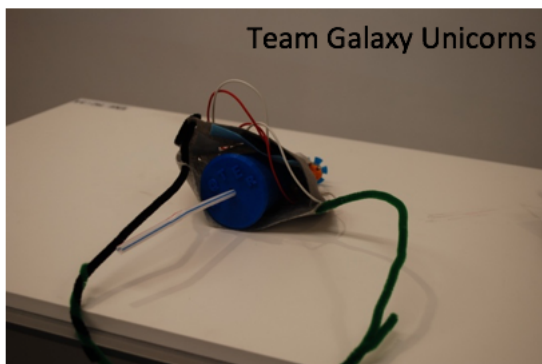
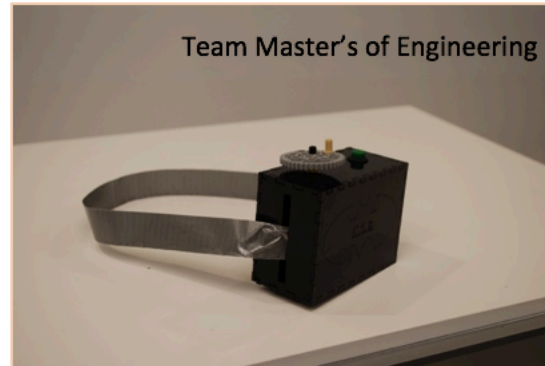
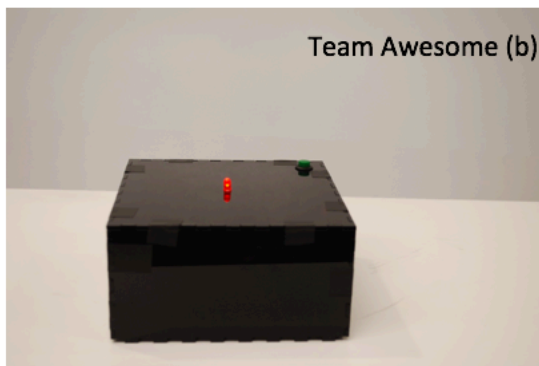
**Figure 2: Context: Swimming.** Team Ship Sinkers solved the problem of campers who are afraid of swimming, are not able of entering the pool, or enjoy the pool without having to swim.



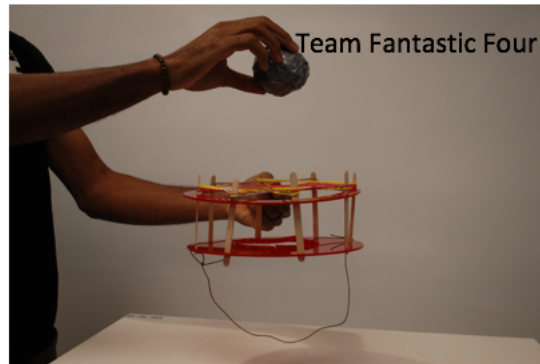
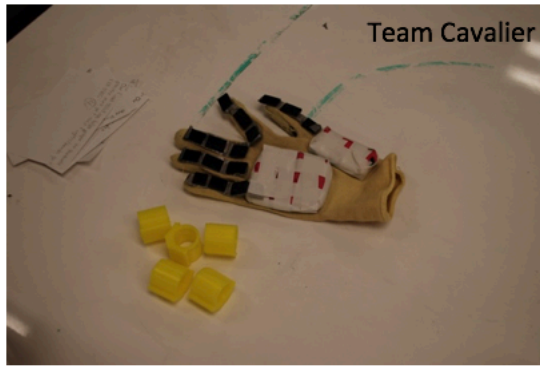
**Figure 3 (a & b): Context: Transportation.** Team Sailor Scouts solved the problem of walking and reaching the camp stations in a timely manner. Team White tigers solved the problem of not getting from one place to another quickly.



**Figure 4 (a & b): Context: Helping people with disabilities.** **Team Tech Crew** solved the problem of blind people not being able to see, by using tactile senses. **Team Majestic Empire** solved the problem of people in wheelchairs who are not able to travel without being pushed.



**Figure 5 (a,b & c): Context: Accessories.** **Team Awesome (b)** solved the problem of communicating whether they wanted to share their lunch or not. **Team Master's of Engineering** solved the problem of inconvenient judo belts that require tying. **Team Galaxy Unicorns** solved the problem of campers having less energy at soccer stations.



**Figure 6 (a,b & c): Context: Making sports safer. Team Cavalier and Team Awesome (a) solved the problem of injury to hands while playing the game ‘sharbade’. Team Fantastic Four solved the problem of injuries due to the ball hitting their head while playing basketball.**

### Research Question 3

How does participation in interest-based engineering challenges meet intended learning outcomes related to the engineering design process?

All the students engaged in the engineering design process to create solutions for their chosen problems. The intended learning outcomes included developing the skills and abilities to engage in engineering design practices such as, concept generation through brainstorming, evaluating the pros and cons of their top ideas, developing prototypes of their solution ideas, and communicating their final solutions. The following is evidence for how students working on different contexts achieved the intended learning outcomes.

The team “sailor scouts” was interested in helping campers travel between stations faster and without having to walk. They brainstormed many ideas for generating concepts to solve this problem. They drew and sketched up various versions of prototypes. After concept generation, they came up with ideas like making a hover board, a floating object, or a waterslide. They listed pros and cons for concept reduction and dismissed options considering that they may fall off hover boards, it may catch fire, they couldn’t manage floating on an object, and that using water slide would get them wet. So, they designed a prototype which was a portable, inflatable trampoline cart with rails, and would be pulled by their team leader. They made it inflatable to be portable and also after considering a team member’s comment, “what’s good about an inflatable, it could be light and not too heavy”. They also made it “semi-soft so it can go through sides”.

The final prototype was informed by their interests in their team leader pulling them on a bike, inflatable transportation, and hover boards. The rails were put on the cart to cater to their concern for safety, and the trampoline was added for the presence of a fun element. Even after deriving a problem statement based on their interests, the students could learn about engineering and the engineering design process. They successfully demonstrated to have learnt concept generation using brainstorming, concept reduction using pros and cons, and prototyping. By solving a problem involving their interests, the team created a prototype design that met the constraints of reaching stations faster, durability, portability, safety and enjoyment, while learning the intended outcomes.

Team “ship sinkers” also showed to have achieved the intended learning outcomes. Their problem statement was to help campers afraid of water to enter the swimming pool and enjoy, without necessarily having to swim. They devised a prototype to fit the constraints and solve their problem. They used ideas from their interests like Sandy Peach’s dome in SpongeBob square pants, bubbles, and their personal knowledge of how turtles have shells on their backs, to generate ideas about their prototype. After brainstorming to generate concepts and sharing ideas and discussing within the team and with the supervisors, they came up with four ideas: an underwater dome, a robotic shark, bubbles, and motors on the bottom of their feet. Then, they used constraint of what they could build using the 3D printers or laser cutter, and listed concept pros and cons to reduce their ideas. They reduced their ideas to an underwater dome using concept reduction. They realized that they could not make a robotic shark, and so combined their ideas of an underwater dome and bubbles. They finally settled with their solution of an underwater dome that would be placed inside a pool and could be accessed with a slide from the top of the pool. Throughout this process, team “ship sinkers” exhibited brainstorming for concept generation, using pros and cons and constraints for concept reduction and prototyping.

Team “Galaxy Unicorns” came up with the problem statement that campers did not feel energetic at the soccer station. They also used brainstorming for concept generation. They brainstormed within their team members and with the supervisors to come up with the ideas of “fanny pack with a straw”, “build a canopy for shade”, “low poured sprinklers for cool down” and “shoes into cleats”. They also used pros and cons and feedback from other teams for concept reduction. They finally designed their prototype to be a fanny pack with a water bottle and a long straw to drink water while playing. Their final design came with a water bottle and a mini fan to cool off the heat. Thus, we observe that this team while catering to their interests also learnt the intended outcomes which were brainstorming for concept generation, using pros and cons for concept reduction and prototyping.

## Recommendations and Conclusion

Our findings from before the activity support previous findings<sup>19,21</sup> related to thing-oriented stereotypes and perceptions of engineering. In our pre-activity surveys and interviews, students with higher recorded thing-orientation scores exhibited a stronger inclination toward engineering as expressed in their pre/post interview responses, and saw a connection between their personal interests and the nature of engineering. On the contrary, students with higher person-orientation scores exhibited a weaker inclination toward engineering. We reached the above findings using a

quantitative instrument used to measure participants' thing vs. person-orientations and the qualitative semi-structured interview, and observation data.

Analysis of the deliverables of the activity (i.e., the final prototypes and the student work), make a compelling case for the diversity of interests that can be catered to by engineering activities while still achieving the intended learning outcomes. A content analysis of pictures of the prototypes students created uncovers the different interests that engineering can appeal to. Also, analysis of student work provides empirical evidence for students engaging in engineering design challenges that are interesting to them, and successfully achieving the intended learning outcomes.

Our post-activity surveys and interviews provide constructive evidence that supports our conceptual framework behind the design of this intervention. Where students from our first two group (thing-oriented and inclined toward engineering) exhibit higher relatedness to engineering, the second group (person-oriented with weak inclinations toward engineering) show a rise in their inclination towards and the ability to relate their interests to engineering. This work has implications for diversity and inclusion initiatives within engineering, and innovation as it pushes the boundaries of contexts within engineering.

With this work, we provide evidence for the successful implementation of an interest-based framework for engineering challenges. The framework and the activity has implications for introducing engineering to students in P-12 settings, including students from populations typically underrepresented in engineering. By supporting students to create artifacts they find personally meaningful, enriching their perceptions of engineering, and facilitating their learning of engineering, we can broaden the contexts of engineering to broaden participation.

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