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Using an Embedded Researcher Approach to Explore Student Outcomes and Relationship Development during an Intensive Engineering Apprenticeship Program (RTP)

Ms. Lori Caldwell, Utah State University - Engineering Education
Dr. Angela Minichiello P.E., Utah State University

Angela Minichiello is an assistant professor in the Department of Engineering Education at Utah State University (USU) and a registered professional mechanical engineer. Her research examines issues of access, diversity, and inclusivity in engineering education. In particular, she is interested in engineering identity, problem-solving, and the intersections of online learning and alternative pathways for adult, nontraditional, and veteran undergraduates in engineering.

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Abstract

The purpose of this qualitative research study was to explore student outcomes related to engineering skills and team relationship development during a three-week intensive engineering apprenticeship program (EAP) during the summer of 2019. This EAP introduced students to engineering by placing them in teams and asking them to build and customize the design of an underwater remotely operated vehicle (U-ROV). Students were also tasked with competing with the U-ROV in a timed obstacle course at the end of the program. In this study we examined how students participated in and built intra-team working relationships within the EAP using an embedded graduate student researcher, who simultaneously functioned as a team member, and an approach informed by ethnographic research methods. Data were generated by the graduate student researcher through a reflective journaling practice, design artifacts detailing materials produced by students, as well as debriefings conducted with program mentors and directors. In accordance with an approved IRB protocol, de-identified data were segmented, coded, and then codes were recombined during multiple successive coding passes to develop themes that describe common threads relating student experiences in the program. The findings provide insights into how students (a) engaged with the outreach program tasks, (b) developed relationships with other members of their assigned teams and program mentors, (c) worked through the engineering design process, and (d) worked to achieve stated program goals and outcomes. The findings of this study are important for developing deeper understandings about how high school age students experience intensive engineering outreach programs that are designed to introduce them to real-world engineering design and development. Findings can be used to inform new approaches for developing and assessing engineering outreach programs.

Introduction

The engineering education community recognizes the lack of diversity in the field and is actively working to break down barriers that inhibit the participation of women and minoritized racial and ethnic groups in engineering education and engineering careers. Despite these ongoing efforts, engineering enrollment is below optimal levels and there continues to be an overall lack of women and students from minoritized racial and ethnic groups within engineering fields (Davis et al., 2012). For example, over the past five years, engineering degrees were earned by students from underrepresented groups at a fraction of the rate they were earned by majority students (Society of Women Engineers, 2019; Wang & Degol, 2017), suggesting that current approaches to recruit and retain young people into engineering professions are still not adequate.

Currently, one of the most widely used approaches to recruit precollege students into engineering is outreach programs conducted at K-12 schools, colleges and universities, and government (e.g., Department of Defense (DOD)) and private industry sites. Engineering outreach programs are implemented to accomplish many purposes including: a) encouraging secondary and precollege student interest in engineering careers, thereby building a pipeline of competent students and workers (Doerschuk et al., 2016; Rivoli & Ralston, 2009); b) engaging community members in engineering as a way to foster positive feelings towards an institution; and c) introducing a diverse range of young students to engineering disciplines as a way to improve diversity within the field (Jeffers Andrew T. et al., 2004). However, despite the increasing implementation of outreach programs as engineering recruitment experiences, student developmental outcomes that come as a result of participation in outreach programs are not well understood. Outreach assessment methods commonly rely on self-reported measures through immediate and/or delayed student surveys, short participant interviews, teacher and mentor interviews and surveys, and program enrollment data (Bogue, 2005; Bogue et al., 2013; Bottomley, 2002). While these assessment methods likely provide sufficient quantitative data to justify an outreach program to financial stakeholders, more in-depth understanding of student outcomes that result from participation in outreach programs is needed to inform the design, development, and assessment of engineering outreach programs that are culturally transformative.

Purpose

Considering the need for more effective and authentic assessment of student outreach programs, the purpose of this research study was to explore student outcomes related to engineering and teaming skills development during an intensive Engineering Apprenticeship Program (EAP) for high school students. The voluntary EAP was offered at a U.S. military base for three weeks in the summer of 2019. The primary goal of the program was to increase student interest in DOD civilian engineering careers by engaging high school students in authentic engineering activities and exposing them to discipline specific mentors. This study used an "embedded" graduate student researcher, who functioned as a high school EAP team member, to participate in the activities with the students and generate qualitative data based on these experiences to examine the engineering skill and intra-personal outcomes of high school students enrolled in the program.

Research Questions

We guided our study by the following two research questions (RQ):

1. How do students participating in an intensive engineering apprenticeship program develop and/or exhibit their engineering skills?
2. In what ways do student participants develop and /or exhibit interpersonal relationships with their team members?

Theoretical Framework

The EAP that served as the context for this study was designed to motivate students to pursue engineering careers, as well as develop professional skills related to teaming and intra-personal working relationships in an engineering environment. In our conceptual framework, three interrelated concepts are thought to affect student outcomes in the EAP: the learning environment, student motivation, and team dynamics (Figure 1). In the following section, we describe our conceptual frame as it relates to student participation in engineering outreach activities using Lave and Wenger's (1991) theory of situated learning.

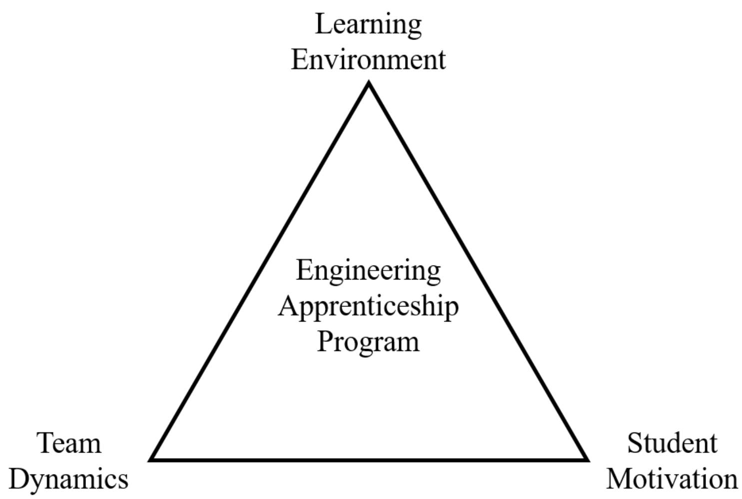

Figure 1. Conceptual framework concepts.

Learning Environment

Engineering outreach activities relate the learning material to the real-world environment by demonstrating and interacting with engineering applications in practice. Several dimensions have been proposed to describe the STEM learning environment: personal growth, relationship, and system maintenance and change (Moos, 1980). The personal growth dimension refers to opportunities afforded to students to develop personally through engaging in engineering activities. The relationship dimension refers the extent that students are involved in the physical and social setting. The system maintenance and change dimension refers to the extent in which the environment is orderly, is clear in student expectations, and responds to change. When all three dimensions are present in an engineering outreach program, both student skill development in academic and social contexts are fulfilled (Lave & Wenger, 1991; Moos, 1980).

Student Motivation
The primary goal of engineering outreach programs is to intrinsically motivate students to engage in authentic engineering activities. In turn, it is thought that, through engagement in engineering activities, middle school and pre-college high school students will gain interest and excitement about pursuing STEM-related careers. Motivation research suggests that intrinsic motivation requires that three needs are met within the learning environment: autonomy, competence, and relatedness (Vennix et al., 2018). The need for autonomy refers to the extent that students feel willing to engage in the engineering outreach activity (Ratelle & Duchesne, 2014). The need for competence refers to the degree that students understand the concepts and have the appropriate skills to succeed (Deci & Ryan, 2000). The need for relatedness refers to students' desire to establish meaningful relationships with other student participants and program mentors(Baumeister & Leary, 1995). When these needs are met within the learning environment, students are more intrinsically motivated and thus are likely to experience an increase in appreciation for and interest in engineering.

Team Dynamics
Engineers are social workers who operate in teams with various skill levels and areas of expertise to solve complex, ill-defined problems. Engineering educators value group projects and teamwork-based activities for a number of reasons including needs to fulfill ABET standards and to prepare students to work in industry (Borrego et al., 2013). Successful team-based instruction employs cooperative learning and includes four aspects: positive interdependence, individual accountability, face-to-face interaction, and self-assessment of team functioning (Woods et al., 2000). Positive interdependence refers to all team members being responsible for the project as a group so that success is achieved when all members work towards the final goal. Individual accountability refers to the idea that each student is responsible for a portion of the work that will be used by all team members. Face-to-face interactions refer to the amount of time spent working or meeting in person. Self-assessment of team functioning refers to the extent that each team member feels that the team as a whole is working towards meeting their common objective. When these aspects are met, students are more likely to feel fulfilled in their teamwork and a positive experience participating in the engineering outreach program.

Researchers' Positionality
The two researchers, a graduate student researcher and an assistant professor in engineering education, approached this study for the purpose of uncovering new insights about how high school students act and interact within an intensive engineering outreach environment. Both are interested and involved in the development of new outreach tools and experiences that are effective for diverse student recruitment in engineering. The graduate student researcher, who holds a bachelor's and master's degree in biological engineering and is currently pursuing a doctoral degree in engineering education, has substantial experience mentoring high school students and supporting science and engineering outreach events. Because she is older than high school age (age 25) and a trained engineer, she recognized the need to bracket her age-related biases and substantial engineering knowledge as she participated as an EAP team member and conducted data analysis. Additionally, the engineering education researcher, who is also a registered professional mechanical engineer, recognized that her experiences as a practicing engineer might bias her interpretations of student experiences during EAP activities and worked to mitigate their effects during the data analysis.

Methods

EAP Context
The EAP, which has been run during summers since 2012, was administered by four engineering student mentors and three program directors in the summer of 2019. Students were randomly assigned to one of four teams with five members per team. The students attending the EAP were typically from the local area, living within 40 miles of the program site. Students were high school students, entering grades 9 – 12, and had expressed interest in engineering prior to attending via their application essays. Program space was limited, and students were required to apply to participate three months prior to the start date by submitting an application and three essays describing their interest in engineering and their academic goals. As part of the apprenticeship program, students were compensated for their time and effort (approximately $10/hour, four hours per day). Compensation empowers the student participants in multiple ways, perhaps the most important being that the students become contractors employed by the United States military and are true apprentices to practicing engineers. In addition, student compensation encouraged participation from students who may come from families in disadvantaged socio-economic situations by covering the potential cost of not working.

Over the course of the three-week EAP, students were tasked with designing an underwater remote operated vehicle (U-ROV) that would be used in a final timed competition focused on student driving skill, U-ROV agility, and a team engineering notebook. The primary goals of the EAP are to (1) recreate an authentic engineering experience that closely mimics the real-world DOD engineering environment and (2) increase student interest in pursuing engineering. In an effort to recreate an authentic engineering environment, students were provided minimal information about the final competition tasks during the first two weeks. Three lectures, approximately forty minutes each, were given during the first two weeks to introduce the concepts of buoyancy, the engineering design process, and computer programming. Program mentors were available to aid students in the design process throughout the EAP, but teams were encouraged to develop unique designs and test solutions prior to asking for assistance. Help was provided only when students requested it. This hands-off approach by mentors enables students to develop independent problem-solving skills.

Research Design
In order to explore how students develop skills and relationships in an intensive outreach program, this study employed an embedded graduate student researcher as a team member in one of the four teams participating in the EAP. Students participating in the EAP did not know the identity of the embedded researcher. The embedded researcher participated fully in all EAP activities with her assigned team throughout the program, while trying not to unduly influence the students' team development or design process. This research study was approved by our university's Institutional Review Board.

Data Collection
At the start of the EAP, the embedded graduate student researcher was randomly assigned to a design team along with the other high school students and participated fully in all activities just as if she was a high school participant. At the end of each daily EAP session, she generated qualitative data in the form of (a) handwritten field notes describing her experiences and the

experiences of other student she witnessed that day, (b) digital images of student work, and (c) notes from program mentor debriefs for that day. All data was recorded by hand in a research journal immediately after the other EAP students left the program site to ensure that students remained unaware of her identity as an embedded participant-researcher. Specifically, no identifiable information was recorded; pseudonyms were used in the field notes to aid in describing the interactions and experiences of individual students. Gendered pronouns, based on how students presented themselves during the program (and not necessarily how they self-identified), were used to describe events wherein gender appeared to be relevant.

Written field notes included details about the structure of the EAP, daily interactions of group members, and the iterative design process activities that students engaged in to develop a U-ROV. Since we could not record field notes in the moment, all field notes and student quotes were written down immediately following the end of the day's activities. Program mentor debriefs were conducted daily after the students in the program had gone home and notes were captured during the meeting. A final debrief was conducted with the program and site directors at the end of the program. Debriefings were semi-structured around three main topics: (a) student design progress, (b) student team development, and (c) overall program observations.

Data Analysis

After the conclusion of the EAP, de-identified data were segmented, coded using in vivo codes (Saldaña, 2016), and then recombined during multiple successive coding passes to develop themes that connected common threads describing student outcomes as related to the research questions. In the first cycle of coding, we identified descriptive information about student activities and organized the data into four types: field notes, artifacts, notes from program mentor debriefings, and notes from program director debriefings. These categories were separated and organized chronologically. First round in vivo coding was used to identify student actions and activities. Then we included analytic memos with comments and reflections in each category.

For the second cycle of coding, the different data types were combined to show the chronological progression of the EAP from multiple perspectives. In this cycle we combined common codes and added analytic memos with additional comments and reflections on the combined data set. We developed a codebook with definitions and examples for each code that was used to identify themes relevant to student outcomes and relationship development throughout the student experience in the EAP.

Ensuring Quality

Throughout this study, we implemented several approaches for ensuring research quality, including triangulation using multiple forms of data, peer debriefings, and extensive researcher time in the field (Creswell, 2014). Four types of qualitative data were collected and analyzed to develop resultant themes: researcher field notes, student artifacts, notes from program mentor debriefings, and notes from program director debriefings. Regular peer debriefings between the graduate student researcher and the engineering education researcher were conducted throughout the analysis process to enhance the authenticity and transferability of the findings. We further engaged in a debriefing session with the EAP program directors where we presented themes and solicited their insights on our emerging findings. Last, the graduate student researcher spent three weeks, four hours per day (60 hours total) embedded within the EAP in order to gain deeper understandings student experiences in the program.

Limitations

The study is limited in at least two ways. First, the study's setting – a DOD sponsored EAP – and the intensity of the EAP environment are likely quite different from that of other high school engineering outreach programs. Therefore, care should be taken in attempting to generalize findings to all engineering outreach programs. Second, some may consider our focus on researcher interpretation (and lack of direct student data) as a limitation to this study. However, we believe that our approach, which was informed by ethnographic methods and afforded an insider perspective to student skill development and relationship building as they occurred within the teams, provided unique and compelling insights that could not be otherwise gained using more conventional research approaches.

Findings and Discussion

In this section we describe the findings resulting from this study. We identified four distinct themes: (1) developing engineering design skills, (2) teaming skills development, (3) changing levels of interest in engineering, and (4) reinforcing engineering stereotypes. The first and second themes were used to develop answers to our two research questions respectively. The third theme relates to the stated goals of the EAP and the fourth theme applies to the situated context and intensive nature of the EAP. The in vivo codes that combined to form resultant themes are shown in Table 1.

Table 1. Identified themes, codes, code descriptions and code instances.

Code	Definition	Instances
Theme 1 – Developing Engineering Design Skills		
Designing	Brainstorming modifications for the U-ROV, occurred individually and as a team	47
Testing and evaluating results	Performing component or system tests on their U-ROV to check operation or look for the source of an error	45
Building	Physically constructing a new part or altering an existing part on a U-ROV; using tools	39
Practicing U-ROV driving	Testing the U-ROV in the small practice pool or competition tank; drivers typically rotated	21
Researching	Using a computer to find examples of designs used in previous years or technical specifications of a U-ROV component	11
Theme 2 – Teaming Skills Development		
Mocking as bonding	Verbally teasing or making fun of a student or group of students from a different team; typically used as a team bonding activity during the first week of the EAP	14
Unhelpful team member	Not participating or helping in teams, often distracting the team members who are working	7

Instigating conflict	Initiating physical conflicts between U-ROVs in the test pool or competition tank; starting large arguments between teams over small problems	3
Whispering to exclude	Whispering and emphatically staring or pointing at another student	2
Theme 3– Changing Levels of Interest in Engineering		
Excited about using engineering tools	Expressing physical (clapping, grinning, jumping up and down) or verbal excitement about using a tool to build (e.g. soldering iron, digital multimeter)	9
Talking about the EAP	Talking to each other about their experience within the EAP; positive or negative	6
Discussing plans for future	Talking about plans for college or their next year of high school; potential class schedules, electives, majors, club involvement	5
Comparing self to practicing engineer	Verbally comparing self to a practicing engineer they know personally or through the EAP	2
Theme 4 – Reinforcing Engineering Stereotypes		
Generalizing all students in the program	Talking about students (typically negative) in terms that grouped all students together	9
Negative talk about engineering field	Saying something that depicts the field of engineering in a discouraging or destructive way	7
Gender specific comment	Saying something that only applies to a single gender	4
Deficit focused comment	Saying something about a student or group of students that focuses on a lack of positive traits or on a negative trait	2

Theme 1: Collaborative Design Work (RQ1)
This theme, and the codes used to help define it, was used to inform our answer for our first research question on students developing and/or exhibiting engineering skills. We observed students in all phases of the engineering design process and specifically noted their improved skills in designing, testing, and evaluating results from their vehicles.

Designing. In this EAP students are required to work in teams to design one final product to be used in the final competition. This structure compels students to collaborate during all stages of the design process and was used to develop answers for our first research question. One example of this was noted on the third day of the EAP following the first deep tank test: “Students were left with ninety minutes to work on the design of their U-ROV without physically building anything. … Teams made drawings in their engineering notebooks and browsed the store items available for purchase to modify their designs.” For the team with an embedded researcher, this led students to consider what they might be tasked with in the final competition and they decided to add a probe, additional thrusters, more flotation, ballast, and an underwater video camera to the U-ROV (Figure 2).

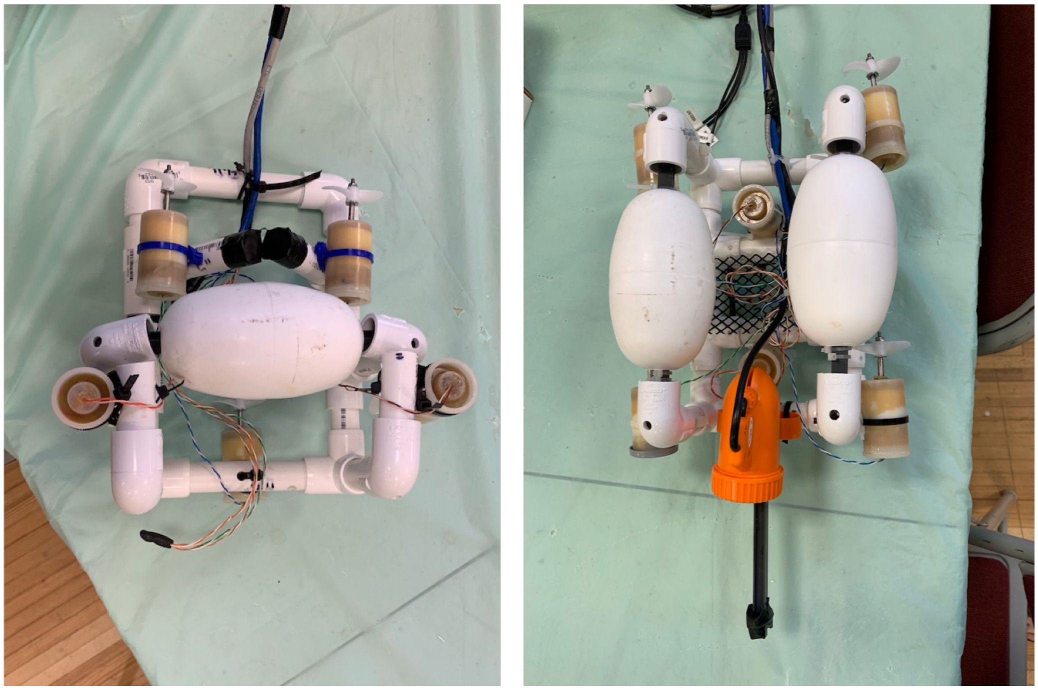

Figure 2. (Left) Initial U-ROV design used in the first deep tank test. (Right) U-ROV design modified with additional thrusters and flotation, a different overall shape, and an underwater video camera.

Testing and evaluating results. The U-ROVs are complex vehicles with many dependent systems that are further complicated by being waterproofed by hand with seals and wax. Students became adept at trouble-shooting their vehicles by changing one variable at a time then retesting to find the error source. During the final day of week two, the team with an embedded researcher worked to find an error in a motor: "The Green2 motor was acting up and wouldn't operate in reverse and only operated in the forward direction sometimes. Ben ran a couple different code patches and determined that it wasn't a software issue. … Emma found the issue in the waterproofed motor connection."

Building. Most students participating in the EAP seemed comfortable reading the basic building manual provided on day one and were eager to get started. Safety lessons were provided for all power tools and soldering irons. After completing the initial build, teams were asked to modify their vehicles to test picking up objects in the small pool. "[We] had a droopy spear that couldn't hang on to the picked-up objects, so we added a hook by attaching the blunt half of a plastic knife to the tip [of the spear] using electrical tape. Another team fixed the same problem by stuffing cut pieces of foam pool noodle inside the PVC pipe spear." In general, teams worked independently and seemed to make an effort to come up with unique solutions to problems.

Practicing U-ROV driving. The final competition required teams to operate their U-ROV at a depth of twenty feet to pick up objects one by one and place them in the designated zone. Each member of the team was required to drive the vehicle for an equal amount of time. Because of this, teams spent a lot of time practicing driving skills in the small test pool and the competition tank with varying levels of success. Week one: "We finished the U-ROV before testing it in the three-foot-deep pool outside, it worked! Our vehicle can pick up a thick rope ring and a weighted whiffle ball." Week three: "The deep tank test didn't go super well for any of the teams. We struggled navigating at the bottom [of the tank] and couldn't pick up any of the objects that had tilted to the side because our U-ROV has small feet on the bottom so the motors don't hit the ground."

Researching. When making design decisions there was a tendency to discuss modifications in an unhelpful, circular manner that led to disagreements: "Ben suggested using four thrusters on the vehicle instead of three and placing them all in the same direction, like thrusters on a satellite. [Image of satellite thrusters pulled up on team computer.] Will didn't seem to agree with that idea or think it would work. Ben brought it up four separate times." This brainstorming session, where two team members were disagreeing and neither were willing to compromise, was concluded by another team member, Alex, saying: "I think there's real value in picking someone's idea and running with it. I mean, if it doesn't work, we can always just change things or something." This type of intra-team dynamics was observed often with different students taking on the role of peacekeeper in an effort to work together as a team.

Theme 2: Teaming Skills Development (RQ 2)

One of the main goals of this EAP is to introduce students to the real-world engineering environment they would be a part of should they choose to eventually work at the program host site. To be successful in this EAP, students had to work collaboratively with others. This theme, and the codes used to develop it, informed our answers to our second research question on developing and/or exhibiting interpersonal relationships with team members. The following codes describe different ways that team relationships were developed and were used to help construct an answer to our second research question.

Mocking as bonding. One way we observed students interacting in the face of competition was strengthening their own team relationships by ostracizing or taunting members of other teams. This was observed primarily in the first week of the EAP between the male members of teams. One example of this occurred on the second day between two members of the team with an embedded researcher and a student from another team: "Ben stopped teasing Will today and instead made fun of a boy on a different team. Will joined in and seemed excited and relieved to be in on an inside joke." This semi-hurtful teasing was used as a bonding experience between Ben and Will, who had been the brunt of Ben's jokes during the first day. There were also instances when team members teased each other in a more good-natured way: "Ben and Alex made semi-inappropriate jokes with and about each other and laughed uproariously."

Unhelpful team member. There are many tasks to manage when operating the U-ROVs in the small pool or the deep tank. Since the vehicles are not operated wirelessly, one member normally managed the bulky wire tether, one monitored the control board and battery, one drove while watching the underwater video feed, one observed the vehicle from above to help orient the driver within the tank, and one recorded data in the engineering notebook. Even though this process required all the team members to help, there were instances on all teams when one or more students did not participate. At the beginning of the second week during a deep tank test: "Will drove the U-ROV and managed the tether (not an easy task to do both at once), Ben laid down, Emma watched for the first half and took notes for the second half, Alex watched and checked battery voltage every fifteen minutes, and I took notes the first half and spotted the second half."

Instigating conflict. Another way we observed students react under the pressures of ill-defined competition was resorting to underhanded tactics. In this EAP each team was provided a budget of program money to be spent on supplies to build their U-ROV. There were opportunities approximately three times per week to earn extra money through quizzes or by winning a smaller challenge session. There was enough program money for teams to purchase all necessary components (PVC pipe, tape, zip ties, and an underwater video feed), though teams were cautioned to use their funds wisely and save a portion for repairs or design modifications that would be needed on the final week. One program mentor described an incident that took place on Tuesday of the third and final week of the program: "[They're] a group of little thieves. They've been slowly collecting things from other groups and from my own supply boxes. I found it all when I was double checking their budget sheets." This type of underhanded tactic to hopefully have an advantage over the other teams in the final competition was also observed on other teams and sometimes in more physical ways: "Ben spent the most time driving the U-ROV [in the small practice pool] and instigated multiple confrontations with other teams. Confrontation might not be right because it wasn't hostile, but more of a destructive play. One student in another group was particularly upset with Ben and asked him multiple times to stop." The confrontations typically took the form of using his own U-ROV to crash into other teams with the intention of tangling the wiring or knocking small pieces off of the other U-ROV.

Whispering to exclude. This form of team bonding was observed during lectures provided by the program mentors, not while actively working on the U-ROVs. During the first week, a mentor lectured on the engineering design process and gave a brief history of engineering innovations. When a student raised their hand to answer a question and was incorrect, "some students quietly chuckled … two girls whispered to each other and giggled while glancing at the incorrect student."

Theme 3: Changing Levels of Interest in Engineering

A broad goal of every engineering outreach program is to increase student awareness and interest in pursuing an engineering career and is a primary goal of this EAP. This theme, and the codes used to develop it, was used to help understand how the program functioned in terms of student engagement and interest.

Discussing plans for the future. This code was characterized by students verbally expressing an increased or decreased level of interest in pursuing engineering to another student, the embedded researcher, or a program mentor. Since a primary goal of the EAP, and other outreach programs, is to encourage students to pursue engineering in the future, we found this particularly insightful. During a debrief in the second week a program mentor shared: "Sophia told me that she is rethinking her STEM focus from mechanical or hands-on engineering to more biological or environmental. It's not that she dislikes [this EAP], but she's learned more about her interests. She said, 'It's not for me.'" This sentiment was shared by other students whose parents had encouraged them to apply for the EAP.

Talking about the EAP. In an informal discussion, the embedded graduate researcher spoke to the other female student on her team who expressed: “I didn’t really know if I’d like [this EAP] because my friend ended up in a different session, but I learned how to solder and that’s cool. I’m thinking about maybe mechanical engineering, but I still have a couple years [of high school] before I have to decide.”

Excited about using engineering tools. Most students had used the relatively simple power tools provided for building (e.g. electric drill, electric sander) but it seemed few had used tools that were more discipline specific like a digital multimeter, microcontroller, or soldering iron. “Students seemed excited to start soldering and working the code for the Raspberry Pi.”

Comparing self to practicing engineer. At the conclusion of the EAP, all students are seated in a large circle with the program site director who asks for feedback on the experience and some insight into how they’re feeling about engineering. Student responses in this setting were public and required, and typically kept short. Though some students didn’t seem fully comfortable sharing their feelings, Alex shared: “I’m interested in STEM and I like it even more after coming to [this EAP]. I’m thinking maybe electrical engineering, partly because my sister is in chemical and I don’t want to be compared to her forever.” There was a diverse mix of student feelings shared towards the program and towards engineering.

Theme 4: Reinforcing Engineering Stereotypes

This EAP differs from others in that it is trying to recreate a highly specific engineering context – DOD civilian engineering. This focus is reflected in the program organization as students are given an ill-defined problem with little information about the final tasks to be performed. The program directors feel that this environment provides an authentic engineering experience, since practicing engineers must often uncover hidden and or emerging constraints as they design systems, products, and processes. While this environment may be more representative of an authentic engineering practice, our data shows that it introduced a source of anxiety for the students who are competing against other teams and affected the way the students interacted.

Generalizing all students in the program. The program directors who run this project have been doing so for many years and tended to discuss the current students in terms of all students who had attended previously. Some of this generalization seemed to be in an effort to compare their teaching methods and gauge student progress in terms of previous years. After helping two separate teams fix the same issue with their microcontroller during the second week, one program director shared: “Students never understand why something doesn’t work the second time if it worked the first. They rarely change just one variable at a time so they can’t tell what’s really going wrong.”

Negative talk about engineering field. Though a stated goal of this EAP is to encourage high school students to pursue engineering careers in the future, we observed multiple instances where use of engineering stereotypes may have unintentionally discouraged students, especially students who are currently underrepresented in STEM potentially because of these stereotypes, from doing so. One example of this took place on the third day of the program after the students’ first U-ROV test in the twenty-foot-deep test tank where the final competition would be held. None of the U-ROVs performed at depth and a program mentor gave a short talk about the design process, stressing that failures of this kind, that happen early in the design process, are good because they give engineers a chance to redesign and retest in time to meet their goal. While encouraging the students to not be afraid of making large changes because they felt attached to their design, he said, “This is engineering. In engineering we’re cold and calculated, so if you wanted something warm and fuzzy, you should go into French poetry.” This comment led to some shared anxious looks between students.

Another example of this theme occurred during an interview with a program site director. We discussed the difficulties that students have forming team relationships, especially when there are one or two students who seem to be outsiders within their team: “One group has a couple of uncomfortable students; it’s always interesting to see how the students handle it. In engineering, this is what you deal with. People are just all over the map, some everyday normal folks, and some, ‘Holy crap, shit’s gonna get weird.’” This attitude towards personality differences occurring within engineering was expressed in other circumstances as well, sometimes in front of the student participants.

Gender specific comment. One example we feel is worth sharing was brought up in the same program site director interview described above. This comment was said in reference to the possibility that some of the female students were not as interested in the design aspects of the EAP as their male counterparts. “There’s a nurture aspect of bioengineering that appeals to women. There’s a direct line to a human being.” While saying this, his female colleague, the program director, nodded her agreement that maybe girls were more suited to more nurturing engineering disciplines.

Deficit focused comment. During a debrief with program mentors during week two of the EAP, one said, “[This team] is way behind the others. They don’t have the skillset or the teamwork, sometimes it’s just luck of the draw. Some kids have a little better understanding of mechanics and electronics and some will never get it.” This focus on the aspects of the program that students are not yet performing well in might skew the program mentor’s overall perception of the team in future student interactions or research debriefs.

Conclusions

The findings of this research suggest three specific areas that merit thoughtful consideration for those involved with developing and implementing engineering outreach programs for high school aged students. These areas are: (a) the level that the program attempts to replicate an authentic engineering experience and its effects on student engagement and interest, (b) the level of program mentor involvement required to build student competency and intrinsic motivation yet still encourage student design freedom, and (c) required training provided to program mentors to more fully encourage women and minoritized racial and ethnic groups to pursue engineering education and careers.

Our study showed that students benefitted from participating in the EAP, in part because it was designed to closely mirror the actual engineering environment of the program site. The program directors made every effort to ensure that students had an authentic engineering experience: “We try to be an honest representation of what engineering is and make sure they understand there are fun and serious aspects of what we do. … It's a pretty good representation of being an engineer, especially [here]." Though we found authentic engineering experiences to be important for engineering skill development, it's important to note that students in this situation exhibited high amounts of anxiety. Care should be taken to maintain the outreach program goal to encourage students to pursue engineering while replicating this authentic environment.

In most engineering outreach programs, the program mentors and directors spend a substantial amount of time interacting with student participants. Our study showed that students developed and used engineering design skills with a hands-off mentor approach that was designed to encourage student exploration. Allowing students to build, test, fail, and redesign encouraged close teamwork and full use of the engineering design cycle. Another critical aspect of program mentorship is that mentors serve as role models for what practicing engineers look like. Our study showed that mentors, and the students themselves, can unintentionally reinforce negative engineering stereotypes. In light of this and considering the push for increased minority student participation in engineering, feel that students participating in intensive engineering outreach programs should receive diversity and inclusivity training. Additionally, we believe that mentors should act as role models and hold themselves to high standards of professional conduct while striving to minimize expressions of stereotypes in engineering. This will require a high level of self-awareness on the part of program role models, but we feel the efforts to reduce imagined or real social barriers in engineering are worth the effort.

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