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Outreach Program Evaluation through the Lens of Engineering Identity Development (Evaluation)

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Introduction

Recent efforts in public policy and higher education have sought to meet the growing demand for a workforce skilled in Science, Technology, Engineering, and Mathematics (STEM). The United States Bureau of Labor Statistics has reported the growth of STEM jobs is expected to grow twice that of all other occupations. This amounts to approximately 8.0% growth by 2029 [1]. As Byars-Winston points out [2], U.S. policy has attempted to improve the lack of qualified workers to fill the increased demand for STEM occupations. Similarly, the evolving STEM field is increasingly in need of a diverse workforce to solve complex problems [3]. Equity in the classroom has been used as a method for achieving diversity in the STEM workforce. Linda Nilson in *Teaching at its Best: A Research-Based Resource for College Instructors* points to the purpose of pursuing equity in the classroom: "Equity is really about increasing and broadening student participation, not only in discussion but in higher education and beyond" [4].

Interventions to improve participation and retention from underrepresented populations in STEM fields include scholarship programs [5], mentoring programs [5], and culturally responsive pedagogy [4]. Another intervention method for improving interest and persistence in STEM is outreach [3]. Outreach—specifically, STEM Outreach—is an informal, typically hands-on project-based learning exercise performed by a STEM or STEM education expert to increase knowledge of and interest in STEM disciplines [5], [6]. Research has illustrated the positive effects an outreach program can have on students, including a bolstered self-efficacy [6] and improved knowledge of STEM disciplines [3].

Although outreach programs have been used at all levels of pre-college education, research suggests outreach programs should target younger students, as high school and college aged students have already developed perceptions of engineering and their own identities [7]—manifesting itself as yet another barrier to underrepresented groups participating in STEM. Outreach programs have been assessed using some aspects of engineering identity including interest and self-concept [3], [6]; however, the literature lacks sufficient quantitative analysis of outreach program activities using engineering identity as the lens for assessment of the outreach program efficacy [5], [8]. Outreach programs targeted at the middle school age or before may be important for challenging younger student perceptions of engineering and to develop their engineering identities [9].

Currently, limited research reports on the state of student engineering identity in the state of South Carolina. With the growth of the manufacturing and technology industries within the state, there exists a unique need to support these industries with a skilled and diverse workforce. Considering the importance of middle school aged students' role identity development, this study seeks to assess the efficacy of an outreach program in bolstering engineering identity in middle school aged students in the state of South Carolina using the validated RIS-E survey [7].

Theoretical Framework

This program leverages seminal work from Lent *et al.* regarding Social Cognitive Career Theory (SCCT) [10], [11] and Gee regarding identity [12]. In these works, Lent *et al.* highlight the importance of internal and external factors that influence career choice and persistence. Specifically, terms including interest, performance, self-efficacy, and outcome expectation are used to summarize a model for career-related decisions. Gee also discussed these external factors, or an "interpretive system," that recognize identity. In subsequent work, researchers have utilized the SCCT and analytical approaches to develop engineering identity frameworks which have been reported in the literature as potentially successful approaches for understanding influences on student identification with STEM fields. Additionally, engineering identity has been reported in the literature as a framework for improving student understanding of, motivation for, and confidence in engineering [2], [7], [13], [14]. Identity has also been a useful tool for assessing informal educational activities by providing an explanation for future career choices [7], [9]; thus, this study seeks to utilize an engineering identity survey as a method for outreach program assessment and future activity development.

Although many definitions for engineering identity exist in the literature, the central theme is the feeling of identification with engineering as demonstrated by interest, performance, competence, or recognition. If some or all of these vectors are supported, research has shown a student may be more likely to identify as an engineer—leading to improved motivation and persistence in engineering. Carlone and Johnson focused on competence, performance, and self-recognition. They defined competence as "Knowledge and understanding of science content". They defined performance as "Social performances of relevant scientific practices". They defined self-recognition as "Recognizing oneself and getting recognized by others as a 'science person'" [13]. Later work from Hazari *et al.* added interest which was defined as "personal desire to learn/understand more..." [14]. Lastly, distinctions have been made between external and internal recognition [7]. Although many approaches exist for how to define engineering identity [13]-[16], research from Paul *et al.* measured engineering identity of elementary students using a validated survey on four scales: competence, interest, self-recognition, and recognition from others [7].

Methods

In partnership with Duke Energy, the EXPLORE Mobile Lab was founded in 2019 at Clemson University as a STEM outreach program for middle school (6th-8th grade) students designed to complement classroom instruction with hands-on engineering applications and concepts. The EXPLORE Mobile Lab provides the materials required to do the hands-on activities and includes a primary faculty member that administers the outreach program activities, either in-person or virtually, and a staff member that works with interested teachers to schedule the program activities and align each with the engineering field and the academic standards that students are reviewing in their grade level.

Teachers interested in hosting the EXPLORE Mobile Lab have the option to incorporate nine different program activities. Each activity enables students to connect principles they learn in their classroom environment to real world problems and subsequently solve those problems with the engineering design process using informal, hands-on experiences.

During the activities, the primary faculty member administering the outreach instruction introduced engineering as a general field and the subsequent topics of importance for the activity and the interest of students. Students were generally interested in fields of engineering, salaries and wages, education requirements, and education rigor. The activities were subsequently administered after the introductory discussion. Each activity was designed to provide students with experience in the engineering design process. This was accomplished by allowing ample time for brainstorming, planning, and drafting—spending most of the time on creating an artifact. The last phase of each activity consisted of testing independent and dependent variables by evaluating the artifact design. The available activities developed for the outreach program and excerpts describing each activity are detailed below in Table 1.

Table 1. Names of representative activities offered by the program for teachers to select accompanied by activity descriptions and the general engineering field with which each activity connects.

Activity name	Activity description	Engineering connection
Bridge the Gap	Can you build a bridge with popsicle sticks? Engineers are constantly being given the challenge of designing a sustainable structure with limited resources. In this activity, students will be challenged to build a bridge that will span the distance between two containers of sand. They will then test the bridge to see how much weight it can carry. During this challenge, students will discuss how to use the engineering design process throughout the activity to evaluate and improve on their bridge design.	Structural/civil engineering, architecture, mechanical engineering.
Keep the Heat In	What is the purpose of the insulation inside the walls of a building? Engineers are tasked with making buildings more energy-efficient, while keeping costs down. In this activity, students will explore the concepts of heat transfer as they design their own insulation system. They will conduct tests to evaluate the efficiency of the insulation. Throughout the activity, they will discuss how to use the engineering design process in applications such as home insulation.	Civil, materials, chemical engineering
Coding a Robot	Can you program a robot to move around the room and play music? Engineers design computer programs that run video games and store your favorite playlists. In this activity, students will use a graphical user interface (GUI) program to make a robot follow certain commands. Once students learn the basics of programming, they will be able to create their own programs to move the robot around the room! This is a great introductory coding activity to show students the basics of computer programming.	Computer, Electrical engineering
Build a Better Body	Can you design a prosthetic leg? Engineers in the field of medicine have the challenge of designing artificial organs, replacement body parts, and machines that diagnose problems	Bioengineering, Mechanical engineering

	inside the body. In this activity, students will design a prosthetic lower leg. They will empathize with people who may have lost a limb in an accident or serving in the military, and then work together in teams to design a device to function as the lower part of their leg. Students will test their device and discuss how they could improve their design in the future.	
Protect your Egg	Can you design protective equipment for athletes? An egg is a delicate object. In certain sports such as football, rugby and lacrosse, humans are considered delicate, too! In this activity, students will design, build and test protective padding for an egg drop. Students will test their device and discuss how they could improve their design in the future. Watching the transformation of energy from potential to kinetic, observing the impact and working under materials constraints introduces students to "sports engineering" and gives them a chance to experience some of the challenges engineers face in designing equipment to protect athletes.	Bioengineering, Materials, Mechanical, Chemical engineering
Looking at the Stars	How light wavelengths work? Spectrographs are used both in ground- and space-based telescopes to help astronomers figure out the materials that make up stars, planets, and planetary atmospheres. Mechanical and electrical engineers build these spectrographs to advance our knowledge of astronomy. The engineering of a spectrograph determines what kind of light it can analyze. For example, the materials involved affect what can be seen through the spectrograph and whether spectral lines can be seen or "resolved" at all.	Environmental, Mechanical, Electrical,
Nuclear Energy	How powerful is nuclear energy? Nuclear energy comes from splitting atoms in a reactor to heat water into steam, turn a turbine and generate electricity. Ninety-five nuclear reactors in 29 states generate nearly 20 percent of the nation's electricity, all without carbon emissions because reactors use uranium, not fossil fuels. Nuclear engineers research and develop the processes, instruments, and systems used to derive benefits from nuclear energy and radiation. In this activity, students will create and analyze a chain reaction that exemplifies the fission reaction occurred during the generation of nuclear energy.	Environmental, Mechanical, Electrical, Nuclear

More information on the activities can be found on the program website: https://cecas.clemson.edu/mobile-lab/

Table 2, below, summarizes the number of schools, students, and districts that have received EXPLORE Mobile Lab activity instruction, as well as the number of special events—like "Career Day" or extracurricular camps—administered by the program for each year the program has been active.

Table 2. Program administration data organized by year of program since inception including number of students, schools, counties, and special events.

Year	Cycle	Mode	Number of students (fall/spring)	Number of schools	Number of South Carolina counties	Special events
1	2019-2020	In-person	5,229/3,646	74	23	11
2	2020-2021	virtual	320/2,022	33	9	4
3	2021-2022	In-person or virtual	1,887/1,071	20	9	11

Although previous academic years have allowed the mobile lab to give in-person instruction, some of the program activities administered as part of this current study were administered virtually; however, the activities administered virtually were unchanged from their original, in-person version. To ensure this, necessary supplies, instructions, and workbooks were sent to the participating teachers for each student. The most frequently administered activities were "Bridge the Gap", "Build a Better Body" and "Keep the Heat in". Figure 1, below, shows the distribution of activities administered during the three years of the program. Since the program's inception, 14,175 students have participated in the program's activities with 8,875 students receiving instruction in the first year, 2,342 students receiving instruction the second year, and 2,958 students receiving instruction the third year.

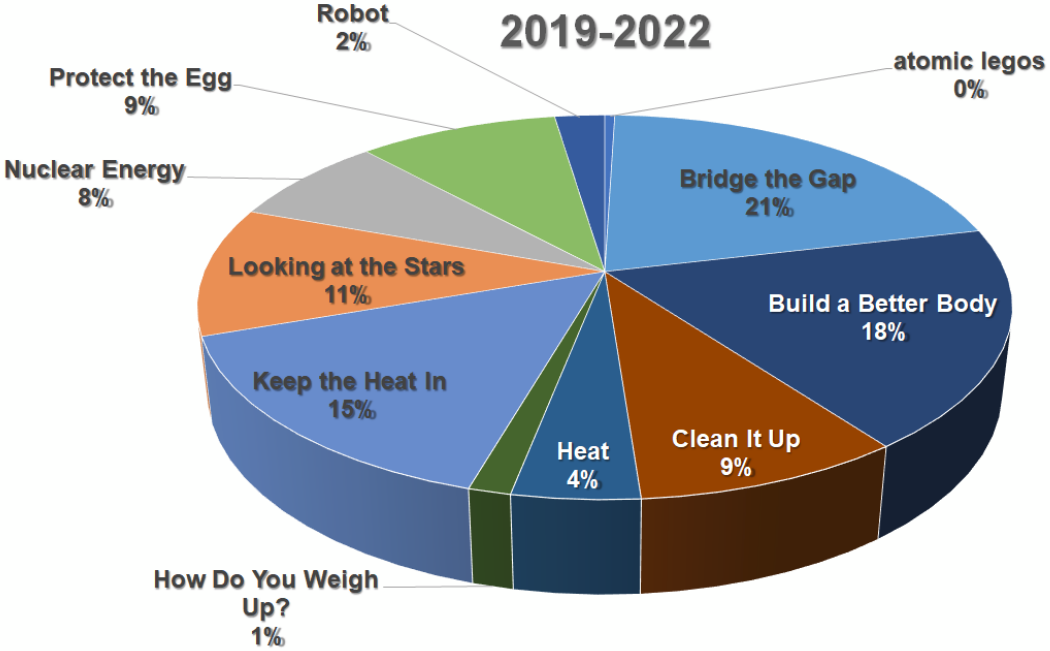

Figure 1. Distribution of activities administered by the program as determined by participating teacher's selections since program inception.

The EXPLORE Mobile Lab has been established and performing outreach functions since 2019; however, the assessments of the EXPLORE Mobile Lab influence on middle school student engineering identity is limited to April 2021-January 2022. During this period, approximately 2200 students received outreach instruction at 30 schools across 14 school districts in South Carolina. The schools included in this study ranged from urban to rural and included 11 Title 1 schools.

To develop a baseline of students' understanding of engineering and students' engineering identity, an IRB-approved pre-survey was administered prior to participation in the outreach program. Following the program activities, an IRB-approved post-survey was administered to assess changes in perceptions, understanding, and identification with engineering. The surveys were designed using the Role Identity Surveys in Engineering (RIS-E) [7]. This included four categories of questions that each represent a different identity vector: interest, competence, self-recognition, and recognition from others. To validate the survey for use with middle school-aged students, the Cronbach's Alpha was measured for all responses. The result from the Cronbach Alpha test was 0.96 which suggests the measurement tool is highly reliable and validated for the population surveyed in this study.

This study analyzed responses from 14 schools across 9 school districts totaling 2143 survey responses. An Analysis of Variance (ANOVA) with a 95% confidence interval was performed on the results from before and after the intervention for each identity vector. Additionally, a case study group consisting of 72 students that received EXPLORE Mobile Lab outreach instruction three times was also analyzed. 39 paired survey responses were used to compare identity vectors before the first intervention and after the third intervention using a Paired t-test with a 95% confidence interval.

Results

All Responses

Figure 2 below demonstrates the distribution responses from all completed pre- and post-intervention surveys (n=1424 and 719) organized by identity vector. The mean value of each identity vector increased from before the intervention to after the intervention. For all except the Interest vector, this increase was statistically significant (α=0.05).

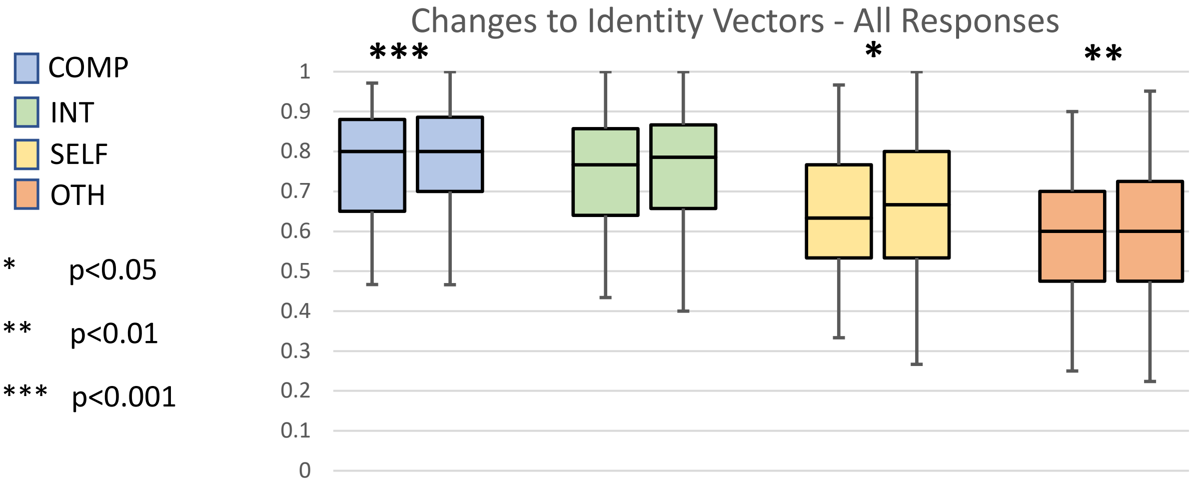

Figure 2. Comparison of all pre- and post-activity responses for each identity vector measured: (from left to right) Competence, Interest, Self-recognition, and Recognition from Others.

Subset of Schools with Low Participant Attrition

Of the survey responses collected from all schools, 1,424 were collected prior to the intervention and 719 were collected after the intervention leading to an overall participant attrition rate of approximately 50.5%. However, since survey administration was performed by individual teachers in at the schools served, the non-completion of surveys after the intervention was largely localized to individual schools. Because of this, a subset of nine schools with a low individual participant attrition rate (<50%) were selected for further analysis.

The demographic information for this subset is included below in Table 3. ANOVA performed for each identity vector across the pre-intervention survey responses from these nine schools showed no significant differences in either Competence or Interest, but did show differences in the other vectors, with schools D and I scoring significantly higher on Self-recognition and schools E and F scoring significantly lower on Recognition by others.

Table 3. Demographic Information for Schools Analyzed

	Locale	% Free & Reduced Lunch	% URM	School Size	Student/Teacher Ratio
School A	Town	58.8	24.00	541	14.62
School B	Rural	48.3	31.78	793	14.42
School C	Rural	52.4	5.88	340	17.17
School D	Suburban	10.5	18.13	888	14.10
School E	Suburban	60.5	32.78	749	12.08
School F	Suburban	37.5	12.20	328	13.16
School G	Suburban	100.0	90.90	1594	13.58
School H	Rural	100.0	13.83	629	13.10
School I	Rural	100.0	43.93	741	13.47

In the nine schools analyzed, the mean score of each identity vector increased from the pre-intervention survey to the post-intervention survey in all but one case (School D, Competency). However, of these increases, only one was statistically significant (School A, Competency) at $\alpha=0.05$.

Case Study School

Although the results above did not show a statistically significant increase in any of the individual engineering identity vectors following a single intervention from the Mobile Lab, when the post-survey was administered to a group of students after three repeated interventions at a case study school (School A), statistically significant increases were observed in both the Self-recognition and Recognition by Others vectors, along with non-significant increases in the other vectors. These survey results are presented below in Figure 3.

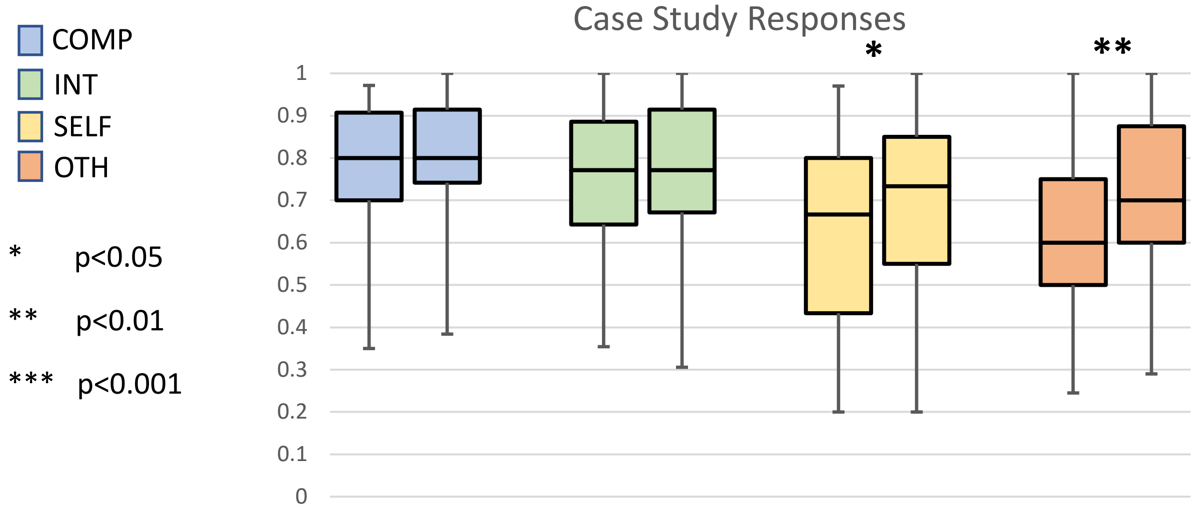

Figure 3. Results from the RIS-E survey comparing responses from before the first activity to after the third activity in a case study group (n=39) from a single school.

In addition to the average results from the case study classroom, the changes in each vector from the pre- to post- intervention survey were also analyzed at the individual student level. From this analysis:

4/39 students had decreased scores in each of the four vectors;
22/39 students had decreased scores in at least one of the identity vectors;
30/39 students had increased scores in at least one of the identity vectors; and
15/39 students had increased scores or no change in each of the four identity vectors.

Discussion

The results from this study evaluating the EXPLORE Mobile Lab outreach program through the lens of engineering identity development in middle school-aged students using the RIS-E survey suggest that increases in identity vectors can be seen from before the program intervention to after the activity. Although smaller changes in interest were seen when analyzing all responses, statistically significant increases were seen in competence, self-recognition, and recognition from others. One reason the interest vector may not have improved could be due to the prior degree of interest in engineering being high. Since the teachers at each school select the students that are receiving the EXPLORE Mobile Lab outreach instruction, it is possible the students surveyed were already interested in engineering. Another reason the change in interest may not have been as great as the other vectors could be due to a lack of interest in a specific subject area to which the activity was related. This informs future efforts to tailor the outreach program activities to students interested in specific engineering areas. For example, it is possible that some students would see greater improvements in their engineering interest if they were exposed to the “Build a Better Body” activity as it relates to biomedical engineering as opposed to the “Keep the Heat In” activity that relates more to civil and mechanical engineering.

Although the competence and self-recognition identity vectors had statistically significant increases, the recognition from others identity vector increased greatly. It is thought this could be due to the administering of the activity by a professional engineer and not the teacher in the classroom. Additionally, it was not investigated whether the virtual or in-person platforms would have affected this exposure to a professional engineer; therefore, future studies evaluating the efficacy of the EXPLORE Mobile Lab through the lens of engineering identity should investigate the ways in which recognition from others identity vector increases during the activities.

This study sought survey responses from middle school aged students; however, the investigators relied on the teachers in the classroom to administer the survey before and after the program activities. Although this did not occur every time, sufficient data was gathered to appropriately assess the efficacy of the outreach program activities to affect engineering identity. Despite this, the method was unable to procure completed surveys from all students participating in the program. This is likely due to the challenge teachers face in the classroom to ensure each student is completely filling out each survey. Due to a lack of available technology in the classroom, it is also possible that teachers do not have the ability to administer the survey in the classroom.

This study investigated the efficacy of the outreach program activities to affect engineering identity in middle school aged students; however, the activities were administered both in-person and virtually. Moving forward, the efficacy of the program to affect engineering identity in students should be compared between virtual and in-person activities. While researchers and teachers remain cautious of the latest COVID 19 variant, it is important to improve upon virtual techniques; thus, if the results of a future student suggest that the program is not as efficacious virtually as it is in-person, the differences in program administration can be addressed to improve the efficacy of the program's virtual activities.

The results above demonstrate the ability of the EXPLORE Mobile Lab to affect change in students' engineering identity; however, the change is statistically significant following multiple interventions rather than just a single intervention. This suggests that repeated outreach program activities may have more of an effect on the students' identification with engineering than a single exposure. In the case study results, greater increases were seen in the recognition vectors. It is hypothesized that having the students work on the activity in a group, having the program facilitated by an engineering faculty, and having the faculty member reinforce the idea that they did an engineering task could be the reason for improvements in the recognition vectors. Furthermore, the results above indicate the ability of the RIS-E survey to track an individual students' degree of engineering identity. Future work may also leverage this approach to investigate the ability of the outreach program to improve identity from different intersectional groups.

Conclusion

This study sought to evaluate the EXPLORE Mobile Lab outreach program through the lens of engineering identity development. The use of the RIS-E survey instrument enabled researchers to investigate pre-program and post-program differences in engineering identity vectors while also providing information about how individual students can be affected by the program. The results presented in this study suggest the EXPLORE Mobile Lab activities can improve engineering identity vectors, particularly recognition from others. Additionally, repetitive exposures to the outreach program activities have demonstrated the ability of the program to affect more vectors like competence and self-recognition. This work has informed the group to continue performing these activities with middle school students; however, future work should include an investigation of how the demographics and intersectional groups may predict effectiveness of the program. Future work should also investigate the differences in effectiveness of the program to affect identity development when the activities are administered in person and virtually. Lastly, the EXPLORE Mobile Lab should seek to engage middle school-aged students uninterested in engineering. The perspectives to improve the EXPLORE Mobile Lab are a direct result of the findings presented in this study.

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