Meeting Schools Where They Are: Integrating Engineering Outreach Curriculum in the Classroom Without Forcing an Agenda

Austin Hayes

Austin is a PhD student in additive manufacturing and wind energy. He is a co-founder of the Triple E Initiative and began the collaboration with STEM Launch for the Triple E Initiative. He oversees volunteer coordination, partnership with the middle schools, and logistics of the Triple E Initiative. He has experience meshing classroom learning with hands-on lesson plans to engage K-12 students in STEAM.

Vani Sundaram

Vani is a PhD student in robotics at CU Boulder. She is a cofounder of the Center for Equity in Mechanical Engineering action subcommittee. She oversees outreach events, communicates with partnering schools/ organizations, and recruits ME department members to help with the STEAM events. Vani has 10+ years of experience mentoring undergraduates and K-12 students, including starting a similar STEAM program at her undergraduate institution.

Graham Williams

Graham is an undergraduate student who participates in the Center for Equity in Mechanical Engineering and K-12 related activities. He helps coordinate outreach events, generates interactive STEAM-based lesson plans, and interfaces with the Department of Mechanical Engineering at the University of Colorado Boulder to ensure the longevity and prosperity of the proposed K-12 outreach efforts. Graham has a strong, life-long track record of community service, including helping design and build tiny homes, bus stops, and other structures for the Community First! Village, an innovative attempt to address the homelessness crisis in Austin, TX.

Shreya Venkatesh

Shreya is a PhD student who works with the Center for Equity in Mech to facilitate K-12 outreach events. She previously participated in a project-based learning class for students in rural schools in Colorado and continued on as a mentor for their related workshops and programs during the summer. Additionally, she has experience working with science/art museums geared towards middle and high school students and has experience managing and creating scientific exhibits to encourage K-12 interest in STEAM.

Claire Isenhart

Antonio Yervez

Celesse Myles

Vera Sebulsky

Kaushik Jayaram

Marina Vance

Gregory Whiting

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Abstract

Many middle school students lack an understanding of what engineering is, leading to an inability to see themselves in the field and a decreased likelihood that they will pursue engineering. This is especially prevalent in families and communities where children may not have engineering role models. In the US, such communities are more likely to include students from underrepresented groups in STEM. Providing early engineering exposure to middle school students in their respective classes offers the benefits of providing role models to the students while ensuring external engineering curricula are relevant. The University of Colorado Boulder (CU Boulder) has implemented an Early Engineering Exposure initiative (Triple E Initiative) designed to form relationships between CU students and middle school students through weekly in-classroom teaching experiences in the fall and an interactive science fair in the spring. We drafted the curriculum for four weekly classroom teaching days based on problem-based learning, promoting a seamless integration into the classroom. This enabled us to provide engineering outreach curriculum to schools in an engaging manner that did not require changes to normal programming. From an educator's perspective, shifting the curriculum load from the middle school teacher to the university provides insight into how engineering concepts can be taught to ensure maximum effectiveness. CU Boulder's Mechanical Engineering department followed this month-long program with a science fair (Triple E Fair) to showcase the variety of projects in mechanical engineering and offer students firsthand experiences with real engineers. This model resulted in a 39% increase in students' understanding of what engineering is (self-reported) with a higher level of engagement and interest in college education.

Introduction

Problem-based learning (PBL) has been touted as a means of teaching engineering in a holistic manner, and it has shown successful outcomes across universities internationally[1]. This model has extended towards younger students with emphasis on developing interdisciplinary problem-solving skills by addressing problems using technical, mathematical, and social understanding. Special attention has been placed on making engineering content "relevant" through hands-on demonstrations and tangible experiments designed to spark interest in engineering. Examples include creating an environmental education course in which students build a greenhouse using 5E principles in Turkey; this resulted in an increase in scientific creativity scores[2]. Educators also saw an increase in the use of maker-spaces and problem based learning projects that complemented state learning standards in the United States[3]. Case studies on teacher adoption of PBL are favorable with an educator's belief that "STEM integration will give students a variety of 21st century skills they can develop[4]."

Field trips can be a vital tool for cementing classroom learning. In language comprehension, immersion in the culture fosters heightened lingual learning[5]. In engineering education, field trips offer the opportunity for students to connect abstract math and science concepts to real world applications. Unfortunately, in the educational curriculum, field trips are typically considered one-off learning experiences[6]. While this model still results in exposure to new experiences, field trip experiences that complement the classroom curriculum can result in greater comprehension and retention[7]. In engineering education, combining lesson-based classroom curriculum with concepts the students will experience during a field trip breaks up the monotony of classroom teaching and improves retention.

The idea of a role model has already been used as a method to augment participation in engineering. Early research demonstrated that middle school students from underrepresented groups in STEM engaging with engineers from similar backgrounds has a positive influence on their attitudes towards STEM[8]. The conversation around who a role model is, why they are a role model, and who they are a role model to is an ongoing discussion[9] that is different for each individual due to cultural perception, personality traits, and individual goals. Additionally, a student's belief that they can achieve similar success to a role model is significant to increasing participation in engineering. Therefore, forming a good relationship with students through repeated interaction and open conversation is more likely to result in the successful implementation of role models in engineering education.

In this case study, we developed 7th grade engineering education curricula which seamlessly blended into the classroom curriculum. We coupled this curriculum with a science fair field trip that highlighted providing diverse role models for 7th graders in Thornton, CO. Graduate students at CU Boulder ran and developed the program and this method resulted in greater student understanding of what an engineer is and how to achieve a similar path.

Methods

The first Early Engineering Exposure (Triple E) Initiative was conducted between the fall of 2021 to the spring of 2022. The Triple E Initiative consisted of two components: four in person classroom teaching days and an external field trip to CU Boulder's campus for a science fair. Both components were designed to complement each other with the teaching days occurring first so that middle school students could develop a relationship with CU Boulder students before the science fair.

The program was funded by a CU Boulder Mechanical Engineering diversity, equity, and inclusion (DEI) grant with the goal to specifically impact students from underrepresented groups in STEM. In the fall of 2021, we partnered with STEM Launch, public Title 1 K-8 school in Thornton, CO which already applies PBL in its curriculum and offers an engineering class. The 130 students we worked with self-reported as: 54% male identifying, 46% female identifying, 80% Hispanic, 17% White, 2% multiracial.

Before the classroom teaching days, CU graduate students met with a 7th grade teacher at STEM Launch Middle School to determine when to conduct the in-classroom teaching portion. We selected a frequency of once a week for four consecutive weeks for classroom teaching. Specific emphasis was placed on learning what topic areas were taught during the proposed timeline and integrating CU Boulder's curriculum with that of the 7th grade teacher. By taking this extra step, we were able to make customized lesson plans to integrate as seamlessly as possible into the classroom. This integration provided a sense of familiarity to the students without disrupting classroom routines. During classroom teaching, 5-6 CU students were present, resulting in a 7th grader to CU student ratio of 5:1. Each classroom teaching day was split into a warmup session using topics covered by the teacher in previous days, a 10-minute presentation introducing the topic area, a 30 minute hands-on activity that uses the concepts introduced in the presentation. During the hands-on activity, 7th graders were split into groups with a CU student leader to improve participation and provide individualized attention. One goal of this in-classroom experience was to provide 7th grade students with the opportunity to ask CU graduate students questions about their experiences in engineering one-on-one. A diverse group of CU graduate students volunteered for the event, inadvertently providing the middle schoolers with several potential role models that may share similar backgrounds with them. For instance, a majority of the 7th grade students were native Spanish speakers. Of the CU Boulder volunteers, 33% were Spanish speakers who were able to connect with the 7th graders on a deeper level through shared culture and language. These volunteers were masters and PhD students conducting research at CU Boulder. This connection may have a positive impact on Hispanic STEM student identity[10].

Following four consecutive weeks of in-classroom teaching, we embarked on the second part of the Triple E Initiative: an interactive science fair. The entire 7th grade class was invited to CU, where current undergraduate and graduate students created interactive exhibits showcasing their research. Exhibits included a robotic dog, bubble boiling visualization, high-speed imaging, wind turbine models, and solar cells. CU covered all the costs of the science fair, including busing, food, and supplies, in order to ensure the event would be held at a net zero cost for the middle school. This is particularly important in ensuring schools with fewer resources have access to science fair events like these. The fair also included a campus tour and dining hall experience which allowed the 7th graders to witness university life firsthand and gain a more personal experience with the idea of higher education.

Survey data was used to assess the impact of the Triple E Initiative on the 7th grade students' understanding of engineering and to collect feedback on the initiative for future growth. Students were asked about how well they understood what an engineer does before and after the fair. They were also given the opportunity to provide feedback about the events themselves in the form of open-ended questions about their experience. Questions asked on the survey included answering the following statements about the experience on a scale of 1 (strongly disagree) to 5 (strongly agree):

1. At the beginning of the year, I knew what an engineer does.
2. Now I know what an engineer does.
3. I enjoyed having CU students come into the classroom to teach.
4. I enjoyed coming to CU on a field trip for the Triple E Fair.

After these questions, students were asked a series of open-ended questions to assess how to improve the fair, which exhibits were most engaging, and questions on the in classroom experience:

1. Comments/Feedback about the classroom experience. (ie: Did you learn something from the activities? Enjoy hearing from CU students? etc?)
2. Comments/Feedback about the Field Trip experience. (ie: Did you have enough time at the exhibits? Learn from the exhibits? Talk with CU students? etc?)
3. Any other thoughts/feedback?
4. What was your favorite exhibit?

Results

The Triple E Initiative resulted in quantitative increases in students' understanding of what engineering is with a 39% increase in understanding measured before and after the fair with surveys. We also received feedback from students and teachers on successful engagement with the students and promoting engineering education. We have separated the results of this case study into two components: in-classroom problem-based learning and science fair engagement.

In-Classroom Seamless PBL Integration

The four curriculum plans were developed to integrate seamlessly into the educators' classroom curriculum. We matched template, organization, and activity format and provided novel tools and interactive exhibits. By sticking to the normal classroom routine alongside providing new experiences, we were able to maximize student engagement and convey real-world applications of concepts students were learning in class. The teacher also stated that students were more engaged during these lessons than he had seen in the classroom previously. Furthermore, this technique of creating lesson plans to complement the educators' was a welcome reprieve for the teacher. One of our goals in designing these lesson plans was to ensure there would be no additional burden on the educator to force our curriculum to fit their existing lesson plans. By working with the educator to develop the curriculum, we achieved greater engagement and effectiveness. For example, in the first class, we complemented standard 7th grade material on the brain by discussing technologies enabling the study of the brain and incorporating an EMG activity measuring the electric potential of muscle impulses (Table 1).

During class, the high ratio of CU graduate students to 7th graders (1:5) helped maintain engagement. Each hands-on activity and CU Boulder class presentation was designed by CU students to integrate smoothly into the educator's curriculum in alignment with the Colorado Academic Standards. The educators involved in this outreach project told us our approach of integrating outreach efforts into the existing classroom curriculum was advantageous, as it made their preparation easy and allowed the content to become more meaningful. Existing classroom material was reinforced by graduate students in an interactive manner that developed problem-solving skills. We also observed that having Spanish-speaking graduate students created a noticeable increase in student connection and engagement with the curriculum. This supported

Table 1: CU Boulder problem based learning activity and educator curriculum

Date	Educator Curriculum	CU Boulder Activity
11/8/22	Brain structure and function	1. Match animal brain structure with function 2. EEG signal with digital multimeter. Observe signal and couple EEG to TENS unit to "control" another person's muscle with your muscle impulse
11/15/22	Bones in the human body	1. Overview of what mechanical properties are useful for bones 2. Compared the material mechanical properties of animal tissue and bone to artificial samples.
11/29/22	Epidemiology and attack rates	1. Discuss role of engineering skills in epidemiology 2. Calculate attack rates for a variety of situations of food borne illness
12/6/22	Bacteria and Viruses	1. Explain physics behind instruments allowing us to see small bacteria and viruses 2. Students view slides of biomedical engineering researcher and match what they see to what the slide sample is from 3. Discuss role of computer algorithms in automating cell counting and biomedical applications

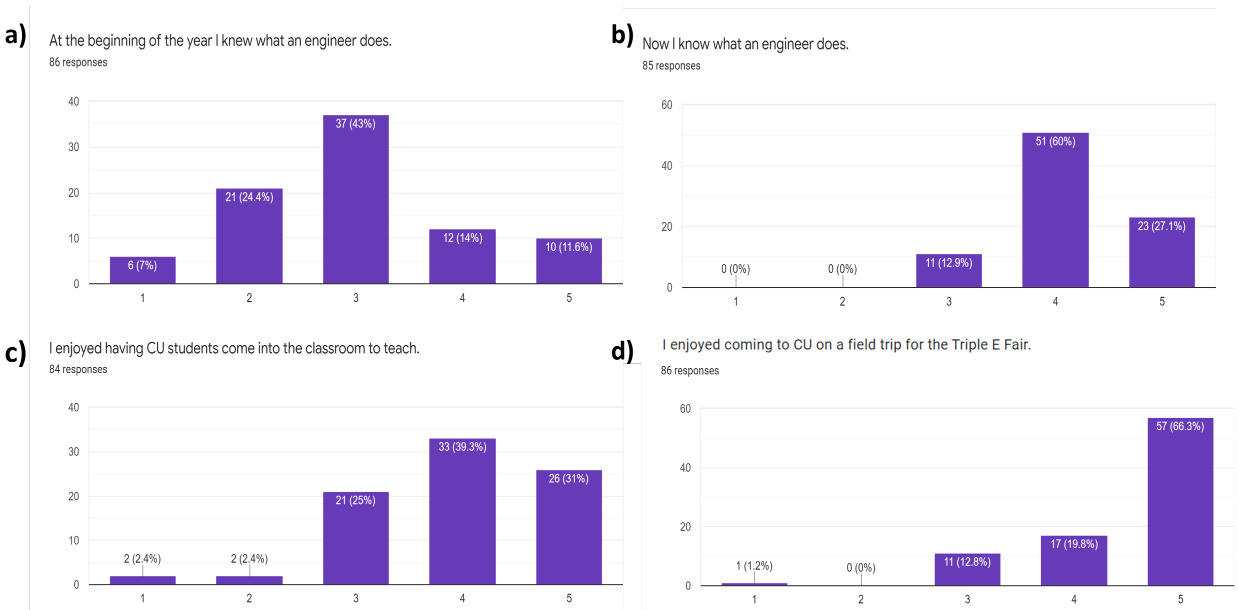
our earlier assertion that students would respond positively to the placement of role models, i.e., to being taught by graduate students that shared cultural or lingual backgrounds with them. The cost to create hands-on demonstrations and logistics for volunteers for all four classroom visits was $800.

Science Fair Engagement

The science fair portion of the Triple E Initiative involved 20-30 graduate and undergraduate students at CU Boulder who created exhibits showcasing different facets of engineering. Over 12 research labs and 2 undergraduate senior design projects were present, representing air quality, structural design, heat transfer, wind energy, solar, virtual reality, construction safety, and additive manufacturing. Our goal was to demonstrate that an engineer does much more than just build cars, bridges, and airplanes, and this was accomplished with the multidisciplinary exhibits displayed during the Triple E Fair. Each exhibit consisted of an interactive activity to make the research memorable to and understandable for a 7th grader. Teacher feedback included noticing the students' excitement and engagement for the science fair as well as overall stronger interest in college and the University of Colorado Boulder specifically. We included a campus tour and meal at the dining hall as a component at the Fair in order to provide a glimpse at higher education.

Survey Data

Statements from teachers and students were noted during the Triple E Initiative for qualitative assessment alongside survey data. Survey data was collected before and after the classroom and science fair portions of the Triple E Initiative to assess the effectiveness of the fair (Fig. 1). These surveys were administered through a simple Google Forms layout, through which students rated how strongly they agreed with provided statements and were given the space to include their own statements if they chose to. Results indicated a 39% increase in students' understanding of what an engineer does as well as a high degree of satisfaction with both the in-classroom teaching and science fair components. 86% of students answered agree or better to enjoying the science fair portion of the Triple E Initiative and 70% said the same for the in person teaching. This difference suggests students were more engaged during the science fair which solely had interactive exhibits. Greater engagement could be achieved by incorporating more time to interactive activities during the classroom learning sessions. Furthermore, open-ended questions demonstrated that many students made the connection that engineering is multifaceted and indicated an overall interest in STEM.



e)
- “I think that we should have college students come in more”
- “I enjoyed hearing from the CU students and I liked going over there.”
- “I learned that engineering is not just making houses”
- Did you learn something: “not really but if I work hard I can go to CU boulder.”

Figure 1: Survey results and comments from Triple E Initiative

A key component of the Triple E Initiative was ensuring all components were introduced at zero cost to the school. Since we selected schools from more low-income regions, covering the complete cost of the events, and thus removing economic barriers, was a vital part of this initiative. The cost to administer the fair was approximately $3,000 and included renting an on-campus gymnasium, providing busing for the 130 7th graders, lunch for students and volunteers, and materials for exhibits.

Conclusion

This case study discusses lessons learned from the 2021-2022 CU Boulder Triple E Initiative, a 7th grade engineering outreach program. Engineering education was enhanced by using a combination of problem-based learning and field trips. Special emphasis was given to smooth integration of outreach curriculum with the existing classroom curriculum. This made the outreach topics and university student-lead classes tangible to the 7th grade students by offering real-world interactive activities along with classroom teaching. The in-classroom teaching was coupled with a spring science fair to showcase a wide variety of engineering topics through interactive exhibits. Additionally, this fair included a tour of the university campus and student life to add a personal touch to middle school students' perspectives on higher education. Student response to the Triple E Initiative was overwhelmingly positive, with a 39% increase in understanding of what an engineer does accompanied by an overall enjoyment of the classroom and fair portions of the Triple E Initiative. As many of the students were from a traditionally underrepresented group in STEM, this response was encouraging for future outreach efforts. It also supported previous research and our expectations that placement of role models from similar backgrounds positively influenced student perspectives on career paths and overall interest in STEM. Student feedback supported the quantitative survey results, suggesting that students identified paths to success in engineering and demonstrate critical thinking in their engagement with the fair's exhibits.

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