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A Community-Engaged Model for Rural STEM Education: Lessons Learned from the Development and Implementation of a STEM-focused Engineering Design Program for Rural Middle Schools (Evaluation)

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Abstract

Providing access to high quality STEM educational opportunities in rural communities is a significant challenge that will require multiple stakeholders to address. This paper will discuss the development and implementation of a community-based engineering design program for rural middle school students (grades 6-8), highlighting student outcomes and lessons learned as the project team worked to build collaborative partnerships to bolster students' STEM content knowledge and interest in STEM careers. This work is part of a National Science Foundation Innovative Technology Experiences for Students and Teachers (ITEST) project that was designed to provide students with authentic, real-world STEM experiences in engineering design and advanced manufacturing. In this project, the NC State University Colleges of Engineering and Education collaborated with two middle schools in a rural school district in NC, local advanced manufacturing companies, and a regional educational advocacy organization to co-develop the STEM program. As a part of the program, students participated in a 3-part, grade level-specific STEM elective course in advanced manufacturing, received mentoring from undergraduate engineering students, and had the opportunity to engage in supplemental STEM enrichment activities outside the classroom.

More than 650 students across both schools have participated in at least one year of the STEM program over the last five years. This paper will describe the impact of the program on students' science content knowledge and STEM career interest, as measured by proficiency scores on end-of-grade (EOG) science tests and S-STEM student survey data, respectively. According to results of an ordinal regression analysis, the number of years spent in the STEM program had a significant impact on students' science content knowledge. It was found that students who participated in one year or more of the program had an increased chance of scoring higher on the science EOG in the 8th grade regardless of their score at the onset of the program. Additionally, analysis of S-STEM survey data indicated that program participants had a strong interest in engineering and chemistry, with 61% of students expressing an interest in engineering and 58% in chemistry.

Fundamentally, this project was built on collaborative partnerships. We found that prioritizing mutual respect and acknowledging each partner's strengths were essential to building lasting, effective partnerships. Valuing the contributions of each partner is particularly important when working with rural communities who are often viewed from a deficit lens as it relates to educational opportunities. Through this collaborative effort, we were able to equip rural students with the skills required to enter the engineering pipeline, thus meeting workforce identified needs of community partners and solidifying enduring partnerships. In this paper, we will detail our approach to cultivating these essential relationships and the subsequent challenges and opportunities that emerged throughout the process. This work has implications for community-engaged researchers who work in rural communities, offering a framework for building sustainable partnerships that lead to positive student outcomes.

Introduction

Providing high-quality STEM education opportunities in rural communities remains a significant challenge with many barriers. Existing research supports a move away from a “deficit lens” on student opportunities toward experiences and programs that actively engage the local cultural and industrial assets of less populated areas [1, 2]. The development of multi-stakeholder partnerships is essential to strengthening rural STEM education, as these collaborations enable schools to leverage community-specific strengths and bridge critical resource gaps that often hinder rural districts. Research [3, 4] has shown that community-university partnerships can be particularly effective in improving rural students’ outcomes and experiences in STEM. In a study investigating the impact of a two-year community-engaged STEM program led by Texas Tech University in partnership with a local school district, it was found that students participating in the program experienced growth in 21st century skills (e.g., collaboration, creativity, critical thinking and communication) and demonstrated increased interest in STEM by the end of the program, particularly those from underrepresented groups. Additionally, it was reported that the collaboration with community partners informed by research facilitated improvements to their program and student outcomes [4].

Pendley and Shahid [5] assert that successful, long-term community-engaged partnerships (CEP) are based on relationship building and adhere to the key principles of community engagement which include reciprocity, co-design, asset-based approaches, participatory and community capacity, dissemination and sustainability. The ‘old’ model of imparting knowledge and expertise into communities or extracting research data without ever returning must be replaced by a new paradigm that moves beyond temporary grant-funded projects to long-term, sustainable change in these communities. In the current work, we designed the program for long-term viability beyond the funding period by reducing costs through DIY robotics kits, creating accessible lesson plans for diverse teaching backgrounds, and cultivating industry partnerships for potential future funding.

Community-engaged, mutually beneficial relationships have driven the work discussed in this paper. By developing partnerships across the industry-research-practice divide, we were able to provide consistent academic support and targeted resources to students and teachers that can be scarce in rural districts due to geographic and budgetary constraints [6]. These long-term collaborations that started as simple conversations moved beyond a one-off intervention and cultivated a multi-year, multi-cohort STEM elective program that encouraged not only participation in engineering but overall academic success. Through tiered mentorship and professional and social development opportunities for youth and adults, we were able to target a shared goal of broadening participation in engineering while strengthening STEM content mastery and engineering identity for students and teachers [7].

Program Overview

This STEM-focused program for rural middle school students represents a collaboration between the Colleges of Engineering and Education at NC State University, a rural school district in NC, a regional educational advocacy organization, and local advanced manufacturing companies. This project was funded by the National Science Foundation Innovative Technology Experiences for Students and Teachers (ITEST) program in 2020, and its goal was to engage rural middle school students (grades 6-8) in authentic, real-world STEM learning experiences within engineering design and advanced manufacturing. The project consisted of three main components: a 3-part, grade-level specific STEM elective course in advanced manufacturing, mentoring support by undergraduate engineering students, and supplemental STEM enrichment outside of the classroom. Students entered the program as sixth graders and participated in the STEM elective course in each year of middle school. A subset of students also participated in the North Carolina Mathematics and Science Education Network Pre-College Program (MSEN), which provides informal STEM enrichment opportunities through its Saturday Academy and Summer Scholars programs. The project team partnered with six local advanced manufacturing companies to develop the content for the course, serve as guest speakers in the classroom and provide site visits to their facilities.

STEM Elective Course

The STEM elective course was designed to introduce students to STEM concepts within the context of advanced manufacturing. Course topics and learning outcomes were determined based on input from our industry partners. The goal was to create a course that represents the knowledge and skills that students would need to be successful in those industries. Table 1 provides an example of learning outcomes and course topics separated out by grade level [8]. The course consisted of various hands-on, project-based learning activities where students had the opportunity to explore the engineering design process and how it connects to advanced manufacturing. The STEM elective course was divided into three focus areas within the advanced manufacturing industry: food processing, pharmaceuticals and energy systems. Students engaged in design projects related to each of these sectors of advanced manufacturing.

The duration of the course varied by school based on factors such as teacher availability, logistics associated with the structure of the school day, and district mandated changes to instruction. On average, each course lasted for roughly 6-9 weeks. In the early stages of the program there was variability in the course delivery mode due to the project start date coinciding with the onset of the pandemic, which forced schools to transition from in-person to virtual learning. Once the schools became fully operational after the pandemic, the primary mode of delivery was in-person during the school day.

Table 1. Learning Outcome and Course Topics by Grade Level

	Year 1	**Year 2**	**Year 3**
	6^{th} Grade	7^{th} Grade	8^{th} Grade
Topic	• Manufacturing vs. Advanced Manufacturing • Introduction to Advanced Manufacturing in the Food, Pharmaceutical	• Advanced Manufacturing Technologies in the Food, Pharmaceutical and Energy Systems Industries • Engineering Design in Manufacturing Environments	• Advanced Coding • Advanced Statistics • Advanced Microsoft Excel • How does data analysis and interpretation drive business decisions?

<table>
<tr><td></td><td>and Energy Systems Industries
● What is research?
● Engineering Design Process
● Introduction to Coding
● Oral/Written Communication</td><td>● Introduction to Microsoft Excel
● Introduction to Basic Statistics
● Data Collection
● Data Analysis and Interpretation
● Preparing a Scientific Poster</td><td>● Career Opportunities in Advanced Manufacturing
● Career Opportunities in STEM
● Preparing an Oral Presentation</td></tr>
<tr><td colspan="4">Learning Outcomes
At the conclusion of the course sequence, students will be able to:
1. Define the term advanced manufacturing and provide examples of advanced manufacturing technologies.
2. Explain the difference between traditional manufacturing and advanced manufacturing.
3. Define the term research.
4. Describe examples of research being conducted in advanced manufacturing and in STEM fields generally, and the potential impact of that research on society.
5. List examples of career opportunities available in the advanced manufacturing industry and in the various STEM fields.
6. List and describe the steps of the engineering design process.
7. Implement the steps of the engineering design process in the design of various artifacts, including manufacturing systems.
8. Demonstrate knowledge of basic coding required in the programming of Lego Mindstorms, Raspberry Pi computing and Arduino microcontrollers.
9. Demonstrate growing proficiency in oral and written communication of technical information.</td></tr>
</table>

Near-Peer Mentoring

Integration of a near-peer mentoring model into the STEM elective course supported the transformation of a traditional classroom into a supportive, scaffolded community of teaching and learning. Mentors for this project were selected from engineering students at NC State. The students were invited to apply via email or personal connections to the research team, and notably, they were paid for their time and travel to the school district. Near-peer mentoring, where the middle school participants were mentored by near-age mentors (in this case, undergraduate and graduate students), is described in the literature as an opportunity to boost student learning engagement in intimidating settings such as a specialized STEM course [9,10].

There are several benefits to near-peer mentorship that result in heightened youth engagement. First, it is well-supported that students are more likely to recognize themselves as an "engineering person" when they see relatable role models who lower the psychological barriers to math and science identity [11,12]. Second, by connecting middle school students with high school or college mentors who are only a few years ahead of them, the attainability gap is bridged by positive presence [13]. Mentors can speak directly to what high school or college courses are like, helping to provide youth with a concrete roadmap for their academic futures, which can strengthen STEM persistence [10]. And third, mentors can serve as a stopgap between youth and teachers by providing social-emotional support that can be lacking in youth-adult relationships [14]. The inclusion of near-peer mentors helped to create an environment where participants benefitted from relational wealth, empowering them to recognize their own capabilities as contributing members of the classroom community through multi-level support and encouragement.

Supplemental STEM Enrichment

A subset of students from each school participated in a Saturday Academy and Summer Scholars program as part of MSEN. The MSEN program prepares students in the state to attend four-year colleges and universities to pursue majors in STEM fields. To be eligible to participate in these programs, students had to be enrolled in one of the STEM elective courses and express an interest in participating. The Saturday Academy took place on NC State's campus for 4.5 hours on Saturdays from October through March of each academic year (10 Saturdays). Student participants engaged in various STEM-related activities through a series of ancillary courses in math, science, career awareness and robotics.

The Summer Scholars program also took place on NC State's campus for two weeks over the summer. As a part of the program, students completed an engineering design project related to advanced manufacturing. Additionally, students were able to tour the manufacturing facilities of our industry partners. The final two years of the project consisted of a one-week long summer residential program where students had the opportunity to experience college life by living in a dorm on campus as they worked on their projects.

Program Implementation

The STEM elective course was originally intended to align with the 9-week quarter system at both schools, with each class session lasting 45 minutes over a 9-week period (Fig. 1). However, as previously stated, school-level logistical hurdles and pandemic disruptions forced variations in how the courses were ultimately delivered. The course was first implemented with 6th graders with a new grade level course being added each year of the project. One teacher was tasked with teaching the entire course sequence at their school. The teachers participated in an annual one-week long workshop over the summer to help prepare them to teach the courses. In these sessions, teachers were able to practice with the technologies that they would be using in the classroom, develop lesson plans, request materials, and exchange ideas with each other.

We experienced high teacher turnover throughout the project, with nine teachers and 4 principals (including 3 principal changes at one school) cycling through the program over the last five years. Our experience aligns with broader trends in rural education where annual teacher turnover is estimated at 9% [15]. High turnover rates significantly hinder the retention of STEM educators in rural districts. This leads to a decline in educational quality, as schools are more likely to deal with vacancies by cancelling planned course offerings or assigning non-STEM teachers to teach those classes [15].

The data presented in this paper represents students enrolled as sixth graders in the 2020-21 academic year and completing the course sequence in 2022-23 as eighth graders.

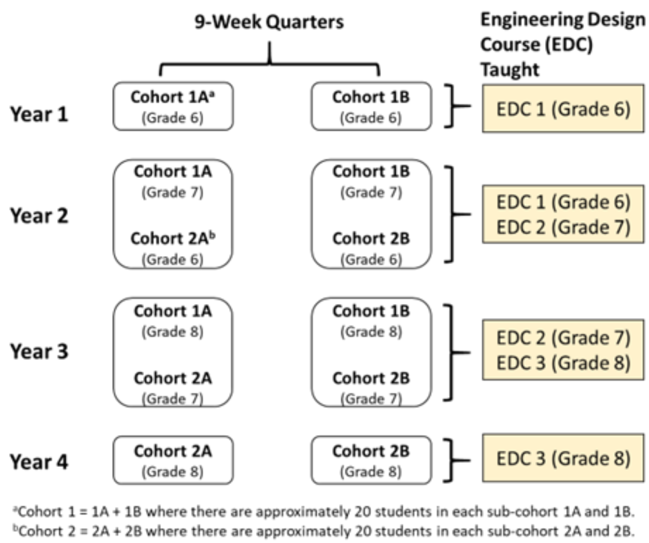

Figure 1. Example STEM Elective Course Teaching Schedule

Over 650 students have participated in at least one year of the STEM program over the last five years. The total number of students that have taken the courses each year is provided in Table 2 below. The initial goal was to have every student at each school take each of the three courses. However, that was not possible due to limited staff being available to teach the course. The majority of students participating in the STEM program were from underrepresented groups, with a nearly equal number of males and females (Tables 3 and 4).

Table 2. Number of students participating the program by year

	Number of Students Participating	
Academic Year	**School 1**	**School 2**
2020-2021	47	44
2021-2022	85	60
2022-2023	93	120
2023-2024	120	115

Table 3. Distribution of Program Participants by Gender

Variable	Category	Frequency	Percentage (%)
Gender	Male Female Other	39 39 4	47.56 47.56 4.88

Table 4. Distribution of Program Participants by Race

Variable	Category	Frequency	Percentage (%)
Race	American Indian / Alaskan Native Black / African American Hispanic / Latino Multiracial Other White / Caucasian	1 46 12 5 4 14	1.22 56.1 14.63 6.1 4.88 17.07

DeSIRE Project Student Outcomes

STEM Academic Achievement

Students exhibited positive academic growth as a result of their participation in the STEM program. To measure the STEM program's impact on student STEM knowledge, the North Carolina science end-of-grade assessment scores (EOGs) for grades five and eight were utilized. The assessments measure students' knowledge of science content articulated in the NC Essential Science Standards, and scores are reported as "Not Proficient", "Level 3", "Level 4", and "Level 5". The fifth and eighth grade tests serve as the pre- and post-intervention measures, respectively.

A Bayesian ordinal regression analysis between 5th and 8th grade scores showed that students enrolled in the STEM course had an increased chance of reaching higher science proficiency at the end of the eighth grade year. Analysis showed that students who participated in more years in the STEM program increased their probability of scoring higher on the 8th grade EOG, while decreasing the probability of scoring lower or "Not Proficient." Importantly, we found that students who scored "Not Proficient" in 5th grade were three times more likely to earn a Level 4 EOG score with just one year of participation in the STEM program. This analysis validates the academic impact of this program and similar initiatives on students' science-based knowledge [16].

Career Interests

In addition to academic achievement, the Student Attitudes Toward STEM (S-STEM) survey [17] was administered before and after students participated in the STEM course to examine student career interests. Students were provided twelve distinct STEM career areas with detailed information about what each entails.

Analysis of survey data varied across the different STEM fields based on student characteristics. For example, awareness of science careers was 85% lower among non-male identifying students compared to those who identified as male. Awareness of engineering careers varied based on grade level and middle school, where awareness was 82% lower in 7th grade compared to 6th grade, and 75% lower in one middle school compared to the other. Similarly, math career awareness was 55% lower in 7th grade compared to 6th grade and was 3 times greater in one middle school compared to the other. Finally, awareness of technology careers was 72% lower in one middle school compared to the other. A possible explanation to these varied results could be the autonomy each school had in implementing the STEM program. In some of our classroom observations, we noted that one school's STEM program focused on hands-on learning and advanced manufacturing processes, while the other appeared to have more classroom assignments focused on general science topics.

While STEM career awareness varied across gender, grade level and school, the data on STEM interest offered more definitive insights into the program's impact. Using a Kruskal-Wallis H test, analysis of the S-STEM data found that the strongest career interest among program participants was in the engineering field, followed by chemistry and computer science. The STEM program's emphasis on engineering and advanced manufacturing aligns with these findings, suggesting that the course directly influenced students' career exploration. Classroom observations corroborated this connection, as we saw students engaging with robotic arms, Raspberry Pi computer modules, and Arduino microcontrollers, effectively bridging the gap between the curriculum and career interest.

Lessons Learned in the STEM Partnership Development Process

At the core of the STEM program's positive impacts are the strong partnerships developed in support of the project and ultimately the community. The lessons learned from developing meaningful and lasting community relationships can serve as a springboard for others desiring to launch similar projects in their communities.

Aligning Goals

Effective partnership development depends, first and foremost, on goal alignment. During initial meetings with the school district, administrators shared with the project team that building STEM capacity in the region was a priority. While they had successfully established initiatives in their elementary and high schools, they identified a critical need for expanded programming at the middle school level. Lessons learned from our prior work with high school students revealed the importance of introducing STEM concepts at an earlier age [18]. Furthermore, we found in a previous study with high school students that our STEM research program did not lead to any meaningful shifts in students' career interests despite the program being viewed positively by participants. This outcome aligns with existing research [19, 20, 21, 22] suggesting that interest in STEM careers begin to take shape long before high school, reinforcing the need for exposure during the formative elementary and middle school years. After those initial meetings, focusing on middle school students emerged as a shared goal. Both sides viewed this as a win-win, and it formed the basis of our partnership.

Leveraging Strengths of Rural Communities

When working with rural communities, it is vital to approach the partnership from an asset-based perspective rather than from the traditional deficit standpoint. Historically, rural education has been framed by what it lacks, resulting in limited access to the critical resources needed to deliver high quality STEM programming in those areas. By recognizing the inherent strengths of these communities, we can more effectively address these long-standing inequities in resource allocation. In this project, we were able to leverage the resources of a local educational advocacy organization that was already doing work in the region to bring STEM learning experiences to schools in the district. This organization had established relationships with local industry and were working with them to bring programs like "Lunch with an Engineer" to the schools, which served to connect students with local engineering professionals. Additionally, that organization sponsors a yearly innovation challenge where students design an original invention and present it at a Shark Tank-style competition. When the project team learned of these existing programs, we were able to leverage them to provide additional high impact STEM experiences for students in our program.

Maintaining Adaptability for Long-Term Success

The ability of all partners to adapt has been critical to the success of this program, particularly at the onset when things were constantly in flux due to the Covid-19 pandemic. As previously mentioned, there was a great deal of variability in terms of course delivery mode (in-person vs. virtual vs. hybrid), duration, and course content at the beginning of the project primarily due to the pandemic. Implementation was a challenge as we shifted from in-person to virtual learning, exacerbated by the broadband and technological barriers common in rural areas. To keep the project moving forward, the team redesigned the in-person course for virtual delivery. After the project began, we learned that the technology available at the schools was not compatible with software that was slated for use in the courses. Again, we were forced to pivot to free, web-based STEM learning resources such as Tinkercad and other simulation tools that were accessible to all students. These online simulation tools allowed the PD facilitators to adequately prepare the teachers and meet project objectives without sacrificing instructional quality.

Establishing Mutually Beneficial Partnerships

One of our priorities from the outset was to gain a better understanding of the needs of the district in order to design a program that addressed their specific needs while also providing value to the project team. We recognized that in partnerships between large universities and small rural districts, a perceived power imbalance can lead to district leaders feeling overwhelmed or without a meaningful voice. Being mindful of this dynamic going into our initial meetings, we established early on that we were seeking a truly collaborative partnership where both the University and the school district maintained an equal voice throughout. As a result of our approach, district leaders felt empowered to further engage with us, knowing that their expertise was valued. Consequently, each party was able to identify tangible value in the partnership: researchers gained critical insights into STEM implementation in rural settings, manufacturing companies were able to build a pipeline to meet future workforce needs, and the University fulfilled its land-grant mission of serving the state through research, outreach and engagement.

Open Communication

Given the multifaceted nature of this project, maintaining open lines of communication was essential to ensure continued stakeholder engagement. One approach that we found to be effective was sharing annual one-page infographics that provided an overview of the highlights for the year, including student participation numbers, course activities, successes and challenges and next steps for the following year. These infographics helped to build trust with the industry partners by demonstrating how their input was being integrated into the program. Similarly, principals were able to use the infographics to provide high-level updates to district administrators on project progress at their respective schools. Another strategy that we employed was to conduct annual year-end meetings with each principal to reflect on what had gone well and identify some of the challenge points that required adjustments for the following year. We also implemented a just-in-time teacher professional development (PD) approach where teachers were encouraged to contact PD facilitators at any time even outside of scheduled PD sessions to ask questions [8,7]. This open-door policy empowered teachers to seek out support when needed, fostering confidence in their ability to effectively administer the courses.

Conclusion

The STEM project engaged in the novel approach of bridging the gap between classroom learning and local industry. The five-year initiative empowered underserved rural youth to engage in real-world STEM applications. The project generated positive benefits to every stakeholder connected. Students benefited from the implementation of hands-on engineering-focused curriculum aligned to local industry, mentoring by NC State engineering students, connections to industry professionals, and access to informal STEM enrichment programming. The school and the teachers benefited from the project by receiving high quality professional development and the requisite materials needed to deploy the project-based learning activities. University and community partners benefited from the project through the formation of lasting relationships that can serve as a sturdy foundation for future projects.

As this STEM program sunsets, it leaves a strong legacy behind. The program concluded by fulfilling its mission to make a difference in the rural community served by the project. Ultimately, the project led to a new generation of students who are more connected to the technological opportunities within their own communities.

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