Development and Implementation of K-12 STEM Outreach Programs in Industry and Academia: Successes, Challenges, and Lessons Learned

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Introduction

According to the U.S. Department of Labor (2022), the number of job openings in STEM (science, technology, engineering and mathematics) occupations is projected to grow by almost 11% by 2031. To meet this projected demand, STEM professions must prioritize recruitment. Outreach initiatives are well-known recruitment tools that professionals in industry and academia can implement to encourage student recruitment into STEM degree fields. While most outreach initiatives typically focus on high school students, research shows that students' career decisions are influenced at a much earlier age. Therefore, it is necessary for industry and academia to target an even younger demographic all the way to kindergarten and first grade. This paper highlights different outreach initiatives developed in academia and industry to teach K-12 students about STEM. The primary goal of these programs is to make younger students aware and excited about career opportunities in STEM fields. These outreach initiatives utilize innovative teaching strategies and curricula to teach K-12 students about STEM, what skills are necessary to work in STEM careers, and what types of careers opportunities are available. A summary of each program will be shared as well as program successes, challenges, and lessons learned.

Literature Review

Benefits of K-12 Outreach Programs

Facilitators and student participants benefit from K-12 outreach programs. Hendrickson, Bye, Cockfield, Carter, and Elmer (2020) found that these outreach programs help enhance awareness and understanding of the subject matter, develop relationships between program facilitators and K-12 teachers, and increase K-12 student interest in the subject matter. STEM outreach programs can provide new and innovative strategies to teach math and science, which can reduce the workload on K-12 teachers in those subject areas (Moskal & Skokan, 2011). According to Aguayo (2018), having STEM ambassadors in the classroom assisted in making learning math and science easier for K-12 students. Student participants also reported an increased confidence in those subject areas. College students who served as facilitators or mentors discovered new confidence and excitement about their major and career choice through involvement in outreach programs (Scherrer, 2013). These facilitators also felt a sense of altruism for working with and helping younger students learn more about different disciplines. For programs that involve younger facilitators, such as college students, there is less of a generation gap between student participants and the facilitators. This smaller age gap can be advantageous because the K-12 student participants may relate more to facilitators who are closer in age (Aguayo, 2018).

In addition to helping student participants learn new information and skills, these programs also help facilitators grow and develop. For example, outreach programs help undergraduate and graduate students gain professional development experience and develop both technical skills and soft skills including communication and presentation skills. Scherrer (2013) noted that an improvement in communication skills can benefit college students' professional lives.

Challenges Faced by Outreach Programs

Though outreach programs have benefits, challenges also exist. Finding and maintaining funding for outreach programs is one identified challenge. Potential sources of funding include external grants, internal grants and monies from higher education institutions, and corporate funding. Rincon and George-Jackson (2016) found that both the source and amount of funding greatly impact the way outreach programs are structured and if programs can be sustained over the long term. Another identified challenge is geographic location. Hendrickson et al. (2020) discovered that students in rural areas are at a disadvantage to be able to participate in these programs. This can be true for both facilitators and student participants. Developing curriculum is another challenge. Schuman and Shannon (2018) noted that many K-12 science and math teachers use handouts and memorization exercises instead of active learning activities in their lesson plans. Those types of passive activities leave students disengaged and less interested in careers in math and science. The learning activities used in these outreach programs must be active to capture the attention of the student participants. Lastly, the long-term success of outreach programs is difficult to document. Tracking student participants over time is challenging. Hendrickson et al. (2020) discovered outreach programs are effective in the short term but don't translate to a continued interest in STEM related careers for students.

Best Practices

Best practices have been identified for outreach programs. The relationship between the program and the community partner is essential for an outreach program's success. For example, when partnering with schools, Schuman and Shannon (2018) found that creating buy-in with the school's administration and teachers was essential. In addition, partnering with a teacher who was open to trying new ideas in the classroom was important. Hendrickson et al. (2020) suggested using current existing connections and relationships with schools and hosting an informational session to try to recruit teachers who were interested in partnering with an outreach program. Developing strategies to recruit and retain volunteers for outreach programs is another identified best practice. Schuman and Shannon (2018) noted that both finding and scheduling volunteers for these programs can be a challenge. Having a sustainable group of volunteers is essential for the success of outreach programs. A third best practice is to remember the importance of adaptability, creativity, and flexibility when coordinating and implementing outreach programs. Komoroske, Hameed, Szoboszlai, Newsom and Williams (2015) discussed how these skills are imperative for collaborations with K-12 partners. A fourth best practice is to identify and pursue a wide variety of funding sources for outreach program. Shepherd, Ufnar,

and Chester (2018) determined that having diverse sources of potential funding is important in case one source of funding ends.

K-12 Outreach Program Examples

This paper highlights six K-12 outreach programs that educate students about STEM disciplines. The outreach programs are facilitated by undergraduate programs at three higher education institutions and one STEM related employer. Institutional context, an overview of each program, a description of the program's curriculum and learning goals, program outcomes, and challenges encountered are discussed for each outreach program.

Programs #1 and #2

Institutional Context

Elon University is a selective, mid-sized private university known for engaged undergraduate instruction and experiential learning. The curriculum is grounded in the traditional liberal arts and sciences and complemented by professional and graduate programs. Elon Engineering is a unique blend of a liberal arts education and a traditional engineering education. The mission and commitment of Elon, emphasize "putting knowledge into practice" and the establishment of an "ethic of service." This aligns with the first tenant of the engineering profession, serving humankind; therefore, integrating service-learning projects into the engineering courses is embraced. Service-learning has been done in both introductory engineering and upper level thermodynamics courses at Elon.

Curriculum/Learning Goals

First-year engineering students facilitated an afterschool activity through a service-learning partnership with a nearby elementary school. The aims of the partnership were to boost retention and durable skills development among engineering students and to encourage young people to consider their potential for a career in engineering. The curriculum materials used were developed by PBS and accompanied its television show Design Squad (now Design Squad Nation). It is "high-energy, high-drama reality TV that lets kids show off their smarts as they design and build working solutions for real-world clients—people who are hungry for clever ideas from a new generation of innovators" (U.S. National Science Foundation, 2010). The creators also developed a companion website which features materials that may be used by parents to supplement at home, by educators as a teaching resource, or by mentors for community outreach. All of the materials seek to improve technological literacy and educate viewers/participants about the engineering profession.

Engineering Thermodynamics is a course offered to third year engineering students at Elon University. The course is a traditional exploration of how energy transformations are used to benefit and improve the quality of life through such practical systems as gasoline and diesel

engines, steam power plants, refrigerators, and heating and cooling systems. Engineering is Elementary® is a project of the Museum of Science in Boston to develop and support engineering literacy among elementary students and teachers. The project encompasses curriculum units themed by engineering discipline and science topics. Each curriculum unit includes a storybook to introduce the engineering design problem, lesson plans, and worksheets to assess student learning. The unit that seemed most appropriate for use in the Engineering Thermodynamics class is entitled "Now You're Cooking: Designing Solar Ovens." In terms of science topic and engineering field, it is categorized as energy and green engineering. The accompanying storybook is entitled, Lerato Cooks Up a Plan, which features a challenge to design a well-insulated solar cooker. Though included in the engineering thermodynamics textbook, modes of heat transfer and sustainable practice through green engineering are typically not emphasized in the course due to time restraints. Therefore, incorporation of this unit offered a unique opportunity for engineering students to study, teach, and apply this material. The connection to the developing world gave them a stronger appreciation for the applicability of engineering to improve quality of life.

Engineering students shared the roles of lecturer, elementary student team facilitator, and supplies gatherer/distributor. Since they had no prior training in teaching, the lecturers were required to practice the presentation for an audience of their peers in the class period prior to the actual talk. The necessary supplies were on hand to complete the design challenge. The constructive criticism the lecturers received often led to drastic improvements in their presentations. The friendly, relaxed environment provided a perfect setting for allaying fears, calming nerves, and boosting confidence. It was also helpful for the students to have practiced the design challenges to have a clearer understanding of potential difficulties, hazards, additional needs, and outcomes.

Who Was Involved

Both projects were done in partnership with the Academically and Intellectually Gifted (AIG) program at a local public elementary school. This program serves fourth and fifth grade students who have been identified as gifted learners. They are instructed by a resource specialist in the areas of reading and/or mathematics. The school principal and resource specialist identified the participating students and obtained parental permission. Since the resource specialist knew the students best, she also assigned the elementary students to teams of two or three. The first-year engineering students traveled to the elementary school to engage in the activities immediately following the regular afternoon dismissal.

Issues related to recruitment and retention can be addressed in a service-learning partnership between an elementary school and first-year engineering students using Design Squad design challenges. The elementary students demonstrated improved learning and achievement in science and mathematics, increased awareness of engineering and the work of engineers, understanding of and the ability to engage in engineering design, and interest in pursuing engineering as a

career. The first-year engineering students reported increased engagement in the course, deepened curricular knowledge, more interest in civic engagement, improved communication skills, enhanced teamwork skills, and personal growth in areas such as leadership and preparedness. Preliminary assessment data also indicated that the Engineering is Elementary® unit was an effective tool for engaging elementary and engineering students in an engineering service-learning project. The elementary students' preliminary assessment data indicated they improved and deepened their understanding of engineering, and they were interested in and enthusiastic about learning about engineering. Their teacher praised the clear connection to social studies and opportunity to expand her students' understanding of the world. The engineering students appreciated the opportunity to serve in the community, engage in a hands-on project, and learn about one way that engineering can be used to serve globally. The engineering students were assessed on their ability to communicate about engineering with novices. It was evident that the engineering students initially struggled to explain the complex concepts related to the project to the novice audience, but dramatically improved over time.

Challenges

A number of first-year engineering students had bewildered looks on their faces when the outreach project based on Design Squad was introduced. Many were nervous about working with young people and fearful that they were glorified babysitters. Since then, this has been addressed in part by inviting the students' teacher to campus to discuss what they should expect from the elementary school students. Secondly, perseverance also helped as the two groups of students formed relationships and reported missing one another on weeks that class did not meet. Otherwise, challenges cited included insufficient time, classroom management, desire for more space to work, insufficient closing discussion, and inability to include more students. In addition to the items discussed above, assessment and evaluation of the degree to which the participants involved in the Engineering is Elementary® outreach experienced gains emerged as a challenge. We attempted to assess 1) the elementary school students using five minute papers in which students responded to a teacher-supplied prompt, 2) parents of participants using an evaluation at the conclusion of the unit, and 3) the engineering students using a reflective journal. Both the parents of the elementary school students and the engineering students failed to complete their assessments. This indicates that reliance on intrinsic motivation is not enough.

Programs #3 and #4

Institutional Context

The next two outreach programs were developed at the University of Illinois Urbana-Champaign, a large public land-grant university with a strong research foundation and undergraduate/graduate student engagement in service learning and outreach.

Curriculum/Learning Goals

The first program combines a two-semester graduate course and outreach to high school students enrolled in the AVID (Advancement Via Individual Determination) program. The outreach

focused on tenth grade students. The theme of the projects focused on accessibility and healthcare for individuals with visible disabilities. Working with graduate engineering students, the teams were introduced to engineering design using micro-controllers, circuit kits, and other components. To introduce the entrepreneurial content, curriculum components of the NSF I-Corps program were used to provide the students with general knowledge of the entrepreneurial process. The three goals of the program were to enhance the experience of engineering students engaged in community outreach by providing additional content to the engineering students focused on social justice, equity, access, and inclusion, to engage high school students with an introduction to STEM via hands-on design and practice, and to provide the high school students with an opportunity to see STEM skills and expertise used to directly impact the lives of individuals that may be differently-abled. Some participants in the program were selected for the opportunity to gain additional experience working in a research lab for a few weeks during the summer. Additionally, the engineering graduate students gain valuable perspectives of how engineering should play a role in addressing social justice issues that plague society.

A second outreach initiative, the Exploring Engineering Through Toy Design (EETD) program, has adapted the Toy Design Guides curriculum from the Lemelson-MIT and the Toy Product Design class at MIT. The students enrolled in the university course serve as mentors and facilitators to fourth grade students interacting with various toy products. The university students are asked to observe the play of students and to also conduct interviews to gain more insights. Those ideas are taken back to the lab on campus to develop prototypes and to get students interest, feedback, and help in the design process. The goal of the EETD program is to engage school students in STEM through playing with toys, learning about the unique engineering of toys, and finally designing toys.

Who was Involved

The AVID outreach program was initially developed using a graduate college grant developed by collaborating faculty from engineering, education, and liberal arts and sciences. This program initially focused on training science graduate students in K-12 teaching and lesson development using the now defunct NSF GK-12 Graduate Research Fellowship as a model. It was later modified to focus on engineering education and outreach in collaboration with the local school district's AVID program. The mission of AVID is to close the achievement gap by preparing all students for college readiness and success in a global society. AVID is a college readiness system that takes students with the potential and determination to attend college and supports their academic success in the rigorous courses required to enroll in four-year universities. In the AVID elective course, students are taught the skill sets, such as purposeful note-taking, organization, public speaking, and responsibility, necessary to be successful in those rigorous courses. Many students in the AVID program were the first in their families to attend college, come from low-income or minority families, or have unique personal circumstances that require a greater academic support system within the school day. AVID creates an atmosphere of positive peer pressure for the students so they are pushing each other to strive for success. After a

three-year hiatus, the program project was redeveloped in 2017 with the help of a NSF CAREER grant to focus explicitly on bringing social justice concepts into STEM teaching and outreach at all levels. In addition to introducing social justice concepts into STEM, the program expanded to bring in entrepreneurship training.

The EETD program was developed by engineering faculty and is supported by the Engineering Research Center (ERC) located on campus and the college's engineering first-year experience program. This program began in Fall 2023. The EETD program combines a first-year engineering course with outreach to an elementary school. The on-campus course provides an introduction to engineering design, project management, toy design, and the human centered design (HCD) approach. Students work in small teams on an engineering design project focused on creating and building playful products/services while working with fourth graders.

Challenges

Although the AVID outreach program integrates with a university course, funding the outreach activities is a challenge. Additionally, scaling the course experience across the college is another constraint. There is limited capacity for students to be able to learn these very critical integration concepts of STEM and social justice. Additionally, scaling the course across high schools is also limited by available resources.

The EETD program is in the early beginning. The primary challenge for the Fall 2023 engagement was to align the university course schedule with the local school outreach schedule. The university course meets on Mondays and Wednesdays, but the school outreach engagement days are primarily on Fridays. All the students could not attend and participate in the engagement sessions. Additionally, the course runs only one semester. A goal is to expand to fall and spring with the same cohort of university students, but that seems to be a constraint as some students can only take the class one semester. Another challenge is when to start the engagement in the elementary school. The local school district has teaching time and materials requirements and aligning the best day for the outreach engagement can be a challenge. Working with the schools on designated outreach days has been successful; however, the schedule may not always align with the university students' schedules. Some of the more positive opportunities are to bring more elementary students to campus to participate in hands-on learning at the design studio lab and to visit research laboratories. This activity is planned for 2024.

Program #5

Institutional Context

The Let's Build outreach program was developed in 2015 by the construction management program at Ball State University. The construction management program was established in 2004. As part of the program's curriculum, seven hours of technical elective credit are required to graduate with an undergraduate degree in construction management. Undergraduate students who participate in Let's Build earn technical elective course credit.

Curriculum/Learning Goals

The students from Ball State University serve as construction teachers and work one on one with elementary students during the weekly Let's Build lessons. The Let's Build curriculum was developed by the program coordinator who is faculty in the construction management program. The curriculum includes hands on activities and incorporates age appropriate books related to the construction industry. Each week, participants also build a snack that relates to the lesson. The curriculum helps the students to learn skills and concepts about the construction industry. To help incorporate new ideas and projects into the curriculum, the college students are responsible for developing at least one new lesson for the program. This lesson development gives the college students ownership in Let's Build.

The learning goals of Let's Build include to introduce students to the construction industry and careers in construction at a young age, to teach lessons about construction to elementary students, and to include students from Ball State University in an immersive learning project in their local community.

Who was Involved

Since its establishment, Let's Build has formed strong partnerships with several community organizations in Delaware County, Indiana. Those organizations include Muncie Community Schools, Delaware County Community Schools, the Ross Community Center, local Girl Scout troops, and the Muncie Boys and Girls Club. The program has worked with elementary students ranging in grades from preschool to fifth grade.

Challenges

As is the case with many outreach programs, funding for Let's Build is a continuous challenge. The program has received financial support through grants from both Ball State University and several external funding sources. These sources have provided funds to support the program for a short-term duration. Finding funding to finance the program for an extended amount of time is a continual process.

An additional challenge is recruiting community partners for the program. The ideal partners are elementary schools in close proximity to Ball State University. The number of elementary schools in the community is limited. Teachers in elementary schools must also adhere to national educational standards for each academic grade, which limits free time for programs like Let's Build to be included in the schedule of the regular academic day. Identifying new community partners for the program is an ongoing process.

Program #6

Institutional Context

The Corporate Responsibility Division of Cummins Inc. (an automotive engine manufacturing company in particular) has developed an initiative to improve equality of opportunity of STEM

careers among underrepresented minorities (URMs), particularly women, in communities around the world. As part of this initiative, the division has partnered with a prominent women's empowerment nonprofit to develop mentorship and educational programs at various chapters/affiliates of this nonprofit organization throughout North America. Engineers from this automotive company have worked with the corporate responsibility division to plan and execute an after-school STEM outreach program for kindergarten to fourth grade female students that are enrolled in this nonprofit, with project based learning (PBL) as a key component of this outreach effort. Projects include building and testing a fuel-cell car, robotics, 3D printing and programming. The goal of this program is to develop interest in STEM activities among female students to inspire them to pursue STEM careers in the future.

Curriculum/Learning Goals

Multiple sources were used for the curriculum including:

- Pre-packaged activity kits with detailed instructions from a professional society's foundation
- Activity kits from educational companies that specialize in STEM kits focused on hydraulic robots, drawing/sketching robots
- Robotics program modules from a prominent robot educational company in the United States
- Self-developed/original curricula developed by the employee planning/liaison team.

The various pre-packaged kits were also adapted to serve the needs of the students at the nonprofits, with lessons and concepts added or removed as necessary to allow the most efficient delivery of material. In addition, the lessons were modified to allow the students to use Microsoft Excel to plot data rather than just plotting them using pen and paper.

Who Was Involved

Engineering employees from the company plan and execute the lessons at the nonprofit on a weekday afternoon every week during the school year. A core team of employees serves as the liaison between the nonprofit and the corporation, helping to secure the logistics and funding for the activity kits and helping to recruit volunteers, who are employees of the corporation. The corporate responsibility division helps spread the word to recruit volunteers. Staff from the nonprofit also act as facilitators, supporting the corporation employees who teach the lessons.

Challenges

One identified challenge is volunteer recruitment. It is challenging to recruit volunteers on a weekly basis, as employees need to get permission from their managers to leave work earlier around 3 to 3:30 p.m. to participate in the afterschool outreach activities. Work tasks may take a higher priority and so volunteers may be unwilling to sign up. This in turn makes implementation challenging as there may not be sufficient volunteers to cover the large number of students and to provide more individualized attention.

Content delivery was challenging during the 2020 COVID-19 pandemic, as employees were not allowed to participate in community engagement activities on-site during lockdown. Therefore, it was necessary to procure laptops for the nonprofit to allow the students to continue the curriculum via virtual delivery through Zoom. The internet bandwidth at the nonprofit was also not strong enough to allow sufficient laptops connected to the internet, so the number of breakout rooms for individualized attention was limited.

Lessons Learned

The six programs highlighted in this article are examples of unique methods to introduce STEM fields to children. The following are lessons learned from both the challenges and successes of the programs.

Volunteer and Student Recruitment

The first lesson learned is the importance of volunteers to sustain outreach programs. Volunteers, whether that be student or employees at a corporation, are essential for the success of K-12 outreach programs. Identifying and keeping volunteers can be challenging for many reasons, including lack of time, scheduling conflicts, or lack of interest in the program activities. Having consistent volunteers helps outreach programs run more smoothly and allows volunteers to make long term connections with the student participants. A best practice for outreach programs identified in the literature is to develop strategies to recruit and retain volunteers for outreach programs. Offering course credit to college students or providing paid time off work for employees to assist with these programs are two proven strategies used by these six outreach programs to help recruit and maintain volunteers. Developing a plan to identify and to keep volunteers can help outreach programs sustain over the long term.

Funding is Essential

Outreach programs' curricula require supplies for learning activities, which requires financial support. Obtaining and sustaining funding for outreach programs is a best practice identified in the literature. Grants and other funding sources are available for these programs. However, those sources are competitive and are not guaranteed. The outreach programs highlighted in this article received funding from a variety of sources, including national grants, internal financial support from higher education institutions' academic departments and grants, and corporate partners. Finding funding to sustain these programs is a continuous challenge. Using any program funds to purchase materials that can be reused is one strategy to help extend funds. For example, purchasing curriculum kits that do not require additional materials or re-using items such as tools or personal protective equipment can help reduce the cost of outreach programs. Finding sources for funding or donations from industry partners to help provide curriculum and other materials for learning activities can help to ensure the longevity of outreach programs.

Monitor and Adjust

When developing and coordinating K-12 outreach programs, facilitators must be able to monitor

and adjust. Any number of unexpected issues, such as facilitators or student participants not showing up to lessons taking longer or shorter than planned to difficult behaviors by student participants to a global COVID-19 pandemic to lack of engagement or interest, can occur during each session. Having a plan and even a back-up plan is essential. The literature identified flexibility, adaptability, and creativity, as best practices for collaboration with K-12 partners. Utilizing those skills can help facilitators manage any unanticipated issues and help outreach programs thrive.

Involve Industry

Involving industry can aid in the success of K-12 STEM outreach programs. From providing facilitators to donating materials to support these programs financially, industry partners are a tremendous resource for these outreach programs. For example, the Let's Build program secured a donation of PPE, including safety glasses and hard hats, from a general contractor. The safety glasses were used on a weekly basis by the K-12 student participants, and the students took the hard hats home at the end of the program. These hard hats served as a reminder of the program and also provided free publicity for the contractor who donated them. The projected future need for candidates for job opportunities in STEM industries is well documented, and industry partners can benefit in the future by increasing younger students' interest in careers in STEM. This increased interest will hopefully help increase the number of people entering STEM fields and STEM careers. This industry involvement can not only help sustain outreach programs but can have an overall positive impact on STEM fields.

Conclusion

The six outreach programs highlighted in this article are examples of successful initiatives to teach K-12 students about STEM. Additionally, the program's facilitators and volunteers serve as mentors and examples of STEM university/college students in training as well as experienced STEM professionals. Initiatives like these outreach programs are a recruitment tool that professionals in industry and academia can implement to encourage student recruitment into STEM degree fields to help address projected workforce growth.

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