Delivering High Impact STEM Experiences to Underrepresented K-12 Students in Informal Settings: Strategies and Best Practices from Two Case Studies

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Abstract

Two STEM-focused programs were developed: one at North Carolina State University (NCSU) and the other at East Carolina University (ECU). The NCSU program provided a 3-part STEM research methods course and summer research experience for minority high school students in a pre-college program. The project began with a cohort of 37 students, of which 26 completed the program in its entirety with an intent to major in a STEM field. The STEM Girls program at ECU was a lab-based program for middle school girls. The majority of participants had a more positive attitude about STEM after completing the program. This paper discusses the sustainable elements of both programs that could be completed with little to no funding and could be replicated at other institutions. It also explores best practices for delivering STEM content to K-12 students in informal settings and shares advice on ways to engage industry in such endeavors.

Keywords

K-12, STEM, underrepresented, informal, best practices

Introduction

This paper explores low-cost implementation strategies and best practices for delivering STEM content to K-12 students in informal settings and shares advice on successful ways to engage industry in these types of endeavors. Two different programs are discussed: a STEM-focused research program developed at NCSU and delivered to high school students[1] and a lab-based program developed at ECU and delivered to middle-school girls. Both programs focused on increasing STEM learning opportunities for underrepresented students and both have sustainable elements that require little to no funding and could be replicated at other institutions.

There have been numerous reports on the current shortage of qualified STEM (science, technology, engineering and mathematics) professionals in the U.S. and the damaging impact that it will have on the nation's global competitiveness in these fields. As a result, efforts to bolster the number of students pursuing and persisting in these fields have increased. Much of that effort has been aimed at the K-12 level, as research has shown that early and frequent intervention is the most effective way of attracting students to STEM fields[2,3]. The nation's ability to meet future STEM workforce demand will require bringing more minorities and other historically underrepresented groups in STEM into the fold, as it has been projected that ethnic minorities will account for more than 50% of the U.S. population by 2050[4]. Although racial minorities currently comprise nearly 30% of the U.S. population, underrepresented minorities (URM) constituted just 18.9% of all science and engineering degree recipients in 2012, compared to 60% for their white counterparts[5].

While K-12 students typically get exposed to a number of STEM topics in their regular classroom, research indicates there are a number of benefits to STEM learning in informal settings for K-12 students[6,7,8,9]. Hartman et al.[10] assert that collaborative partnerships that bridge formal and informal learning experiences represent an important mechanism for addressing access and equity in K-12 STEM education. Informal learning experiences increase students' interest in STEM and support them in developing critical engineering problem solving and design skills[6]. Denson et al.[7] report eight emergent themes that illustrate the benefits of informal STEM learning environments for underrepresented students: 1) informal mentoring, 2) makes learning fun, 3) time management, 4) application of math and science, 5) feelings of accomplishment, 6) builds confidence, 7) camaraderie, and 8) exposure to new opportunities. Given that students spend the majority of their time outside of the formal learning environment of the classroom, it is critical that higher education institutions continue to develop and offer strong STEM outreach programs to their communities so students of all backgrounds have opportunities to recognize pathways to pursue STEM.

Program Overview & Implementation

The STEM research program at NCSU was funded by an independent private foundation and provided a STEM-focused research methods course and summer research experience for minority high school students (grades 9-11) in the NC-Mathematics and Science Education Network Pre-College Program (MSEN). Students entered the program as ninth graders and continued through to their junior year. The program was designed to provide exposure to research methods, engineering design principles, and STEM careers and professionals. Undergraduate students in the minority engineering program (MEP) at NCSU mentored the MSEN students throughout the project.

The research methods course was taught in three parts over the three year project period: introductory-9th grade, intermediate-10th grade and advanced-11th grade (Fig. 1). Course topics included: the scientific method, engineering design process, data collection and analysis, fundamentals of Microsoft Excel, statistics, and research and career opportunities in STEM. Each part of the course consisted of 10 class sessions for two hours per session as a part of the MSEN Saturday Academy. Class sessions were held on the campus of NCSU.

Figure 1. Pre-College STEM Research Experience Model

The STEM Girls program at ECU began as a community outreach program to help build awareness of the university's new engineering program. Initial funding for the program was through a grant, and funding in subsequent years came from a local manufacturer. Program attendees were girls from the 13 public middle schools in the Pitt County School System. Each school was allowed to select up to eight

girls to attend. Teachers were asked to select a diverse set of students based on interest in STEM and potential to benefit from an off-campus experience.

Demographics of Student Participants

The STEM research program at NCSU began with a cohort of 37 ninth grade students and concluded with 26 students having completed the entire program. Student demographics varied slightly from year to year but the majority of participants (85-90%) were URM with about 65% of them male and 35% female. Most of the students attended schools in two of the surrounding counties. There was also variation in the number of student participants across the three project years due to some anticipated attrition. The number of student participants in the engineering course and summer experience ranged from 20-34 over the duration of the project.

At ECU, all participants attending STEM Girls were female eighth graders. While the program existed for six years, participation data are not available for all of those years. Data indicate an average of 104 students per year attended STEM Girls from 2011 to 2016. Demographic data were only collected in the initial year of the event, and indicate that participants were 42% African-American, 38% Caucasian, 15% Hispanic, and 5% from other races/ethnicities. The demographic spread of the participants remained fairly consistent across the six years.

Program Activities

The program at NCSU provided a variety of research activities for the student participants covering a wide range of STEM disciplines. As a part of the introductory research course in year 1, students conducted research on assistive devices and designed and fabricated a prosthetic limb. The summer experience in year 1 allowed students to explore transportation systems engineering. They learned about the history of autonomous vehicles and how to program Lego® Mindstorms® NXT-G to simulate car movement through various traffic situations. In the second year of the course, participants conducted preliminary research on drone technology and put that research into action during the summer of year 2 where they researched the effect of drone mass on battery life. During the final year of the project, students were tasked with integrating both the scientific method and engineering design process in the modeling, design and testing of a mousetrap car. In the summer of the final year, participants spent four weeks conducting research in the laboratory of STEM faculty member at NCSU. A number of faculty representing a wide variety of STEM disciplines participated in the culminating one month summer research experience.

The MEP undergraduate student mentors attended each Saturday session of the research course. They assisted the STEM teacher in developing the lessons for the course and guided students through the various projects and activities over the duration of the program. MEP mentors proved to be an integral part of the success of the program. STEM professionals from industry and academia were invited to the course to present on STEM careers and opportunities available in the STEM disciplines.

At the ECU program, students were transported via school buses to campus and the day began with a large group assembly. The featured speaker at the assembly was a young female (under 18) who had started her own not-for-profit to help save sea turtles. Her presentation enabled the

students in attendance to see that someone like them (a student) could accomplish great things if they had goals and a plan to meet those goals. After the initial presentation, students were divided into four groups and escorted over to the Science and Technology building to participate in interactive, STEM-focused labs. Each lab lasted approximately 30 minutes and was led by a female faculty member from ECU with expertise in the area. Engaging and age-appropriate lab activities offered students the chance to create, learn, and question. Students rotated through the labs, with each student attending all four labs.

Following the lab sessions, participants were all together as a large group for lunch, and ECU engineering students intermingled among them to share their college STEM experiences. Lunch was followed by the final event, a lesson on 3D printing led by a female engineering student. Post-event surveys indicated participants enjoyed this session the most.

Summary of Program Results

Overall, the NCSU project was very successful based on results from annual program evaluations, which were informed by a variety of sources including program artifacts, observations, focus groups/interviews, surveys and a science content knowledge assessment. Evaluation results showed that the program leaders were able to create and implement a high quality, engaging research methods course and summer research experience that had a positive impact on students' 1) science and mathematics competencies, 2) enthusiasm for science and mathematics, 3) interest in STEM careers and 4) self-efficacy in STEM research and careers.

Of the 26 participants that completed all three years of the program, 19 of them (73%) were accepted into a college or university and intend to major in a STEM field. There were a variety of intended STEM majors identified by students, including marine biology, environmental sciences and engineering, with engineering/computer science making up the largest percentage (47%) of intended majors. Of the remaining seven students, four of them (15%) indicated an intent to major in business and/or marketing, one was undecided and the other two have not provided information on their plans after high school.

A survey that was administered as a part of the program evaluation offers information about the students' perception of their science skills and their degree of enthusiasm about science. Overall, the results were positive, as expressed in Figures 2 and 3.

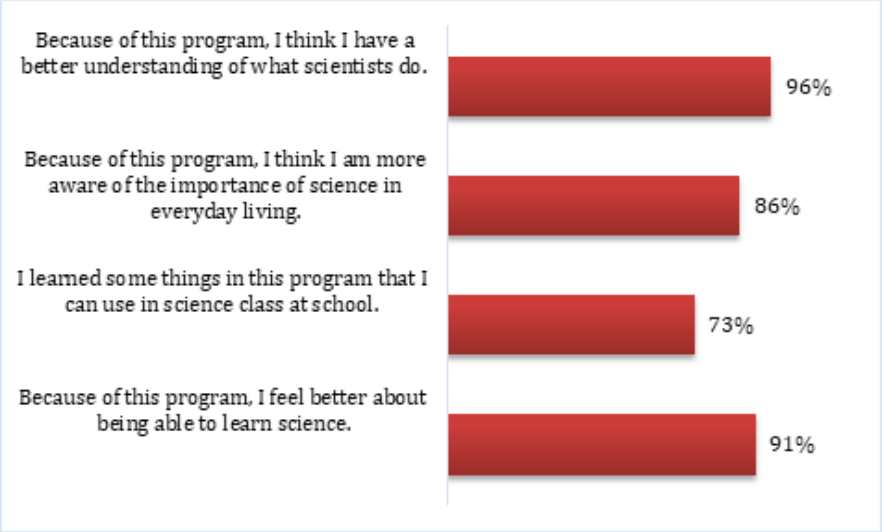

Figure 2. Percentage of students who agree/strongly agree to items about science skill development

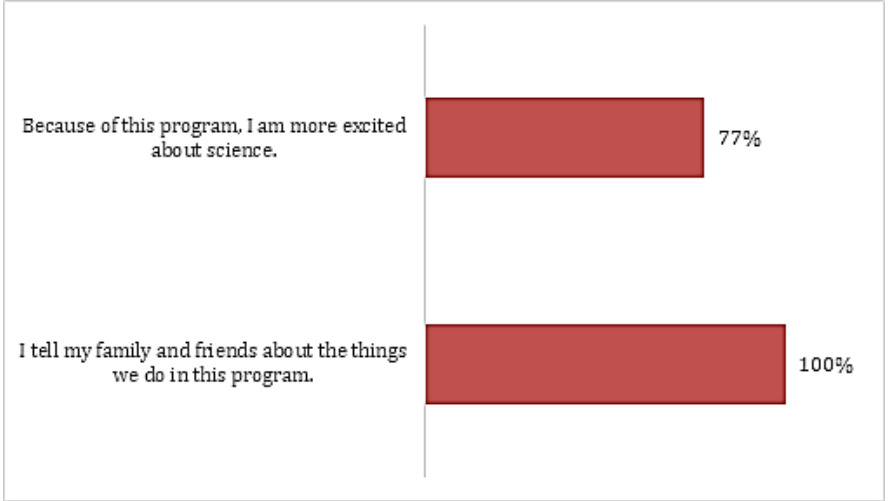

Figure 3. Level of science enthusiasm at the conclusion of the STEM research program

For STEM Girls, participants were given a survey to take following the day-long program. Key findings from that survey for 2014 are provided below in Table 1. As the survey results indicate, a large portion of participants felt favorably about STEM prior to the event. However, a number of them shifted their responses from "Agree" to "Strongly Agree" after taking part in STEM Girls.

Table 1 - Pre/Post Survey Results for 2014 STEM Girls Program[a]

Survey Statement	**Agree**[b]	**Strongly Agree**[b]
I plan on taking STEM classes in high school.	54% / 51% (-3%)	41% / 45% (+4%)
I would like to go to college for a STEM degree.	45% / 39% (-6%)	29% / 39% (+10%)

I believe that I could succeed in a STEM job.	61% / 42% (-19%)	34% / 55% (+21%)
The STEM Girls Conference increased my interest and confidence in STEM jobs and classes.	NA / 36%	NA / 56%

[a]Survey responses for n=102.
[b]Brackets indicate the percentage change in the pre/post-survey responses.

The steering committee that planned STEM Girls each year also received positive feedback from the teachers and counselors who attended the program. Faculty from two neighboring county's community colleges attended the event in 2015, with aspirations of creating a similar event for their local middle-school girls. To date, those other events have not been held.

Low Cost Implementation Strategies

Many of the projects that were conducted as a part of the STEM research program at NCSU were completed with low cost, readily available materials. As an example, students used materials like PVC pipe, Styrofoam and plastic soda bottles to construct the prototypes for the prosthetic limb project. Similarly, the mousetrap car project included materials such as mousetraps, blank CDs, rubber bands, balsa wood and glue. Therefore, cost does not have to be a limiting factor when deciding to integrate STEM activities into outreach programs. There are a number of online resources available that share ideas for K-12 STEM activities that can be incorporated into instruction at very minimal cost and have been vetted by STEM professionals. Examples of these online resources include websites like teachengineering.org and Project Lead the Way. In addition, many universities have K-12 STEM outreach programs and readily publish STEM activities and resources on their websites.

The STEM Girls event at ECU cost under $1000 to hold. The two main expenses were lunch for the attendees (students and chaperones) and t-shirts for participants. ECU worked with a local t-shirt vendor who was able to produce STEM Girls t-shirts for approximately $6.50 apiece. The logo was kept the same each year, and the year was not put on the shirts so that extra shirts could be used the following year. Funding for most of the years of STEM Girls was provided by a local manufacturer. The liaison for that company learned about STEM Girls after two members of the STEM Girls steering committee gave a presentation at a women's event held on campus. As that funding ran low, the three colleges involved in the program each contributed a small amount to cover the cost. None of the faculty who provided labs or oversight for STEM Girls received compensation. The program's opening speaker was given a small honorarium.

Best Practices

There were a number of best practices that came out of the evaluation of the NCSU STEM research program. One of the major ones included incorporating a wider variety of STEM activities into the research course. We found that the heavy focus on engineering-related activities in year 1 may have alienated some of the female students whose interests were more in the medical sciences. Furthermore, we found that interest levels varied from student to student and from year to year. As a result of these findings, we were more intentional in subsequent project years about ensuring

that more of the STEM disciplines were represented in the course and summer activities, and in offering multiple, smaller projects rather than a few larger ones in order to accommodate more of the students' interests[1]. Another key best practice that came out of the evaluation results was the inclusion of the student mentors. A recurring theme from the participants was the value of the MEP mentors. According to participants' comments during interviews and focus groups, seeing someone who looked like them be successful in engineering had a lasting impact on them. Other best practices that emerged included providing more opportunities for reflective thinking about the various research projects, and discussing the role of failure in STEM research. It is important for students to understand that failure is a natural part of the process and therefore, should be expected and embraced as a learning opportunity rather than a shortcoming.

Providing participants with access to STEM professionals was found to be very impactful. In the STEM research program, guest speakers from industry and academia were invited to present on career opportunities in their field and their day-to-day activities working as a STEM professional. In some cases, the speakers were not able to be physically present and in those instances, we facilitated Skype presentations, which cut down on travel costs associated with bringing in speakers that were not from the local area.

For STEM Girls, the steering committee made the difficult decision to keep the event local, only inviting students from Pitt County. Logistically, the event would have needed to start later and end earlier if other counties had been invited, due to busing constraints. The committee also decided that expanding to a group larger than approximately 100 would not work, due to the smaller group sizes needed to make the labs interactive and able to fit in the available classroom and laboratory space. For the faculty leaders, the committee felt it was necessary to utilize female faculty so that the participants could see that someone "like them" had succeeded in STEM. While the specific faculty lab leaders changed over the years, female instructors always led the sessions and labs were always interactive, to the extent possible.

Engaging Industry

Reaching out to local industry can be a great way to give K-12 students exposure to STEM careers and acquire the funds needed to provide informal STEM learning opportunities, particularly if the STEM activities are aligned with a specific company's business goals. For example, as an extension of the STEM research project, we aim to work with local manufacturing companies to develop STEM activities around advanced manufacturing processes. Structuring your program in this way will create a win-win situation for both sides, where students gain access to STEM professionals and companies invest in the STEM workforce of the future. In fact, many companies have an outreach arm whose sole purpose is to develop STEM talent in the local community. Connecting with individuals in those outreach roles can be a great way to start forming and building relationships with industry.

In smaller towns and rural areas in particular, there may also be companies who have a strong culture of serving their local community. As a part of their community service commitment, these companies are often willing to donate to projects that impact K-12 students in their area. Identifying these companies is not always easy, but news of their donations and funded projects is

often published in local newspapers or on local news websites. It may be necessary to work with your institution's Foundation Office to ensure that all protocols for seeking funding are followed.

Summary

Both of these programs successfully engaged underrepresented groups in STEM activities outside of the classroom. The types of activities the programs involved can be implemented at other institutions without the need for a large grant to support them. Using existing resources for content and supplies, engaging with local industry, and utilizing volunteer faculty with a passion for STEM, other two-year and four-year institutions can create informal learning opportunities for K-12 students to help them realize their potential in STEM.

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