Lessons Learned in K-12 Engineering Outreach and Their Impact on Program Planning (Evaluation)

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Jacob Benton is currently a project engineer with Primoris Services Corporation. He provides on site support for construction operations in the highway and bridge construction sector. Jacob holds a B.S. degree in Civil Engineering and a M.S. degree in Engineering with a concentration in civil-structural engineering. As a graduate student at the University of Louisiana at Lafayette Mr. Benton served as the primary assistant for the Engineering Outreach section of the Lafayette Parish School System’s GEAR UP Program.

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Traci Aucoin is currently the Lafayette Parish School System GEAR UP Project Director. She has worked in education for 30 years and has been a part of the GEAR UP initiative for seven years. She began her career as a high school biology and physics teacher before she moved into higher education where she served the University of Louisiana at Lafayette in numerous capacities for over 20 years. She served as Director of the Alumni Association, Director of Special Projects for the President, Director of University College, and Director of High School Relations. Through her work experience at UL, she has been able to develop and sustain strong community and post-secondary partnerships and bring valuable resources and expertise to the Lafayette Parish System GEAR UP initiative.

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Gloria is a Civil Engineering student working towards obtaining her master’s degree in Structural Engineering. Her interest in engineering education stems from having attended a constructivist primary school, and her experience in K-12 education ranges from assisting her siblings with their schoolwork to working as a math and reading tutor for a private organization. She has been a member of the GEAR UP engineering outreach program since 2016.

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Adam K. O’Neill will complete a BS in Mechanical Engineering at Saint Louis University this spring. As an undergraduate his research experience has been in fluid dynamics, specifically flow visualization and CFD, and engineering education, both through mentoring high school design groups and developing STEM based course work. He is also interested entrepreneurship and lean business development.

Miss Sana M. Syed, Saint Louis University
Sana Syed studied biomedical engineering and has proceeded to pursue her PhD in biomedical engineering and engineering education at Saint Louis University. She aspires to go on to work in industry where she will be able to mesh her passion in biomedical engineering and healthcare as well as in education reform in engineering.
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Introduction

The United States relies on a well-prepared workforce to remain competitive in science and engineering. However, the number of engineering graduates is insufficient to cover the growing demand. As a result, an abundance of outreach programs exist throughout the country with a specific goal to increase the interest in engineering and the number of students pursuing engineering degrees. Unfortunately, the ideal format for effective outreach programs does not yet exist and needs formal evaluation. This paper highlights two formal engineering outreach programs that were part of two Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP) grants acquired by the Lafayette Parish School System (LPSS) in Lafayette, Louisiana. Each grant focused on increasing college readiness of a cohort of children from underrepresented minorities and low socio-economic backgrounds through various partnerships including a range of academic areas. This paper focuses solely on the two engineering outreach programs. The first program was a partnership between the LPSS and the University of Louisiana at Lafayette (UL Lafayette) from 2009 to 2015 and the second program is a partnership between the LPSS and Saint Louis University (SLU) that began in 2015 and will run through 2021. Concurrent to the GEAR UP grants, both outreach programs progress with the children as they advance through middle and high school until they graduate. The paper includes a summary of the activities from the first program along with best practices and lessons learned that are supported by qualitative data from a teacher focus group and student respondents. Additionally, the paper also provides a description of the second program including program development and plans for more formal assessment. (Note: The engineering outreach programs are part of the GEAR UP grants. The GEAR UP grants are referred to as “grants” and the engineering outreach programs are referred to as “programs” throughout the paper.)

About GEAR UP

Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP) is a competitive grant program of the United States Department of Education designed to increase the number of low-income students who are prepared to enter and succeed in postsecondary education [1]. It provides states and local community-education partnerships with six-to-seven year grants to offer support services to high-need, middle and high schools. State grants are matching grants including multiple school systems that must include a scholarship component, while partnership grants focus more on collaborations among a school system, institutions of higher education, local and state education entities, businesses, and community-based organizations. The support services include critical early college awareness and activities like tutoring, mentoring, academic preparation, financial literacy, and career education to improve access to higher education for low income, underrepresented minority, and first-generation students and their families.

The Lafayette Parish School System (LPSS) successfully acquired two GEAR UP partnership grants in the past ten years. The first grant began in 2008 and concluded in 2015, while the second grant began in 2014 and will continue through 2021. Both grants began with a
A cohort of approximately 2,300 6th and 7th grade students and progressed with them until they graduate high school. The grants initially included students from six middle schools based on high percentages of underrepresented minorities (71% average) and students qualifying for free and reduced lunch (78% average). The majority of those students feed into four high schools, which the grants also included. The first grant resulted in significant impacts on cohort graduation rates and postsecondary applications, which directly contributed to successfully acquiring the second grant. Nearly all cohort students from the first grant graduated from high school and the majority submitted applications to attend postsecondary education. Table 1 shows comparisons for graduation rates and postsecondary enrollment/application rates between a control group of students from a previous year and the cohort students from the first grant at each of the four high schools. While additional supporting data exists from the first grant as a whole, the scope of this paper focuses only on the evolution of the engineering outreach programs and the lessons learned during that time regarding planning and assessment.

Table 1—LPSS GEAR UP Graduation and Postsecondary Enrollment Data

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The academic performance of cohort schools fails to meet state standards in both core academic and non-core subjects and falls short of national averages on standardized tests. In particular, students from underrepresented minorities and those that qualify for free and reduced lunch perform at lower levels. Recent data for cohort middle schools showed that 8.4%, 13.5%, 21.5%, and 10.0% more non-white students are below basic mastery of English, math, science, and social studies, respectively, compared to white students. Likewise, the data also showed that 13.2%, 16.4%, 22.6%, and 14.1% more students qualifying for free and reduced lunch are below basic mastery of English, math, science, and social studies, respectively, compared to students that do not qualify. Achievement gaps clearly exist, particularly in math and science.

The overall goal of the grants was to establish partnerships and processes that help create a sustainable college-going culture to improve college readiness of cohort students. The partnerships included a variety of institutions of higher education along with community partners and businesses that focused on a range of academic areas. While the first grant was clearly successful, the second grant goes beyond general college readiness and focuses more on STEM. This paper specifically focuses on the engineering outreach programs developed by the lead author at UL Lafayette and SLU that were only small portions of each respective GEAR UP grant.

Outreach Programs

The United States is a historical leader in science and engineering [2]. However, interest in math and science among pre-college students is fading and in many cases students are
deficient in math and science achievement [3] performing at or near the bottom of international assessment [4, 5]. Likewise, enrollment in undergraduate engineering programs has also declined in years past [6, 7]. Particularly, the number of females and underrepresented minorities pursuing engineering degrees does not correlate with percentages in other disciplines [8-10]. Jeffers et al. [3] note the decline may be a result of students’ limited understanding of engineering and Rockland et al. [11] and Yates [12] note that students are just not exposed to relevant topics. Similarly, Bogue et al. [10] state that there is little evidence that outreach activities effectively reach women and those from underrepresented minorities. If the percentage of such groups in engineering is to remain comparable with percentages of the United States’ population, organizations must focus their efforts on these groups. Consequently, an abundance of outreach activities exist throughout the country with a common goal to increase the awareness of and interest in engineering [2, 3, 5-10, 12-17]. Sullivan et al. [13] and Jeffers et al. [3] list a number of activities typically taken by outreach programs, which generally fall into three focus areas: 1) students, 2) teachers, and 3) curriculum development.

Student-focused programs generally include onsite presentations, field trips, mentoring programs, summer camps, and project competitions [3, 6, 12, 13, 15, 17]. Onsite presentations are the quickest and most efficient way to reach a large number of students [3], but presentations do little more than provide an introduction to the field. Likewise, field trips result in much of the same. Mentoring programs provide great influence on students, but most of the programs for students are one to two-week long summer camps or competitions that utilize a variety of hands-on activities [3, 7, 13-15, 17]. Douglas et al. [8] and Ralston et al. [15] note the importance of hands-on learning for attracting students to engineering and some of the most proven attributes of such activities are self-motivation, real-life application, and immediate feedback [2]. Simply put, students need to do some of the engineering in order to learn about engineering [3]. While hands-on activities provide valuable knowledge about the field and enhance various cognitive skills, many of them lack an analytical component, which Fantz et al. [2] states, “gives students a false sense of collegiate engineering programs.”

Numerous outreach programs referenced teachers as a critical component for their success [3]. However, most teachers know very little about engineering [6] and have little to no exposure to the field at all [18]. Ironically and unknowing to themselves, math and science teachers bear the incredible responsibility of maintaining student interest in math and science, which has a major impact on the development of students and their future career decisions [3, 6]. Thus, there is a great need for teacher training to improve engineering awareness and readiness [6, 18]. Researchers recommend introducing engineering in the context of math and science at earlier ages to increase interest and the most direct route to improve math and science achievement is undoubtedly better teaching [3, 19]. Teachers need to learn what to teach and how to teach it [20]. As a result, there is a large movement to provide professional development opportunities for in-service teachers to help integrate engineering content [18]. Jeffers et al. [3] states, “The key is to have informed and motivated teachers that can excite and instill confidence in their students.” Professional development opportunities should introduce techniques for integrating content within the curriculum [6, 20] and teachers should have an opportunity to experience what they will have their students do [13]. Best practices show that teacher workshops followed by student camps are the most effective sequences for teacher development.
This process provides teachers an opportunity to experiment with the concepts and enhance their knowledge in a low-pressure setting [3, 14].

The current educational model used in the United States unfortunately limits curriculum modifications, and state mandated standards and performance measures indirectly limit the creativity of teachers. Although teacher workshops provide the low-pressure environment for teachers to experiment, engineering content must align with state math and science standards for inclusion within the curriculum [2, 3, 6, 12-15]. Some schools offer pre-engineering courses such as Project Lead the Way and The Infinity Project, which compliment existing math and science courses, but require students to be enrolled in a college prep math sequence or have already completed various math courses (e.g. Algebra II) to participate [6]. Furthermore, the programs that do attempt to include engineering within the existing curriculum generally focus on science classes. While these programs all have merit, very few seem to focus on what appears to be the underlying issue: the lack of foundational knowledge in mathematics. Gleason et al. [21] found that math placement has a strong correlation to retention rates in engineering. In fact, students with low placement scores account for less that 10% of engineering graduates and those with scores in the middle account for nearly 40% of dropouts.

In addition to the focus on students, teachers, and curriculum development, partnerships and assessment also play critical roles in successful outreach. Partnerships vary across the board, but are necessary for implementation. Sullivan et al. [13] mention that a strong team representing all parties involved is essential to success. Yates [12] used a “vertical slice” partnership, which included representatives from each level of education (elementary schools, middle schools, high schools, a university, and industry). The most critical partnership is perhaps between universities and school districts. Such connections are important for university access to teachers and obtaining feedback. In fact, program planning should include K-12 teachers and curriculum specialists on the front end for insight on teachers’ needs and plans for sustainability to help generate long-term K-12 community partnerships [13]. Lastly, the value of involving, collaborating with, and consulting assessment specialists in educational psychology should not be overlooked [14].

Assessment efforts are generally an afterthought in engineering outreach programs, tending to focus on short-term results and customer satisfaction. Such types of assessment typically show participants enjoyed the activity, but not whether such activities achieved the outreach goals and objectives [17]. Fantz et al. [2] used formal assessment to determine the influence of outreach activities on the engineering self-efficacy of engineering students. They found only seven of 53 activities had a statistically significant difference on self-efficacy of students who did and did not experience the activity. Of those seven activities, five were pre-collegiate hobbies and two were pre-engineering classes. Although there were no significant differences in self-efficacy with respect to other activities, many still have merit in the outreach process, and assessment results like these are important in planning new programs to ensure the most efficient use of time and resources. Engineering self-efficacy is emerging as a useful theory in evaluating the confidence of students to pursue engineering related professions and the confidence of teachers to teach engineering related content. In particular, Faber et al. [5] and Yoon et al. [18] developed the Student Attitudes toward STEM (S-STEM) survey and Teaching
Engineering Self-Efficacy Scale (TESS) survey, respectively. Such surveys used in conjunction with outreach activities may help allocate time and resources to more influential activities.

In summary, the literature provides valuable information about engineering education in K-12, including typical types of program offerings, what has been most effective, and suggestions for assessment to help evaluate the effectiveness of outreach efforts in the engineering community. This information is incredibly valuable for planning new outreach programs. The research in K-12 engineering education is rapidly progressing and many of the references discussed herein were published during the first program (2009-2015). The following sections provide an overview of the first program along with assessment efforts and lessons learned and how that impacted planning the second program.

Program I Overview (2009-2015)

Program I began with a summer engineering camp that evolved into a yearlong program including on-site presentations, after school activities, and a summer camp. Table 2 lists the activities from Program I with respect to academic year and grade level. Year 1 activities included two one-week summer camps for 7th and 8th grade students, which included a variety of short activities and small-scale projects. As expected, the hands-on activities were the most engaging and qualitative observations quickly confirmed the future potential of the program.

Year 2 activities took a different approach. First, the lead author gave approximately 40 on-site presentations at cohort schools about engineering. The presentations included a brief PowerPoint presentation about engineering, followed by an interactive bridge experiment where students stacked books on pre-made balsawood bridges (Fig. 1(a)). Second, project competitions were implemented across participating schools consisting of a West Point Bridge Designer competition (Fig. 1(b)), balsawood bridge competition (Fig. 1(c)), and a foam core board chair competition (Fig. 1(d)). Lastly, to cap off Year 2 activities, students also had the opportunity to attend a one-week summer camp. The second offering of the camp included collaborating with the College of Education at UL Lafayette. The morning portion of the camp focused on hands-on, math-based activities, while the afternoon portion of the camp focused on hands-on engineering-based activities.

Year 3 activities mirrored those from Year 2. The lead author gave roughly the same number of presentations, but focused more on college awareness and how education can lead to improved quality of life. The project competitions included the West Point Bridge Designer competition, the foam core board chair competition, and the concrete arch competition (Fig. 1(e)). The summer camp also had the same format with the morning portion led by the UL Lafayette College of Education focused on math-related activities and the afternoon portion focused on engineering-related activities. The lead author piloted an interactive module in the morning session of the third day of the camp to illustrate the real-world application of mathematical concepts in engineering. Students were broken up into groups and given a 16 in. by 20 in. piece of foam core board and told to create a box with the largest possible volume that could be used to ship a product (Fig. 1(f)). Some groups guessed the dimensions and just made a box. However, two groups joined together and developed an equation for the volume and manually iterated until they solved for the optimal dimensions. This pilot module proved to be a
pivotal discovery for the future of Program I and planning for Program II. As a result, the participating teachers asked for more modules to use in their classes.

The engineering-related activities took a different direction in comparison to Year 2. Rather than provide several small projects, the camp focused on one large project modeled after *Designing and Building File-Folder Bridges: A Problem-Based Introduction to Engineering* [22]. The objective was to construct the lightest foam core board bridge capable of supporting a team of students over a 10 ft span. First, students sketched a truss design with the assistance of an engineering student mentor. Second, they dimensioned their design and began to fabricate individual members and gusset plates. Lastly, they assembled their bridge using hot glue. The final bridges weighed between 20-25 lbs. Following fabrication, students had the opportunity to load their bridges by climbing onto their bridge. Fig. 1 (g) shows one of the bridges with students atop just before collapse. The foam core board bridge project proved to be much more involved than initially thought and required hours of work by the engineering student mentors and the lead author in the evenings to ensure project completion by the end of the week. While it was overly ambitious, it illustrated what students were capable of accomplishing. Some students showed deeper interest in how and why the bridges collapsed. They began to think critically about design and construction, which led to the development of future large-scale projects.

Year 4 activities continued with the same approach as previous years, including on-site presentations, academic year project competitions, and a summer camp. The lead author gave presentations once more to the majority of the cohort, focusing on his experience as a first-generation college student. The project competitions included the concrete arch for the second time coupled with an 8 ft long wooden bridge competition (Fig. 1(h)) and a Jeopardy challenge to incorporate more math-related content. Additionally, the program included a pilot program of learning modules to use with the afterschool activities along with professional development opportunities for the teachers. The summer camp took a slightly different approach compared to previous years. The morning session still focused on math, but was led by engineering student mentors and the lead author. Students competed in an interactive math-based scavenger hunt. Clues were scattered across the campus of UL Lafayette and tied directly to math problems. Students would solve one problem to reveal a secret coded message that provided the location of the clue along with a second problem, whose answer resulted in the combination of a lock tied to each clue. Students showed a determination to solve challenging problems with their teammates and were amazed by their ability to solve such difficult problems. The scavenger hunt approach undoubtedly engaged the students more than previous years' activities.

The afternoon activities continued with the large-scale project approach. Students were tasked with designing an 8 ft wide by 40 in. tall retaining wall capable of resisting the lateral pressure of limestone backfill using only foam core board and hot glue (Fig. 1(i)). The objective was to construct the lightest wall that would support the greatest lateral pressure. Engineering student mentors helped participating students “design” their walls and aided with fabrication activities, which took about three days to complete. On the fourth day, the engineering student mentors and the lead author tested each wall using a three-sided reinforced wooden box. Each retaining wall was placed just inside the open side of the wooden box and a Bobcat loader was used to place crushed limestone inside the box. Each wall remained in place until the wall failed by overturning, sliding, or rupture. Surprisingly, every retaining wall held the full 40 in. depth of
limestone. One wall required additional limestone in excess of the 40 in. depth along with a push from the Bobcat. Some students began to understand how and why their walls failed and think about what they would have done differently. The effort and time required for construction was appropriate, requiring no work outside of camp hours. However, resetting the test setup for each retaining wall test was very labor intensive for the engineering student mentors. In hindsight, the removal of limestone and resetting the test setup needed more planning.

Year 5 was the last year to include both academic year and summer camp activities. The academic year activities included two project competitions, a foam core board stepstool and a trebuchet competition and the professional development for teachers was tied to both competitions consistent with recommendations in the literature [13]. The foam core board stepstool was similar to previous offerings of the foam core board chair. The objective was to construct the lightest stepstool capable of holding a 160 lb person ascending the three steps. The trebuchet competition was inspired by the Science Channel’s show “Punkin’ Chunkin.” A team of engineering student mentors constructed and delivered trebuchets to each of the participating high schools. During the spring semester, engineering student mentors supervised practice sessions at each high school for participating students and teachers to learn how to use the trebuchets. The purpose of the practice sessions was for each school to develop “launching curves” based on pin release angle and counterweight to aid with the competition. The primary objective for the final competition was to successfully launch cantaloupes and hit various bulls-eyes while simultaneously passing through field goal posts from various locations. The field for the trebuchet competition was 80 yd long and 50 yd wide. A field goal post was placed 20 yd from the end line. Three 20 ft diameter bulls-eyes were painted along one end line and one more in the center 10 yd from the end line. Each school’s team rotated through five different positions on the field ranging from 10 to 40 yd from the field goal post. Fig. 1 (j) shows an aerial view of the trebuchet field. Students successfully learned how to adjust pin angles to control the trajectory and counterweight to control the distance. Overall, they appeared to show an understanding of the engineering concepts associated with the mechanical system.

The summer camp activities followed the same approach as Year 4, but with a slight modification. Rather than hold independent morning and afternoon sessions, the two sessions were linked together. The objective was to legitimately design and construct an 8 ft long bridge capable of supporting 1,500 lb using only DOW Styrofoam and high-strength hot glue (Fig. 1 (k)). The bridge design required students to have a basic understanding of seven engineering topics including basic statics, shears and moments, centroids, moments of inertia, bending stress, first moment of the area, and shear flow. Engineering student mentors guided students through seven problems focused on each topic as part of a scavenger hunt. Like the Year 4 summer camp each problem provided the combination of a lock that secured the next problem hidden throughout the UL Lafayette campus. Riddles inspired by the National Treasure movie franchise were used to identify locations. The seventh location provided students with the design specifications for the bridge, including dimensional limitations and predetermined material properties for the Styrofoam and hot glue. The scavenger hunt took a day and a half to complete and students were unaware they were learning sophomore and junior level engineering concepts. Some students showed a better understanding of the concepts than some college students do.
Following the scavenger hunt, the students were equipped with the tools necessary to design a bridge. Each group of students spent the afternoon of the second day and morning of the third day going through design iterations under the supervision of an engineering student mentor to select their cross-sections. When finished, they provided a bill of materials that the engineering student mentors used to cut Styrofoam to size. Beginning in the afternoon of the third day, student teams began construction of their bridges, which ran through the morning of fourth day and testing occurred during the afternoon of the fourth day. Of the six bridges constructed, two of the bridges successfully supported over 1,500 lb prior to failure, one of which supported over 1,600 lb. This project was the first in Program I that effectively linked a large-scale project with an analytical component to provide a representative example of collegiate engineering and thus overcoming the issue noted by Fantz et al. [2]. The reaction of the students as they watched Styrofoam bridges support over 1,500 lb was clearly that of astonishment (i.e. “Did we really design that?”)

Year 6 was the last year of Program I and only included academic year activities. The trebuchet competition was a great success from Year 5, so it was an easy decision to continue with a modified version of that competition. The trebuchets from Year 5 were disassembled and redesigned to create two, more durable, trebuchets. The trebuchet competition for Year 6 combined the excitement of launching projectiles with the board game Battleship. The competition took place on a 160 ft long by 80 ft wide Battleship course complete with a 4 ft by 4 ft grid and an 8 ft tall wall stretching the entire 80 ft width to separate each side. Each side also included a stationary trebuchet capable of rotating and launching a 4 lb medicine ball over 160 ft along with a series of mobile ship models constructed by engineering student mentors. Participating students then competed against each other in a game of Battleship, but in addition to guessing a location (e.g. D-10), students attempted to hit the location with a 4 lb medicine ball launched by the trebuchet. The competition included two two-hour halves and each team was allotted up to 25 launches per half with a minimum of 20. The competition was a single elimination tournament consisting of six teams and three rounds. Students were consistently able to launch and hit targets even though they could not see over the wall.

In summary, Program I featured a variety of activities over the course of its six years and approximately 300 of the 2300 cohort students chose to participate. The activities included three on-site presentations (these reached approximately 1500 students), more than ten project competitions, and five consecutive summer camps. The engineering camps increased in scale and level of intensity each year as the students increased in age. The activities began with simple projects such as balsa wood bridges and evolved to large-scale projects that required days of construction. Likewise, the afterschool program began with simple projects such as foam core board chairs and concluded with a trebuchet competition modeled after the Science Channel’s show “Punkin Chunkin.” Furthermore, participating students and teachers experienced a series of pilot modules to gauge the possibility of implementing in-class, curriculum-based engineering activities in the future.
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Fig. 1—Examples of the (a) On-site Presentations; (b) West Point Bridge Designer; (c) Balsa Wood Bridge; (d) Foam Core Board Chair; (e) Concrete Arch; (f) Interactive Math Problem; (g) Large-scale Foam Core Board Bridge; (h) Wooden Bridge; (i) Foam Core Board Retaining Wall; (j) Trebuchet Competition; (k) Styrofoam Bridge; and (l) Life-size Game of Battleship.
Assessment Methodology for Program I (2009-2015)

The first program was not initially included in the first GEAR UP grant and was added on a year-by-year basis corresponding to available funds. Like most outreach programs mentioned in the literature, assessment efforts were added towards the end. The authors focused on the teacher experience in an effort to potentially improve the program for the next funding cycle. The assessment of the first program is not empirical research and was designed for continuous improvement. Assessment of Program I included a semi-structured focus group consisting of 11 questions to gather information on the perspectives and experiences of nine participating teachers, none of which had previous experience with engineering outreach programs. Qualitative analysis of the feedback included open, focused, and axial coding [23]. The focus group questions are listed below:

1. What motivated you to participate in the program?
2. How did you incorporate your experiences in the program into your classroom?
3. Are there other aspects you would like to incorporate, but have not?
   a. If so, what are they?
4. What factors are holding you back from incorporating these aspects?
5. What changes in your students have you noticed since implementing these ideas?
6. Are you aware of any of your students who have participated in any aspect of the program themselves (i.e. competition, project, after school, summer camp)?
   a. If yes, what differences do you see between the students who have participated in the program compared to the students who have not?
7. Would you recommend the program to your students? Why or why not?
8. In what ways have you shared your experiences with other educators?
9. Would you recommend the program to other educators? Why or why not?
10. Overall, what do you see as the greatest benefit of the program? The greatest drawback?
11. What could be done differently to improve the program for other educators?

Additionally, the assessment also included a student survey. Feedback from all students would have been ideal. However, graduation and student attrition greatly reduced the number of students available to participate in the survey. Thus, four students who had actively participated since Year 1 that were easily accessible were asked to complete the survey. The student survey included five questions as listed below:

1. Why did you want to participate in the program?
2. If you were to choose a career today, what would you choose?
3. How did the program impact your math and science courses?
4. What was your favorite part of the program?
5. What was your least favorite part of the program?

Assessment Results of Program I (2009-2015)

The qualitative analysis of the feedback from the focus group resulted in four themes: people, resources, mental framework, and project. First, there were several references to the people involved in the program. Teachers noted student-teacher interaction as a motivating
factor to participate in the program, specifically the ability to work one-on-one with the students at a depth not feasible in the classroom. Teachers also noted that students were more comfortable opening up in informal environments such as the afterschool activities along with an increased self-confidence in their leadership and teamwork skills. Students became more willing to collaborate and feed off of those experiences when they returned to working independently. One of the drawbacks of the program was accessibility for some students. Students outside of the cohort were excluded from activities due to grant restrictions, but even students within the cohort were indirectly excluded from activities as a result of other conflicting extracurricular activities.

Second, resources appear to limit the broad dissemination of program activities beyond those formally scheduled. The typical classrooms for some teachers are too small for an entire class to participate in some projects. Teachers indicated some aspects of the program could be incorporated into the classroom, but not regularly; teachers need a way to work the beneficial characteristics of the program into the existing curriculum. The teachers also noted their own self-confidence as a nontangible resource. They expressed a need to feel comfortable enough with the projects and to have enough procedural knowledge to know how to adjust for the unexpected as students progress through activities. Another issue was time constraints. If teachers wish to use project activities in their classes, the activities need to fit within a given class period.

Third, the mental framework of teachers and students plays a significant role in the success of the program. Teachers noticed a growth in students’ self-confidence in math ability throughout the program. Students began to realize they had a better grasp of math content than they originally thought. The teachers believed that student collaboration on intimidating problems helped improve their self-confidence in math and problem solving. The program also encouraged students to think about their future. Teachers noted that students that were not considering college began to think about their futures and what they needed to do in high school working towards that future. Many of the students who began the program early on progressed to be honors students in high school. Additionally, the application of mathematical concepts through hands-on projects allowed both students and teachers to think about math from a different perspective compared to the normal class period.

Fourth, several references were made with respect to the authenticity and content of the project as a whole. The teachers enjoyed the ability to work on real-world problems with the students. In fact, some teachers were able to convert some project activities into mini-lessons for their class. The use of real-world problems made the learning process more meaningful for students by illustrating the application of mathematical concepts they learn in school. Additionally, the hands-on learning was the most engaging for students. Some of the content ironically limited the teachers’ ability to incorporate content into their classes due to the required background knowledge. Teachers felt the math modules were the most direct connection between mathematical concepts and a real-world problem, but the scale of the project was also directly correlated to the level of excitement. The competitions encouraged student learning through students’ ability to manipulate their designs to increase their scores.
While approximately 300 of the 2300 cohort students participated in the program over the course of its duration, a core group of four students consistently participated in almost every engineering related activity. Those students were asked to complete a written survey to evaluate why they chose to participate and how it impacted their future. The small number of respondents is not statistically significant, but the feedback was valuable nonetheless. First, the students chose to participate in the program because they thought it would be fun. One student expressed an interest in engineering at an early age and another thought it would help with her future. Second, all four of the students indicated they would pursue a degree in engineering if they were to choose a major at the time of the survey. Third, the students noted that the program helped them to understand the importance of math and science classes and how those courses would benefit them in the future. They also noted that it helped increase their knowledge in those classes, while increasing their interest. Lastly, the students indicated that their favorite part of the program was the engineering camps, specifically designing, building, and testing the projects. One student reported that while he enjoyed the camps, he most enjoyed the interactions with the graduate students and learning from them.

Lessons Learned from Program I

Several key lessons learned emerged from Program I as a result of the feedback from teachers and students along with general observations of the lead author. First, the initial time required to implement a new program should be considered for planning purposes. Teachers and administrators are overwhelmed with the day-to-day activities in K-12 education and many are hesitant to take on extracurricular work. Thus, teacher and administrator buy-in is an absolute necessity if the goal of the project is to impact a large number of students beyond what is logistically possible through afterschool programs and summer camps. Developing those relationships takes time and requires sufficient planning. Second, student participation in afterschool and summer activities will decrease among the same cohort of students as a result of other extracurricular activities and jobs taking precedence as students increase in age. This may limit the number of students that a program can reach. The teachers noted that some aspects of the program could be incorporated into the classroom, but not regularly. Some teachers created mini-lessons, but need more ways to include the beneficial characteristics into the existing curriculum. Thus, for the most impact, programs should provide age appropriate content that aligns with the current curriculum and state standards that can easily be implemented in the classroom. While curriculum materials are likely the best route to impact a large number of students, students still need exposure to large-scale projects with analytical components to provide a representative example of collegiate engineering. Such projects should also be age appropriate, increasing in level of difficulty as students increase in age. The teachers also noted that the hands-on projects allowed both students and teachers to see the application of mathematical concepts, which made the learning process more meaningful. Furthermore, careful attention should be given to the time required for students to complete large-scale projects and the authors recommend a ratio of 1:4 or 1:5 mentors to participating students for efficient implementation of larger projects. Lastly, one key advantage of a cohort of students provides an opportunity to work with a range of teachers, increasing the potential for long-term sustainability across grade levels.
Overview of Program II (2015-2020)

Program II planning was a direct result of Program I’s lessons learned. Program II still includes two presentations and the summer camps, but focuses more on curriculum materials rather than afterschool activities. The first presentation occurred during the 2015-2016 academic year and focused on general engineering also featuring the balsa wood bridge experiment. The second presentation will occur during the 2017-2018 academic year featuring the lead author’s experiences as a first-generation college student. The summer activities began in 2016 and will continue through 2020, which include a one-day professional development session for teachers that choose to participate, followed by a two or three day camp for students led by teachers. The projects still incorporate hands-on activities, but are more applicable to potential in-class implementation. This format aligns better with best practices from the literature [3, 14]. The change in focus from the afterschool activities to curriculum materials is a direct result of teacher feedback, review of the literature [2], and consideration of program reach. Teachers from Program I expressed interest in more curriculum-based activities; the literature shows curriculum-based activities to be more effective; and in-class activities have higher probabilities of reaching more students (i.e. more than those that choose or can participate in afterschool activities).

The curriculum materials mainly include modules used to teach mathematical concepts in the context of various STEM professions, most of which concentrate on engineering applications. The choice to implement the modules in the math classes rather than science classes stems from advising experience by the lead author and the supporting literature [21]. Lack of math readiness appears to be a major hurdle for many students who wish to pursue a STEM career, specifically engineering. The modules focus on concepts previously identified by participating teachers as those most difficult for students to understand; this is reinforced by data from historical performance records of LPSS students on state tests. The modules are presented to teachers during short professional development sessions, immediately followed by a four-hour Saturday mini camp for students. Like the summer experience, this format gives teachers an opportunity to immediately try out the modules in a low pressure setting as recommended in the literature [3, 14] and provide feedback to the lead author. To date, there have been 11 modules developed for 7th and 8th grade as shown in Table 3 and Table 4, respectively.
Table 3—Summary of 7th Grade Modules Developed to-date.

<table>
<thead>
<tr>
<th>Module</th>
<th>STEM Profession</th>
<th>Topic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Statistician</td>
<td>Fractions and Percentages</td>
<td>Uses statistics in conjunction with professional sports to determine win percentages and standings.</td>
</tr>
<tr>
<td>7.2</td>
<td>Accounting</td>
<td>Fractions and Percentages</td>
<td>Uses salaries of engineers and discusses the differences in gross and net pay to illustrate the use of fractions and percentages</td>
</tr>
<tr>
<td>7.3</td>
<td>Aerospace Engineering</td>
<td>Sample Selection</td>
<td>Uses the possibility of imperfections occurring during the manufacturing process of aerospace materials to illustrate how samples are taken to represent a population.</td>
</tr>
<tr>
<td>7.4</td>
<td>General Engineering</td>
<td>Estimating Probabilities</td>
<td>Uses percentages of graduates in different engineering disciplines and the probabilities of a graduate coming from a specific university.</td>
</tr>
<tr>
<td>7.5</td>
<td>Civil Engineering</td>
<td>Unit Rates</td>
<td>Uses a new brick paving technology and construction estimating to illustrate the importance of unit rates as it applies to costs and efficiency.</td>
</tr>
</tbody>
</table>
Table 4—Summary of 8th Grade Modules Developed to-date

<table>
<thead>
<tr>
<th>Module</th>
<th>STEM Profession</th>
<th>Topic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>Civil Engineering</td>
<td>Slope of Non-vertical Lines Part I</td>
<td>Uses surveying a mountain for road construction to illustrate the need to calculate the slopes of lines.</td>
</tr>
<tr>
<td>8.2</td>
<td>Aerospace Engineering</td>
<td>Slope of Non-vertical Lines Part II</td>
<td>Uses rocket trajectories to illustrate the use of slopes of lines.</td>
</tr>
<tr>
<td>8.3</td>
<td>Biomedical Engineering</td>
<td>Slope of Non-vertical Lines Part III</td>
<td>Uses optics to illustrate how slopes of lines are necessary in medical applications.</td>
</tr>
<tr>
<td>8.4</td>
<td>Aviation</td>
<td>Simultaneous Equations</td>
<td>Uses flight paths to illustrate the importance of accurately calculating the intersection of two lines.</td>
</tr>
<tr>
<td>8.5</td>
<td>Chemical Engineering</td>
<td>Solving a Linear System</td>
<td>Uses the process of diffusion to illustrate how solving systems of equations applies to chemical engineering.</td>
</tr>
<tr>
<td>8.6</td>
<td>Civil Engineering</td>
<td>Word Problems</td>
<td>Uses amusement park and tollbooth lines to illustrate how engineers predict wait times intersecting lines.</td>
</tr>
</tbody>
</table>

The format of each module includes an overview that describes what STEM profession and curriculum topics it covers, an introduction that provides a summary of the STEM profession, the required resources that a teacher needs to complete the module, an interactive example that the teacher uses to guide students, a challenge that students work through, and lastly, a reflection section for students to describe in their own words what they learned about specific topics and about that STEM profession. For example, modules 8.1, 8.2, and 8.3 all focus on the slopes of non-vertical lines. However, each module highlights a different type of engineering, including civil engineering, aerospace engineering, and biomedical engineering, but for the most part, they use the same resources. Fig. 2 (a) shows a schematic of the template used for all three. The purpose of using three different modules to address the same topic is to illustrate multiple applications of a single concept. Modules 8.1, 8.2, and 8.3 are described hereafter to illustrate the format of the modules.

Module 8.1 focuses on civil engineering, specifically transportation engineering. It introduces students to transportation and surveying through examples related to the slope of a line corresponding to roadways. Students use a provided mountain schematic to determine the slope of different lines, which line is steepest, and to understand the difference between positive and negative slope. Students work through an example that portrays a real-world scenario followed by a challenge. Fig. 2 (b) shows a teacher leading the students through the module. The instructions are as follows:
The local Department of Transportation (DOT) hired your surveying company to survey a mountain range for an upcoming project. The mountain range is very steep and the DOT needs you to inspect the six different regions of the mountain (black lines). Your first task is to determine which region is steepest.

Examine each pair of lines given below using the surveying tools provided to your team. Use one piece of ribbon to follow the indicated line and then hold your ribbon in place by placing pins at each end of the line. Have one team member hold one of the remaining two pieces of ribbon to show the vertical distance from the start and end of the line. Have another team member hold one of the remaining pieces of ribbon to show the horizontal distance.

Module 8.2 focuses on aerospace engineering, specifically rocketry. It introduces students to rockets through examples relating the slopes of lines to rocket trajectories. Students use the provided mountain schematic/rocket trajectory template to determine the average slope of the rocket’s trajectory between two given points. Like Module 8.1, students work through an example followed by a challenge. The instructions are as follows:

A new space exploration company has hired you as an Aerospace Engineer to work in their rocketry program. They are planning a rocket launch to deploy a new satellite and want to land the rocket on a level portion of a nearby mountain. Your first task is to determine the average slope of the rocket’s trajectory (red line) between various points.

Use a piece of ribbon to create a line between each of the following sets of points by placing pins at each end of the line. Have one team member hold one of the remaining pieces of ribbon to show the vertical distance. Have another team member hold one of the remaining two pieces of ribbon to show the horizontal distance from the start and end of the line.

Module 8.3 focuses on biomedical engineering, specifically optics. It introduces students to lenses, refraction of light, and optics through examples related to finding the graph of \( y = mx + b \) through joining two distinct points using laser pointers shone through lenses. Students use the provided schematic to determine the equation and slope of different lines passing through two points. Fig. 2 (c) shows a group of students working through the module. The instructions are as follows:

A well-known optical company has contacted your team to create glasses for different individuals. The company would like you, a biomedical engineer, to provide them with information about light passing through the provided lenses.

Your first task is to determine the equations of the lines that project from your lens. Place the center of your lens at the origin \((0, 0)\) (green lines). Shine your laser through your lens. Use two pushpins to illustrate the start and finish of the line. Use a piece of ribbon to highlight that line. Have one team member hold one of the remaining two pieces of ribbon to show the vertical distance from the start and end of the line. Have another team member hold another piece of ribbon to show the horizontal distance.
Assessment Methodology for Program II (2015-2020)

The overall goal of the assessment is to determine how effective the interventions are on math readiness, students’ engineering self-efficacy, and teachers’ teaching engineering self-efficacy along with improved engineering awareness among students and teachers. A multi-method approach will be implemented including the use of focus groups, surveys, and archival data collection. The population of students and teachers in conjunction with the second GEAR UP cohort will be included as potential participants, but only those students agreeing through both parental consent and assent and teachers agreeing through consent, will be included in the study. The cohort for the second GEAR UP grant includes approximately 2300 students, all of which could potentially participate in various activities. However, only students who choose to participate in the Saturday mini-camps and/or the summer camps along with those that have a teacher who chose to implement the modules in their classes will be exposed to the interventions. All students in the cohort will be invited to participate in the assessment of Program II regardless of their exposure to the interventions. Thus, it is likely that some students who agree to participate in the assessment study will not experience any of the interventions and will serve as a control group. The authors also plan to evaluate changes in math readiness, self-efficacy, and engineering awareness based on the amount of intervention exposure. The same approach will be used with cohort teachers.

Student assessment will include a self-efficacy study and evaluation of archival data. The S-STEM survey [5] will be sent home to those students along with a parental consent form and an assent form, which they will return to their math teacher if they choose to participate. Archival data will be obtained from the LPSS for students. This data will include race, gender, and free and reduced lunch status along with math grades for each student from 6th through 12th grade, ACT scores, school, and what teachers each student had for each math class to track intervention exposure levels.

Teacher assessment will include a general questionnaire about their perceived needs, the TESS survey [18], and annual focus groups. The general questionnaire and TESS survey will be sent to all math teachers from participating schools and are solely to gauge teacher needs and evaluate the effect of the program on their self-efficacy to teach engineering. The focus group with teachers who choose to participate in the program’s activities will help gain insight into how the teachers implemented this experience into their own classroom, impact of the program on students, and how teachers introduced the program to others.
Final Thoughts

Engineering outreach programs come in a variety of figurative shapes and sizes, all of which have the goal of increasing interest and awareness about engineering in hopes of increasing the number of students who pursue and attain engineering degrees. Outreach programs generally focus on three areas: students, teachers, and/or curriculum. Regardless of approach, the activities themselves either 1) introduce engineering, 2) affirm students’ interest in engineering, or 3) prepare students for pursuit of an engineering degree. Most of the outreach activities introduce students to engineering and generally include small-scale hands-on projects for elementary and middle school students designed to be exciting and informative. A small percentage of activities affirm students’ interest in engineering through more intensive hands-on projects combined with analytical components that provide middle and high-school students with a realistic example of collegiate engineering. Both types of activities certainly increase interest and awareness, but the underlying issue behind low percentages of students pursuing and attaining engineering degrees appears to be more dependent on adequate preparation. If the engineering community hopes to increase the number of students pursuing and attaining engineering degrees, it must also help prepare those students in addition to peaking interest and raising awareness. However, activities that adequately prepare students to pursue engineering degrees require more in-depth knowledge about K-12 education and how to blend engineering content into age-appropriate activities that reinforce or supplement curricular materials.

Program I used the typical approach to increase interest and awareness about engineering and while those activities were fun and exciting, the majority of those activities were unfortunately not sustainable without the continued presence of external funding. Those activities were used to primarily introduce engineering, while a handful of the activities (e.g. Styrofoam bridge and interactive math problems) provide affirmation and help prepare students to pursue an engineering degree. Teacher feedback showed that activities designed to help prepare students are the most desirable for in-class implementation because they reinforced mathematical concepts with real-world application. Program II still includes activities that introduce engineering and affirm interest because both are essential to the outreach process. However, Program II focuses more on the implementation of activities that help prepare students by reinforcing or supplementing curricular materials, prepared in a way that ensures sustainability after the cohort of students moves on. The authors hope that formal assessment of Program II will show a statistically significant difference in math readiness and engineering self-efficacy between students who do and do not experience the interventions along with a correlation between exposure levels and level of improved math readiness and engineering self-efficacy for both students and teachers.

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