

## **Exploration of Hands-On/Minds-On Learning in an Active STEM Outreach Program**

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# **Exploration of Hands-on/Minds-on Learning in an Active STEM Outreach Program**

## **Abstract**

The importance of encouraging interest in science, technology, engineering, and mathematics (STEM) in students from underrepresented groups is well recognized. Summer outreach programs are a common means of accomplishing this goal, but balancing program content between information and entertainment can be a challenging issue. Typically, programs include hands-on activities to foster enthusiasm, but these activities do not always promote a deeper understanding of the physical principles involved. Active STEM was a five-day summer program highlighting the mathematics, science, and engineering related to the favorite sports of program participants (middle school males from underrepresented populations in STEM). The objective of Active STEM was to create a fun learning environment that students could enjoy, while still promoting deeper thinking with activities that are both hands-on and minds-on. Program instructors (a mathematics professor, an engineering graduate student, and two sports science graduate students) employed a student-centered classroom approach with program content focusing on the exploration of patterns, engineering principles, and mathematics.

A pre-to-post survey was used to measure changes in student interest toward particular areas of STEM. While the participant group was too small for results to be conclusive, an overall increase in interest for STEM topics was documented, particularly in mathematics. Qualitative observations also highlighted the benefits of a classroom atmosphere that emphasized increased instructor-student interaction. These observations also provide insight into the type and amount of activity preferred by students. In general, program participants showed increased engagement in learning when they were allowed substantial time for activity, and they responded best to exploratory problem-solving activities including an engineering design challenge and pattern-based mathematics games. The value of exploratory game playing in the development of mathematical reasoning was clearly observed as well as its role in engaging students from underrepresented groups. It is recommended that future programs of this nature also include a measurement of gains in student critical thinking that result from such game playing.

## **Introduction**

The need to recruit more students to pursue degrees and careers in science, technology, engineering, and mathematics (STEM) is well established. Within the next decade, STEM-based jobs are expected to grow at a rate of 17%, and it is expected that about one million additional STEM graduates will be needed to fill these jobs. Furthermore, about twelve million Americans are unemployed despite four million jobs going unfilled. This trend occurs primarily because unemployed Americans do not have the educational background and skills to fill the jobs available. This lack of educational background is

especially troubling in the STEM disciplines, where a declining number of students is prepared to take rigorous mathematics and science courses.<sup>1</sup>

The push to recruit more students to pursue STEM careers is most prominent for underrepresented groups in STEM, including women and racial/ethnic minorities. These groups are considered important for several reasons. First, the lack of representation from these groups in STEM is considered socially unjust, and there is a desire to create equal opportunity to pursue STEM careers for people of all backgrounds. Stereotyping can have a powerful impact<sup>2</sup> and sometimes drive attitudes toward specific careers in STEM.<sup>3</sup> Second, it stands to reason that increasing representation of these groups would help to fill the growing gap in STEM jobs. Finally, inventions, breakthroughs, and scientific advancements are more likely to thrive when approached with diverse thoughts and perspectives.<sup>4,5</sup>

This paper describes Active STEM, a complimentary, week-long summer program created for middle school males from underrepresented racial and ethnic groups (namely black and Hispanic students). The authors had previous experience designing and implementing several outreach programs, including those that targeted young women in middle school math clubs and one-day engineering programs. There is some evidence of the success of these programs. STEM outreach efforts toward female students are common at Texas Tech University; however, there have been fewer efforts to target their male counterparts who have been underrepresented in the STEM disciplines, and it was decided that this program should focus on that male population. A particular objective of the program was to provide a hands-on learning environment that encouraged minds-on engagement. Many programs adopt hands-on approaches but may lack the deep engagement that promotes conceptual understanding. A further challenge is to provide an entertaining environment while retaining extensive content.

During Active STEM, program participants learned how their favorite sports relate to various concepts in STEM and completed a series of activities related to those sports and concepts. At the end of the week, students competed in athletic and academic challenges that complemented the program content from previous days. A pre-to-post survey was given to students to gauge changes in attitudes toward STEM and interest in STEM careers. Although the sample size for the survey was too small for the results to be generalizable, several qualitative observations on the success of some components of the program, particularly those related to mathematics games and engineering design, are useful for driving future work.

Currently, black men represent 3% of the engineering workforce, and Hispanic men represent 4%. Since 2000, underrepresented minorities' share of engineering and physical sciences degrees and jobs has remained stagnant, and their participation in mathematics has declined.<sup>6</sup> Because racial and ethnic minorities are expected to account for over half of the national population by 2050, it is essential to determine what dissuades students of these populations from pursuing STEM degrees and careers and to take steps to correct it.<sup>7</sup>

The lack of students qualified to fill STEM jobs is caused partially by low levels of student engagement in STEM subjects and a shortage of qualified STEM teachers.<sup>1,8</sup> Regrettably, this shortage is often concentrated at impoverished schools with high numbers of black and Hispanic students. Other resources and educational technology to enhance learning in mathematics and

science also tend to be lacking in these schools.<sup>8</sup> Further, teachers tend to have lower expectations for minority students, and with limited opportunities for advanced placement (AP) courses, minority students are disproportionately placed into remedial courses.<sup>7</sup>

The National Math and Science Initiative (NMSI) has attempted to create and implement programs with measurable positive results for STEM. Their methods have proven to be effective across all student groups but have been overwhelmingly successful with black and Hispanic students. After only one year of involvement in their programs, primarily focused on rigorous pre-college preparation courses for students, schools have typically seen a 200% increase in the number of students passing AP exams from these minority groups, and qualifying scores for black and Hispanic students increased by an average of 107% in mathematics (12 times the national average). The NMSI bases its programs and recommendations on three key factors which have been linked to student success across all groups: student engagement, motivation, and exposure to STEM subjects. They report that students who are engaged and active in the classroom are more likely to use their critical thinking skills, and challenging students with rigorous material is key to active engagement. Complementary STEM activities provided outside of the classroom, such as outreach programs, are also effective for increasing student engagement in STEM fields.<sup>1</sup> Regarding student motivation, it is important for minority students to have role models to inspire them and for students to be exposed to STEM subjects early and continuously.<sup>7</sup> It is also helpful for students to be surrounded by a community of STEM professionals.<sup>1</sup> Although Active STEM does not aim to replicate or validate the programs of the NMSI, the key factors of student engagement, motivation, and exposure to STEM subjects were central to Active STEM's design.

Other sources in the literature have attempted to highlight factors specific to these minority groups that may deter interest in STEM. Two primary factors for both black and Hispanic students are a lack of financial support and poor academic preparation. Hispanic students, in particular, fail to see the value in higher education, partially because they do not want to risk incurring debt, and both groups of students benefit from mentoring programs.<sup>9</sup> Suggested remedies to the STEM gap from underrepresented groups include pre-college enrichment, intervention, and outreach programs. Most specifically, effective educational environments promote collaborative learning among groups of students. These collaborative learning experiences lead to improved academic performance, communication skills, and retention, enhanced student satisfaction with learning, and higher self-esteem.<sup>8</sup>

The authors considered many of the factors described above as they designed the Active STEM outreach program for a group of middle school males from populations that are underrepresented in the STEM disciplines. In particular, they were motivated to provide a hands-on minds-on learning environment bolstered with many opportunities for collaborative work and intensive small group mentoring experiences.

This paper is organized as follows. First, the program design, including student recruitment, structure, lessons, and activities, is presented. Next, the two most well received activities are highlighted and described in more detail. Pre-to-post survey results are then briefly discussed, and qualitative observations on the success of various components of the program are reported. These qualitative observations are the primary basis for the development of a more rigorously

research-based Active STEM outreach program for minority students. Finally, concluding remarks are provided.

## **Program Design**

### *Student Recruitment and Survey*

The instructors and program administrators had targeted a recruitment of twenty middle school male students. However, the actual attendance averaged nine each morning, highlighting the difficulty of recruitment from this particular demographic. Of the nine, five faithfully attended every day. The program participants had completed the 7th or 8th grade at a middle school that ranked in the bottom 3% in student academic achievement of middle school campuses (n=1980) in Texas in 2014 by School Digger.<sup>10</sup> The school's population was comprised of 51% African American and 45% Hispanic students. Over 93% of its students were economically disadvantaged, and 49% were considered at-risk. Assistance in recruiting program participants was provided by university staff that had already developed a rapport with the students and their parents through related outreach programs. Various incentives (such as sports, lunch, and prizes) were offered to encourage students to attend.

Students from whom assent and parental consent had been secured were asked to complete the *Middle and High School STEM-Student Survey*,<sup>11</sup> containing a series of Likert-scale items to (1) measure their attitudes regarding mathematics, science, engineering, and technology, (2) identify their 21st century skills, and (3) learn of their influences and intentions toward attending college. The pre-survey was administered on the first day of the program. Five students who had taken the pre-survey also completed the post-survey on the last day of the program.

### *Program Structure*

Active STEM was structured as a week-long, five-day program lasting from 9:00 AM to 12:30 PM each day. The program was held at the high school to which program participants would matriculate. Transportation was provided to and from the high school for those who could not arrange their own transportation. Lunch was provided at noon each day. Snack breaks were also provided in the middle of the morning.

Program instructors included a mathematics professor, an engineering graduate student, and two health, exercise, and sports science (HESS) graduate students. Instructors aimed to provide information related mostly to the sports of interest to the attending students (found to be football and basketball) and cover a wide variety of possible STEM topics. Further, instructors attempted to achieve a balance between the amount of time spent in lecture-style learning and time spent on activities, sports, and games. To this aim, the first four days of the program were dedicated to two lessons per day with accompanying activities (note that only one lesson and activity occurred on the first day because of the pre-survey). An introductory lecture, which was interactive in nature, typically lasted for about 15-20 minutes, and the remaining time (45-60 minutes) was spent on sports, games, and activities related to the lecture.

The final day of the program was dedicated to a field day where points were awarded to each student for performance on a series of academic and physical challenges. Each student was awarded a prize (either a football, basketball, or soccer ball), and prize preference was given to those whose overall scores were the highest.

### *Lessons and Activities*

The overall goals of the program were to keep students engaged and active in the classroom, to introduce them to adults who study and work in the STEM field, and to cover a wide variety of STEM topics related to football and basketball. Therefore, the lesson style was always interactive—students were encouraged to ask and answer questions and to engage in conversation with the instructors at all times. Activities were hands-on whenever possible and purposefully designed to promote deeper engagement and conceptual understanding. A collaborative atmosphere was also created by having students participate together in physical activities in the sports gym, by having them share calculations in the classroom, and by having them work in teams on an engineering design task.

The amount of active play and hands-on learning experiences varied from topic to topic. Qualitative assessments of the program yielded some information about how well students responded to various types of instruction and activities and which types of instruction were most effective for this student group. An overview of the topics covered, lessons, activities, and primary STEM focus for lectures and activities is shown in Table 1. Activities that included significant physical movement and “playtime” are indicated as “more active”.

### **Lesson Highlights**

During the program, two activities emerged as those most preferred by students: the engineering design activity and the mathematics pattern-based games. Details of these two types of activities are provided in this section.

#### *Engineering Design*

The engineering design lesson began with a 20-minute introduction to the traditional engineering design process.<sup>12</sup> Guided by the instructor, students drew the cycle for the engineering design process in their notebooks. Students also worked through the steps of the engineering design process assisted by the following example situation: Despite wearing helmets, football players are still too frequently receiving concussions. How can the design of the football helmet be improved to prevent concussions more effectively?

Steps of the engineering design process were introduced one at a time, and after each step was discussed, students were asked to provide suggestions for how that particular step of the engineering design process might take place in their example situation. Students were also briefly shown some software tools that engineers use in practice to create, analyze, and improve their designs, such as finite element analysis and modeling in SolidWorks.

Table 1. Day-to-day structure of Active STEM

	Topics	Lessons	Activities	STEM Focus
Day 1	Pre-survey Geometry of a Track	Perimeter calculation for various lanes of a track	Calculation of various lanes of track based on number of steps (more active)	Mathematics
Day 2	Exercise and Energy	ATP, lactic acid management	Football drills and conditioning (more active)	HESS
	Nutrition	Fats, carbohydrates, proteins	Calculation of content of energy bars and associated best cost per bar	Health and Mathematics
Day 3	Vectors	Vector components, combining vectors, distance traveled by football	Football routes (more active)	Mathematics and Engineering
	Collisions	Inelastic/elastic collisions in sports, coefficient of restitution (COR)	Experiment to measure COR between various balls and surfaces	Physics and Engineering
Day 4	Engineering Design	Engineering design process <sup>12</sup> with example problem	Design and testing of a piece of sporting equipment	Engineering
	Projectile Motion	Calculation of time for ball to fall from various heights	N/A due to time restraints	Physics

Following the lesson, students were divided into teams of three to four students each and were given information for a sport they were unlikely to know (for example, underwater hockey). The information contained descriptions of the basic game objectives, playing field, additional equipment, and other relevant rules or game details. The students' goal was to design a game piece (such as a ball, puck, Frisbee, etc.) which could be used to play the sport described in their game information. Note that the name of the sport was not provided, and uncommon sports were used so that students would not have preformed opinions about what the game piece should be. Each team of students was led by one graduate instructor, who prompted the team with design questions to guide them through making decisions about weight, shape, materials, and other design factors.

Following the steps of the engineering design process, students created prototypes of their game pieces. They presented their prototypes, explained their design processes, and justified each of their various design decisions. Finally, the mystery sports were revealed to the students so that they could compare their designs to the actual game pieces used.

## *Mathematics Games*

Mathematical games were introduced at various strategic times throughout the week. It was clear from the first game that students were engaged in competition with the instructor and with one another and in attempting to understand the strategies involved in the game. Henceforth it was beneficial to include a break for game playing at times when students appeared to be tired or lose interest.

The games primarily involved two players competing against one another in various challenges that included subtracting numbers to reach zero, eliminating virtual matchsticks to clear the board, filling Sudoku type squares, and connecting dots to create network patterns. All of the games involved a need to observe patterns and then plan ahead in strategic ways. Several elements of classical problem solving were required to participate in these games. Many of the games are in the NIM category such as that illustrated on the Archimedes' Lab website.<sup>13</sup>

Students began by competing against the instructor and then competed against one another in knockout rounds, with the overall winner taking on the instructor again in the final round. Students were engaged in trying to beat the instructor and in understanding the strategy profile of the game. They were engaged in serious mathematical problem solving without realizing that this was really representative of the kind of pattern observation and deduction employed by research mathematicians. The instructors then took the opportunity to inform the students of this connection between the games and the processes of advanced mathematics.

## **Results**

The pre-to-post survey was completed by five of the program participants. Three were African American, one was of Hispanic descent, and one was Non-Hispanic Caucasian. Neither parent of three of the participants had graduated from college. All of the students reported liking at least one teacher at their school or that at least one teacher had confidence in them. Two indicated having a number of friends who want to go to college, while two reported having only one or two friends who want to go to college. One was doubtful about his friends' desire to go to college. These survey items were designed to indicate general student background and interests in the STEM disciplines.

Because only five students completed the survey, it is difficult to generalize the students' attitudes toward STEM and the impact of Active STEM. However, in general, it was clear that student responses toward mathematics were more positive than those for science and engineering—three of the five students indicated a positive change on items pertaining to an interest in mathematics on at least three survey items, and two students indicated a positive change in interest toward subject areas and jobs associated with mathematics. There are several factors which may have contributed to more positive responses to mathematics questions. First, the questions contained in the “Student Attitudes” section of the survey were designed to measure self-efficacy, interest, and usefulness of a particular area of STEM toward their futures. In the mathematics section, all eight survey items assessed self-efficacy. In the science section, five survey items assessed self-efficacy, and three survey items assessed interest in science or importance of science. In the engineering section, two survey items assessed self-efficacy, and



seven survey items assessed interest in various components of engineering or importance of engineering. Given that the questions for each section of the survey were designed to assess different interests or beliefs, it is difficult to compare student responses among sections, but it is possible that the results for science and engineering would have been more similar to those for mathematics if assessment items in those sections had focused more heavily on self-efficacy. Second, the pre-survey responses related to self-efficacy indicate that the students were already more confident before the program in their abilities in mathematics than in the other subjects. This initial confidence may have caused program participants to be more receptive to mathematics material. Finally, it is also possible that responses to mathematics items were higher simply because students genuinely enjoyed the mathematics portions of the camp the most. One interesting observation is that the highest positive change for the pre-to-post survey was measured for the survey item, "I know for sure I can do advanced work in math." This change is especially encouraging since program instructors made explicit connections between the mathematics games and the nature of advanced mathematics.

Given the high levels of student engagement observed during the engineering design activity, it is somewhat surprising that survey results for engineering were less positive than those for mathematics. One possible explanation for this finding is that the connection of program content to mathematics was more clearly addressed than the connection to engineering. Students may have perceived most activities as primarily related to mathematics (and in fact, many of them did involve some sort of calculation) rather than science and engineering. Additionally, at the beginning of the program, students did not have a clear idea of what engineering careers entail. When asked what engineers do, most students described a mechanic (e.g., "engineers fix cars"). Program instructors attempted to clarify this misconception, but it is possible that the image of an engineer as a mechanic was still somewhat persistent at the end of the program. A more clear and precise discussion about engineering professions would benefit future Active STEM program participants. Finally, the survey items about engineering tended to measure interest in separate components of engineering. For example, three items are included to assess student interest in machines, electronics, and building/fixing things. It is likely that even a professional engineer will not have interest in all separate components of engineering, so the mixed responses to engineering assessment items make more sense in this context.

Because the small sample size prevents any conclusive analysis of the survey results, the researchers perceive that qualitative observations about the success of various components of the program are most useful for discussion and for driving future work. Namely, students appeared to benefit from a classroom atmosphere emphasizing increased instructor-student interaction. During the lessons, students were very willing to answer questions posed by instructors and readily asked questions to clarify concepts. Having graduate students lead the instruction as well as the physical activities, in conjunction with the almost 2-1 student-instructor ratio, may have facilitated the speed with which the students let down their guard and actively engaged in the activities and learning. Additionally, since students enjoyed the high levels of personal interaction offered by Active STEM, the authors suggest that interviews with the students, rather than surveys, will yield more beneficial information and should be included in future program design.

Students also showed increased engagement in learning when they were allowed substantial time for activity, and they responded best to exploratory problem solving activities. One interesting observation was that these activities, namely the pattern-based mathematics games, were not related in any way to sports (the primary incentive for students to attend the program). This observation highlights the value of exploratory game playing in the development of mathematical reasoning and especially its role in engaging students from underrepresented groups.

The academic challenges posed on the last day of the week served as an informal assessment tool for students' ability to remember the information they had learned through lessons and activities. Of all program activities, students clearly enjoyed the pattern-based mathematics games the most. It was also clear that the students remembered best the steps of the engineering design process. This observation highlights the benefit of implementing hands-on engineering design activities in classrooms.

## **Discussion**

Since mathematics is a major underlying topic in engineering education, increasing enjoyment and ability in mathematics could be a key factor for encouraging interest in engineering from students in underrepresented groups. The education literature<sup>14,15,16,17,18,19</sup> highlights the value of game playing in developing numerous skills that are vital for student success in their STEM learning. These include the ability to develop strategies and decide among multiple strategies. Cooperative learning is also enhanced in a non-threatening manner as students debate various strategies or compete against one another. Games provide a fun and motivating environment to develop problem-solving skills, especially in areas that require algebraic reasoning and spatial sense. Game playing has also been shown to lead to gains in number sense on a state test.<sup>20</sup> It is recommended that future iterations of the Active STEM program include a measurement of gains in student critical thinking that result from such game playing.

The level of student engagement in the mathematics games was described earlier. It would be most interesting to study this observation more closely in a future program. Is there something inherent in the games themselves? Is it the competitive element? Is it the opportunity to solve problems in a non-threatening environment? A qualitative analysis of student interview responses would give an insight into the features that trigger the high level of engagement.

Hands-on activities have long been used, especially in engineering, to promote intrinsic interest, motivation, and engagement,<sup>21</sup> and hands-on activities are frequently used in engineering outreach programs.<sup>22,23,24</sup> Complimentary outreach programs that employ hands-on activities are especially useful for students from impoverished schools where resources are scarce, and materials for hands-on activities are not always available. Several hands-on activities were implemented in this program, and it is clear that some were more beneficial than others. For example, the activity to calculate the coefficient of restitution (COR) between various balls and various surfaces was hands-on and similar to a laboratory experiment. By contrast, the engineering design activity employed a discovery-based learning approach to keep students deeply engaged and help them explore the steps of the engineering design process. Implementations of discovery-based design activities have been shown to be beneficial, as noted

in the engineering education literature.<sup>25</sup> It is possible that discovery-based learning played a significant role in both the students' enjoyment of the activity and their ability to retain the steps of the engineering design process.

The authors plan to refine the program for 2016 with a greater focus on the elements of design and game playing. They plan to implement a qualitative study of student reaction and engagement in the program activities. The low student-to-instructor ratio will be maintained in order to retain the level of intense mentoring. It is hoped that this study can provide a proof-of-concept model for deeper engagement coupled with intense mentoring that may be replicated successfully for a broader population of underrepresented, middle school students.

## **Conclusion**

Active STEM was a week-long, complimentary outreach program provided for middle school males from underrepresented groups in STEM. Program participants engaged in a variety of lessons and activities that connected STEM to their favorite sports. Although pre-to-post survey results were collected, the student pool was too small to generalize results. However, an increase in interest toward STEM, especially mathematics, was observed, and qualitative observations yielded useful information for future program design.

Among all program activities, students responded most positively to those which encouraged learning through pattern-based games and hands-on design. Thus, these two factors, along with a small instructor-to-student ratio, will be the driving factors for a refined program geared toward middle school males from underrepresented groups. Exploratory games have the potential to help students develop skills crucial to success in STEM, such as problem solving, algebraic reasoning, and spatial sense, and discovery-based design activities will aim to provide a learning experience that is both hands-on and minds-on. It is expected that students would respond more positively to program instructors (role models) from the same underrepresented groups. It is also recommended that future iterations of the program include a measurement of student gains in critical thinking. The authors plan to develop a website in order to share the lesson plans and results with a broader audience as more evidence accumulates for the merits of the approaches adopted in the program. In the meantime, interested readers are welcome to contact the authors who will be happy to share lesson plans and suggestions.

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