Inspiring Future Young Engineers Through Robotics Outreach

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***Abstract*— This paper discusses a robotics workshop that is run annually to encourage middle school students to become interested in engineering and science careers. The voluntary, five-week program focuses primarily on seventh and eighth graders and includes students from several New Jersey and Pennsylvania schools in the Philadelphia area. The students belong to low-income, at-risk schools, low-risk schools, and special needs schools. LEGO® MINDSTORMS® NXT robotics kits are used to teach robotics concepts in an interesting and fun way through lessons, activities, and competitions. The paper discusses the need for such a program, the benefit, and the curriculum used during the workshop.**

I. INTRODUCTION

As math and science scores continue to fall or remain low within New Jersey"s and Philadelphia"s low-income school districts [3], [28], the potential talent pool of new engineers and scientists continues to dwindle. To address this problem, Lockheed Martin Advanced Technology Laboratories, located in Cherry Hill, New Jersey, has begun reaching out to local school districts. The greatest effort is an annual five-week robotics workshop geared toward seventh- and eighth-grade students that began in 2006. Students from low-income, at-risk schools are brought together with students from low-risk schools in an effort to shorten the gap between the students knowledge base and exposure to engineering and science technologies.

Through the use of the LEGO® MINDSTORMS® NXT Robotics kit [16], students are taught the fundamentals key to robotic applications and software design (Figure 1). Students learn in a fun, fast-paced, team-driven, and supportive environment where they are in charge of how their robot looks and performs. Students enter with little to no experience in applications and software design and leave with a basic understanding that bolsters excitement and intrigue about the potential that science and engineering careers hold.

Fig. 1. A team working with the LEGO® kit at the Robotics Workshop

II. BACKGROUND

A. Motivation

The number of students in the United States enrolling in engineering, science, and computer science fields is on the decline [7], [11], [12], [19]. The problem is even worse for women and minorities in computer science [10], [19]. The number of foreign students in American engineering and physical science graduate programs now exceeds the number of American students in those programs [3]. Todays American students are becoming less interested in engineering, science, and computer science fields, and there are no signs of this improving [27]. There are also a reduced number of American scientific publications, patent applications, and research [3], [7]. While the desire to become an engineer or scientist is on the decline, the demand for engineering and science professionals is expected to rise [26]. Even though there are many possible reasons for the reduced interest [19], the situation needs to be addressed. Engineers and scientists are necessary for worldwide technical growth and for solving many worldwide problems [10]. Educators, engineers and scientists must take actions now to encourage youth to follow rewarding careers in engineering and science.

Unlike jobs in medicine, law, education, and media, there is little exposure to students in engineering and computer science. There are few television shows or movies about the positive aspects of engineering. There is a lack of popular role models in these fields. In addition, unlike careers in the medical field, legal field, and financial field, a student must decide by eighth grade whether he or she wishes to "preserve the option to pursue [a technical] career" by choosing to take Algebra [3]. In many cases, engineering is portrayed as a difficult and undesirable career, and students are turned off to math and science early [3]. Students are unlikely to consider a career in engineering or science if they are not exposed to the interesting aspects of the field.

Robotics education in pre-college curricula is one area where this problem can be addressed. Not only does robotics encourage students to go into robotics-related fields [21], it also encourages general problem-solving skills and math abilities using engineering principles, creativity, and teamwork [30]. All of those characteristics are necessary for almost any engineering or science career. Robotics education introduces students to the more exciting aspects of any engineering or science career [31]. It can also be used to facilitate four fundamental characteristics of learning: active engagement, participation in groups, frequent interaction and feedback, and connections to real-world contexts [29]. Making a robot move for the first time is something that few students forget. Robotic programs provide an education in which students *want* to participate, even voluntarily outside of school [20], [25].

B. Target Students

The primary focus group is at-risk students from Camden, New Jersey school districts. These students are often unable to get the same level of exposure to technology as others. To balance the group and add additional perspective, students from low-risk districts and special needs students were also integrated. This proved to be of great benefit to the students who were able to gain insight into problem-solving from peers outside of their social group. We want these students to understand, regardless of their background, they are capable of becoming scientists and engineers with the right education.

C. Similar Work

There are many educators using robotics to help teach concepts. It is a great hands-on way to approach engineering education [4], [5], [8], [22]. However, much of this work has been focused on college undergraduate studies. At the undergraduate level, robots can be used to teach artificial intelligence, path planning, advanced sensing techniques, sensing electronics, mechanical design, computing hardware, complicated mathematical concepts, programming design, and many other topics spread across several fields. At the pre-college level, the concepts taught need to be more general and more grounded in easily grasped concepts, especially in the case of elementary and middle school levels [23].

Carnegie Mellon University (CMU) has an excellent program for teaching robotics to middle school and high school students [1] with the LEGO® MINDSTORMS® NXT platform [16] and VEX platform [17]. They provide course materials, videos, and lessons covering a wide variety of robotics topics.

Goldman, Eguchi, and Sklar have run summer programs to teach inner-city high school students robotics with LEGO® MINDSTORMS® [13]. The goal was to improve science and math learning experiences by developing curriculum materials that teach concepts via robotics. Participation was voluntary and the programs were run outside of regular school requirements.

New Mexico Institute of Mining and Technology developed a custom robotic platform for use in secondary education. They also developed a curriculum using their platform and organized a course for teaching instructors how to use the platform and curriculum [6]. A problem with this approach is that not all educators have the time to attend a course on using robotics. Many science and math educators have neither a technical robotics background nor time to learn the skills necessary [23], [24]. Robotics is a focused area with many complicated details. Someone who has a robotics background likely does not also have a background in education.

III. CURRICULUM

A. Lessons and Activities

The program consists of four lessons and five competitive events on five consecutive Saturday mornings. Each week the students begin with a warm-up exercise designed to stimulate their minds and open their view about how to solve a problem. The warm-up exercise is then followed by a lesson that has ties to the warm-up. The students are given an opportunity to experiment with the LEGO® kits and programming in four- or five-person teams. At the conclusion of each session, the students are faced with a challenge that either pits them against the clock or the other teams.

Each week, the students arrive in the morning and make their way to their lab table. The teams lab table is changed from week to week to ensure that the students in the front or back of the room do not get more attention and so that the students can learn and interact with different teams each week. The warm-up activity begins shortly after the students arrive.

The warm-up exercises get them excited and energized to learn. The exercises are designed to be fun, interactive and team-oriented. Each exercise highlights key aspects of the week's lessons. This forms a foundation that is easy to understand and ties into a robotics or programming concept.

For example, one of the week's activities splits the students into groups of two. The groups are randomly chosen to increase the interaction between different students. The session involves obstacle avoidance. One student is placed in a rolling-chair while the second student stands behind them. The standing student is given a dark pair of sunglasses with a piece of paper taped to them to greatly limit their field of view. Because of the glasses, they are unable to see any objects in front of them and can only partially see the floor and chair below them. The task is for the students to travel through an unknown small obstacle course laid out among office cubicles and hallways. The student in the chair guides the standing student to push the chair through the obstacle course. The approaches vary from team to team and range from very precise requests of Turn 12 degrees left and then proceed straight 4.5 feet to Straight, straight, STOP! Unfortunately, when the students yelled Stop, it was often too late and resulted in a collision with another team or a wall. After the activity the students are often energized, awake, and ready to learn the days lessons.

Each warm-up exercise is followed by a short discussion session. The group is asked to describe the challenges they faced in the activity and to compare it to a challenge that a robot might face. Often the students are able to make the jump from the activity to its implications in robotics. For the obstacle course, the students recognize that their robot can only do the things that they tell it. If they provide it with bad information, then the results are undesirable. The week's lesson follows from the discussion.

Each progressive lesson involves a new sensor that the students had not seen during prior weeks. The LEGO® MINDSTORMS® NXT kits provide a wide variety of sensors. They include rotation, ultra-sonic rangefinding, color/light, touch and sound sensors. For obstacle avoidance, the ultra-sonic rangefinders are used. The sensor is introduced and each team removes it from their kit. They are asked to describe the sensor and offer a guess as to its function and use. The rangefinder is likened to a bats echolocation, which provides a more familiar element to the sensor. A short programming lesson is given to show how the sensor can be added to a program and then the students are given time to experiment and learn about the sensor.

Once the students have shown that they are somewhat familiar with the use and function of the sensor, the competition for the week is introduced. In this example session, the competition is obstacle avoidance. The robot must race to a barrier and get within a predetermined distance. Once the obstacle is reached, the robot must turn around and race back to the starting line (See Figure 2). In prior lessons, the students learn how to make swing and point turns and drive a predetermined distance. This event requires the prior knowledge along with that gained during the sonic rangefinders lesson. The team that completes the challenge in the fastest time wins a small prize. To ensure that the race is as fair as possible, there is a zone marked around the barrier that each robot must fully enter to qualify for the full amount of points.

The other lessons include swing and point turns, sound sensing, line following, and odometry. Swing and point turns teach the basics of controlling the robots motors and using the software. Turning is an important lesson because it is the basis for more complex programming and robot behaviors. Sound sensing is the first lesson and provided a set of topics that are easy to understand and learn and that provide a base from which to build other programs. Odometry is also introduced early to provide the students with a method for programming based on approximate measurements. Line following and obstacle avoidance are both advanced topics and are saved for the final weeks.

All of the lessons develop skills necessary for the final competition event (Figure 3). Teams apply all of the knowledge they gained about programming and sensors into this event. It consists of tasks that involve all of the previous lessons. Turns are emphasized to a smaller extent, but are an obvious necessity. The event runs much like a choose-your-destiny book where the students choose the challenges they wish to attempt. The competition consists of five primary tasks with bonus points possible on most. Each task is assigned a point value based on difficulty. The point values

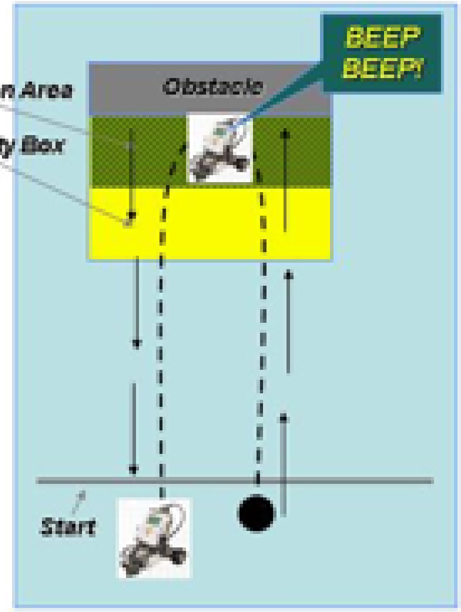

Fig. 2. Obstacle Avoidance Lesson: Course Layout

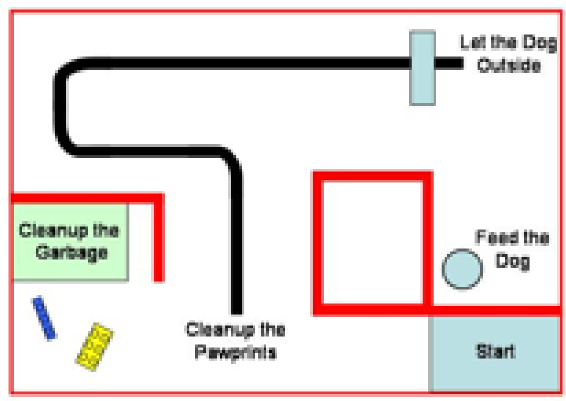

Fig. 3. Final Competition Event Board

are given to the students ahead of time so they can be integrated into the team strategy. Each team is given four minutes to accumulate as many points as possible. The teams are allowed to run multiple programs and may touch the robot during their run, but only if it is in the blue starting square. The event is modeled after a concept developed by Carnegie Mellon University as presented in their workshop tutorials.

The students are told they need to construct a house cleaning robot to maintain the house of a family with a very messy pet dog. The robot is to activate whenever needed and be able to handle the messes that the dog makes. The dog always knocks the trash over, leaves muddy paw prints all through the house and needs to be feed and let outside. The challenges are to accomplish these maintenance tasks.

The first, and usually easiest task, is to activate when needed. In this situation, the robot must react to the dogs bark, which in our case is a hand clap. The robot must respond, either with a sound or motion, when it hears a clap to show it is ready to begin. All teams have gone for this milestone as it is simple to program. This milestone does not have any bonus points available.

The second task is to clean up the muddy paw prints the dog has tracked all through the house. This is a line following exercise along with an odometry test. The robot must navigate to the line and begin line following all the way to the end. This can be difficult if the students rely too heavily on the robot getting to precisely the same location each time they attempt to find the line. At the end of the line is an obstacle that the teams can either knock down or avoid. Avoiding the obstacle is worth bonus points and is considered opening the door to let the dog outside.

The second task can be coupled with a third task, feeding the dog. The location of the dog bowl is at the end of the line of paw prints. The robot must navigate into the area close to the bowl and play a sound which activates the dog feeder and fills the dog bowl with food.

The fourth and final task is to put the garbage back in the garbage can the dog knocked over. This task requires the students to come up with a solution to a problem we had not presented previously. LEGO® pieces are scattered near the trash can (the green box) and must be placed completely back inside the box. Each piece is worth the same point value, but bonus points are awarded if all of the pieces are returned.

After all teams have competed, the scores are tallied. The team with the most points wins the competition and is given the grand prize. The prize typically consists of a book bag, pens, and an organizer/planner. A second award is also presented on the final day; the teamwork award. During the final week of the workshop, each team is taken into a separate room and given a task to complete. The teams are given a bag of large marshmallows, a box of toothpicks and a bag of straws. Their objective is to build a structure out of the given materials that can support a dictionary three inches above the desk. The actual objective is not told to the students, but this gives us the opportunity to closely watch how each team interacts and works together.

The final day ends with a short talk to the students making sure they realize the lessons they learned and the skills they have gained. The students are reminded that they were engineers for five weeks and there is no reason they can not continue to be engineers if they continue their studies in math and science.

B. CMU Robotics Institute Tools

Carnegie Mellon University (CMU) developed an introductory curriculum for robot instructions. The two-CD set includes an instructor CD with lesson plans, tips and quizzes, and a student CD with instructions and video tutorials [1]. These lesson plans are excellently developed and give guidance to our engineers with little or no teaching experience. They would be invaluable to teachers inexperienced with robotics but who are trying to provide a robotics education to their students. While not exactly the same, many of our lesson plans are adapted from lessons taught in these instructional materials.

C. Why LEGO® ?

LEGO® bricks are easily recognized by most children and adults. They are familiar and non-threatening. Students immediately start building when the bricks are placed in front of them. There is no need for a lesson in construction using the bricks, gears, wheels and other parts, because they are intuitive.

The LEGO® MINDSTORMS® NXT robotics kits (Figure 4) add a layer of programming, mechanics and sensing to the traditional LEGO® bricks. This combines the ease of assembly with the sophistication of a robot. The platform allows the students to try different approaches to a problem without fear of breaking the robot or expending large quantities of time constructing [14]. This is an asset to students willing to take larger risks with their designs. In a classroom, no two robots or approaches are ever exactly the same.

The programming environment is the LEGO® MINDSTORMS® NXT Software built on top of the National Instruments LabVIEW environment [18]. The MINDSTORMS® NXT Software is a graphical programming environment that is easy to use and intuitive to many students. The students simply need to drag and drop functional blocks into a flow diagram to create both simple and complex programs from their MINDSTORMS® NXT Robot. An example program is shown in Figure 5.

Support is always important when selecting a teaching tool; especially when electronics are a key component. LEGO® has a wide support network consisting of telephone and email support along with a community of user forums [15]. Additionally, there is a wide following of hobbyists who use these kits and are constantly pushing the envelope of possibility.

The costs of education are rising throughout the country [28]. Teachers and schools are searching for teaching tools that can be reused for multiple years with minimal investment. The cost of a single kit is about 250USD and can be used by a team of four or five students. For a typical class size of approximately 25 students, only five or six kits would need to be purchased.

Fig. 4. LEGO® MINDSTORMS® NXT Computing brick, sensors, and motors

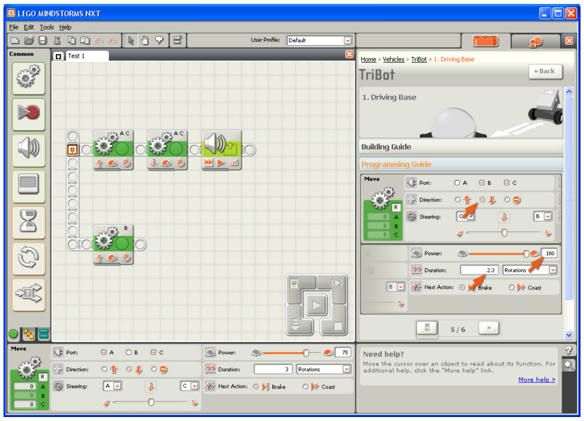

Fig. 5. LEGO® MINDSTORMS® NXT Software

IV. DISCUSSION

A. Getting schools and students interested

Before contacting schools, a small group of engineers met with an experienced area teacher who coaches a successful robotics team. This team won the FIRST LEGO® League [9] Pennsylvania State Championship for their age group in 2005 with an all female team. The teacher was able to provide invaluable advice about how to best attract local schools and how to run the program. The best advice received was to keep the program to five weeks and end it with a final competition. Talking to a local school principal also provided a resource and contact with the school district to discuss the curriculum.

Some schools were more difficult to contact and convince to participate in the program. Cold calling was unsuccessful. The lack of success could be attributed to general suspicion of the program, lack of understanding of the programs goals, or the schools inability to get students involved in after-school programs. Our primary focus group of at-risk, low-income districts proved to be the most difficult to contact and convince to participate. The program would not be successful without the participation of students from these school districts.

An employee of the company was able to provide contact information for a teacher within one of the schools who was willing to discuss the program with us. She was excited about the program and was willing to be an advocate within the school. Additionally, another employee already was involved in a faith-based non-profit group to help students learn more about computers. He was able to garner the support of his group to bring more students to the program.

The first year of the program was successful, but did not include a diversity of students. To garner a larger diversified student population, a group of engineers twice traveled to a target low-income school to discuss the robotics workshop and to talk about National Engineers Week. A second visit occurred to the school just prior to the beginning of the workshop to get the students excited about the program. We also talked to students about the program during our National Space Day program, a yearly event where we invite some local students to view program demonstrations, including a view of our autonomous car that competed in the Defense Advanced Research Projects Agency (DARPA) Urban Challenge [2], a competition where unmanned vehicles maneuvered around each other in a mock city environment.

After these events, students were excited to participate in the program. We had more than 20 students from our target district register for the program. We had interest from several other schools, including a public charter school and a parochial school for underprivileged children.

The biggest selling point for the schools, aside from the educational benefits, was the cost. The company paid the entire cost of the program. The only expense to the school was to get the students to our facility each week. We provided all of the materials, educational tools, computers, robots and lunch to the students.

B. Demographics

During the fall 2007 Robotics Workshop, we had 51 students attend all five sessions. Of those 51, 33 were male and 18 were female. We had several schools participate in the program, which resulted in a diverse set of students with many different backgrounds. Fourteen of the students are considered not at risk from medium to high-income families. Twenty-seven students are from low-income families. Of those, 19 are considered at risk while the other eight are special needs students. This diversity met our goal of attracting both at risk and not at risk students to broaden all students' experiences.

C. Program Costs

Costs to start a robotics workshop are relatively inexpensive. The LEGO® kits cost about 250USD each. The catalog states that these are good for two students to share. We have found that four or five students can easily share the kits, because each person is given a separate role. In addition to the kits, each team requires a separate computer running the LEGO® software, which is included in some kits or can be purchased as a classroom-wide license for less than 300USD. We found some old, used laptops that were perfect for this program. The software does not require current operating systems or high-speed computers. In a classroom setting, desktop computers are fine. However, we like using laptops because it allows the students to take their computers with their robot during competitions. We also purchased the CMU Instructional CDs for 225USD. While not a necessary purchase, they are invaluable to anyone not familiar with the LEGO® MINDSTORMS® NXT system.

Other expenses include poster boards, mats, or wooden trays on which to run the robot tests. Some of these can be purchased through the LEGO® education website. These do not have to be high-cost items. We made our competition boards from foam core and electrical tape.

Prizes can be expensive, but we normally found inexpensive items left over from our company events, like pens and flashlights. Our Human Resources department has given us book bags as grand prizes for our final competition. These did not cost the program anything, but are worth at least 60USD each. Each student receives a paper certificate, a Robotics Workshop t-shirt and a small gift after completion of the program.

Lockheed Martin did allow some engineers to charge their time while developing the program. These costs were minimal. One of our biggest expenses in the program was serving lunch to the students and volunteers. We spent nearly 1200USD in food.

While the actual costs for the program are reasonable, it would be impossible to run a program like this cost effectively without volunteer help. More than two dozen employees volunteered at least five hours on at least one Saturday. Many volunteers were present every Saturday of the program, and there were always at least 10 employees volunteering for any given Saturday. Even at a reasonable rate, having 10 engineers working for five or six hours would be expensive. In addition, the program requires at least two adults to see to the administrative needs of the program, which includes signing-in students, ordering food, and keeping general order. Thankfully, everyone volunteered their time, making this a cost-effective program.

In total, the program has cost Lockheed Martin Advanced Technology Laboratories about 8000USD each year to run.

D. Program Benefits

Companies like Lockheed Martin want to encourage more students to pursue careers in science and engineering. It is in the company's best interest to have a large, diverse group from which to hire new engineers. But working with middle-school students for five weeks does not directly translate into more engineers. This benefit will not be felt for at least 10 more years.

For most of the employees involved in the program, the benefits are more immediate. These engineers want to encourage students to become interested in robotics and engineering because it is exciting to see young students grasp difficult concepts and develop working robots. It feels good to see students learn and become excited about programming. Most students knew little or nothing about robotics or engineering when they began the program. They started the first week using computing programs already built into their robots or written by our engineers. Four weeks later these students are writing their own software code to make their robots accomplish a particular task, like using sonar to avoid objects, using light to follow a line, or using software to navigate a maze.

Marguerite Ferra, director of Gleam, a non-profit faith-based program for Camden children, said, "It"s amazing to watch our kids emerge in this new environment as leaders in the games as well as good teammates. To see their focus, assembling or programming the robots, shows me what kids can do when put into a best learning situation possible."

"As an educator, I am constantly searching for innovative ways to expose our kids to careers in the field of math and science," said Neil Burti, Jr., Carusi Middle School assistant principal. "This program provides a rigorous, fun and engaging arena for this exposure to take place."

V. EXPERIENCES

In our experience, we did not see any difference in the performance of students from low-income schools versus middle-income students. Given the opportunity and the help, all students have been able to be fully active participants on their team lending ideas, programming concepts, and support.

For our program we found that working with close to 40 students is easily manageable and allows for a large, diverse population. Much beyond 40 students becomes unmanageable from teaching and logistical standpoints, given our office space and number of volunteers. The lessons have been taught with as few as 28 students, but this was a smaller group than desired. Forty students can be split into 10 teams of four. With 10 teams, 12 volunteers make a good student-teacher ratio. This allows for closer interactions between the students and the volunteers.

The volunteers are acting in the capacity of teachers and mentors, not disciplinarians. To aid with discipline, teachers, parents and other school representatives are encouraged to attend each workshop. A requirement of at least one representative from each school ensures that discipline can be handled consistently and in line with individual school policies.

VI. FUTURE PLANS

A. Robotics Masters Program

We have had the opportunity to interact with over 100 students with this program. Being able to have an impact on the decisions that these seventh and eighth graders make prior to moving on to high school is a great way to get them interested in and excited about mathematics, engineering, and science. The real challenge is keeping them interested once they have left the workshop. It isnt feasible to continually introduce new lessons in robotics to the same group of students, but it is possible to do this with a smaller subset of the group.

There are always students that stand out from their peers and show their desire to learn and lead. These are the students who should be shown the greatest attention after the five-week program. We are developing a Robotics Masters Program that will teach these special students advanced concepts in programming, robotics and general science.

The selected students will be invited back for an additional multi-week workshop. The workshop will focus on developing the programming and robotics skills that the students have developed and will also give them the skills to teach others. The goal is to have two to three students from each school return for the advanced program. The lessons will cover advanced robotics as well as presentation skills and public speaking. With the support of the company, the graduates will present workshops to their classmates in their school.

B. Student Evaluation

Feedback is continually solicited from the students during the workshop"s duration. While this provides valuable information about current tasks and lessons, it does not provide feedback about the overall program. In the coming year, we will be implementing a formal evaluation to be filled out by each student at the end of the workshop and a separate evaluation to be filled out by the staff from the attending schools. Feedback will be used to help improve the program year after year.

C. High School Workshop

In addition to the Robotics Masters Program, our plans include targeting a program at high-school level students. To really be effective, we need to bridge the gap between our program and the time when the students select colleges and majors.

D. Continuing the Robotics Workshop

In our opinion, the workshop has successfully exposed students to robotics, engineering, math, and science. Our plan is to continue the workshop annually.

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