Robotic Outreach to Attract Primary and Secondary Students to Engineering

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Abstract

Graduate students and faculty at Auburn University's Department of ECE developed an automated Nerf™ launcher for STEM outreach. This robot was created by the authors as a final design project for a robotics course. The robot detects a reflective target using infrared light and tosses a Nerf™ ball at the target. The robot was initially demonstrated to a Title 1 middle school robotics group working on a competition robot at the university. This opportunity allowed for a preliminary outreach event that was well received by the students and teachers: they all expressed enhanced interest in STEM as the design and design process was explained. This response inspired the further use of the robot as an outreach and recruitment apparatus.

To make the device more effective for outreach, targeted instructional approaches for use with different age ranges were created. These approaches vary in technical level and duration as appropriate. The outreach events were shown to increase the interest level of students in STEM fields through anonymous pre- and post- demonstration surveys. The primary goal of the outreach program is to target Title 1 schools and other under-served communities.

Introduction

The United States Bureau of Labor Statistics has predicted that the growth of Science, Technology, Engineering, and Mathematics (STEM) related jobs will be approximately 13 percent from 2014 to 2024; the only field with a higher predicted growth rate is the medical field [1], while the anticipated growth rate of all non-STEM fields is only estimated to be 11 percent [2]. Additionally, the growth of robotics and other automation in the workforce is shifting the demand to high-skill, high-wage jobs [3]. From 2000 to 2008 there was a decline of 32 percent in manufacturing jobs, while overall job growth was still 4.5 percent [4]. This, coupled with the large groups of future retiring engineers [5], makes engineering a very promising career path for students to pursue. Students need exposure to STEM at a young age to encourage them to pursue careers in high demand fields.

Furthermore, a college degree is becoming increasingly important for entrance into the middle class in the United States. The number of students achieving an advanced degree is disproportionally comprised of students from middle to upper class families. This is a trend that has increased over the last several decades, most prominently among females. The college start and completion rate was studied by Bailey and Dynarski using data compiled from 1940 to 2007. They found that, while the percentage of students that started and completed school increased significantly over that time period for all groups, the increase was more pronounced among higher income families. The college entry rates of students from the top quartile of families increased to 80 percent, the second quartile increased to 60 percent, and the bottom quartile rose only 10 percentage points from 19 to 29 percent [6].

One of the reasons that lower income students are unlikely to go to college is that they lack access to rigorous coursework, support services, and knowledge about potential careers requiring an advanced degree [7]. A report by the NPR Planet Money team in 2013 further highlights the need for education: the report showed that people without degrees were more likely to need disability assistance than those with degrees if they suffered an injury. The report surmised that this is because people who become disabled and do not have degrees are less likely to obtain skill and education based jobs that are less taxing on the body. This is an issue that is further exacerbated in lower socioeconomic communities [8].

School systems in a lower socioeconomic society are typically under-resourced [9]. This is even more prominent in science and mathematics, where the success of graduates correlates with the educators' quality of education and experience [10]. Unfortunately, students in low-income schools are less likely to have well-qualified educators [11]. In low-income systems, only 27 percent of high school math teachers majored in mathematics in college, compared to 43 percent of teachers in higher-income systems [12].

As Auburn University is located near many Title 1 schools, the authors decided to design and conduct a STEM outreach project focusing on local Title 1 school systems. The goal of this effort is to make connections with the local school systems while trying to engage and excite the students about STEM fields. This paper will show how the outreach was conducted and highlight the efficacy of the outreach through anonymous pre- and post- surveys of the students. A robot was chosen for this outreach project, as robots have been shown to excite students and provide a good conduit to teach students about STEM [13, 14]. First, the outreach robot is described. Next, the presentation structure and main points are described in detail. We then include a brief description of the structure and purpose of the survey and its questions; a full copy is included in the appendix for reference. Following this discussion, the recorded responses of over 520 students are analyzed to determine the efficacy of our presentation. Finally, the implications of this study are discussed, as well as possible future expansions and efforts.

Robot Description

This section briefly describes the robot designed and built for this outreach project. If you would like any particular details about this robot or the source code and program files used in this project to conduct outreach projects of your own, please email the corresponding author.

Hardware

Figure 1 shows a picture of the fully constructed robot. The robot's only source of sensory input is a Microsoft Kinect^{TM} sensor connected to a laptop. This laptop then controls an Arduino Uno through serial communications. A pan-and-tilt is controlled by the Arduino via power relays that allow it to tilt up/down and rotate clockwise/counterclockwise. The attached Nerf™ Rival Zeus launcher has been modified to remove any gating mechanisms and is activated in an alternative manner: a single power relay is used to provide power to the stock flywheels from the recommended batteries, ensuring that no projectiles are launched harder or faster than intended by the manufacturer. Additionally, a DC fan controlled by a single power relay has been attached to a PVC pipe tube into which Nerf™ balls are loaded, allowing for automatic launching of the balls. All physical interfaces are controlled through power relays by the Arduino Uno, which is a slave device to the laptop connected to the Microsoft Kinect™ sensor. The absence of physical actuation of the Nerf™ launcher was done intentionally to prevent the possibility of other objects functioning in this system.

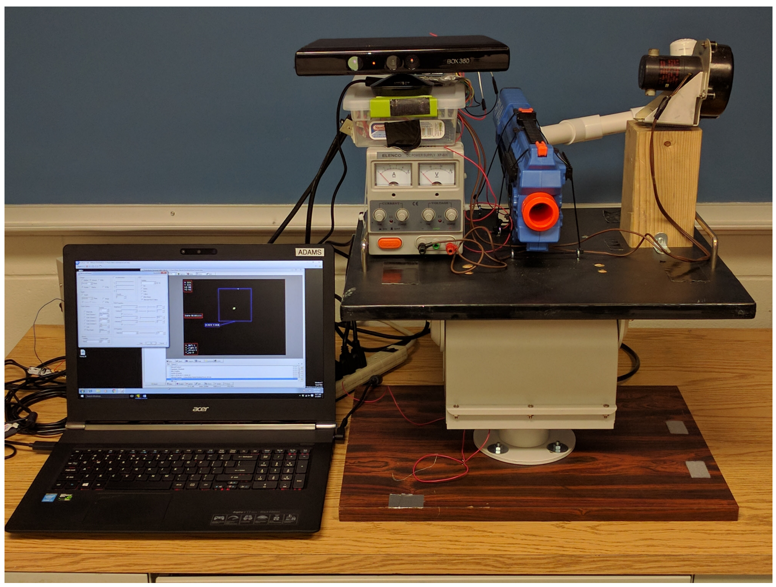


Figure 1: Fully constructed robot for outreach program

Software

Figure 2 shows a basic flowchart of the software used for the robot. The Microsoft Kinect™ sensor transmits data from the infrared spectrum to a laptop running the RoboRealm software. The RoboRealm software then performs basic image processing to filter out all objects below an intensity threshold in the infrared spectrum. Next, the software determines if the target is in the filtered field of vision, what direction it needs to move the pan-and-tilt if necessary, and if the Nerf™ launcher should be activated. Each of these commands is concatenated into a single packet to be transmitted through serial communications to the Arduino Uno, which then actuates the appropriate relays. The computer bases its decisions on the location of the target in its field of view, moving the pan-and-tilt to put the target into a small pre-defined zone before it will send a command to activate the Nerf™ launcher; an example of the output of RoboRealm's image processing can be seen in Figure 3.

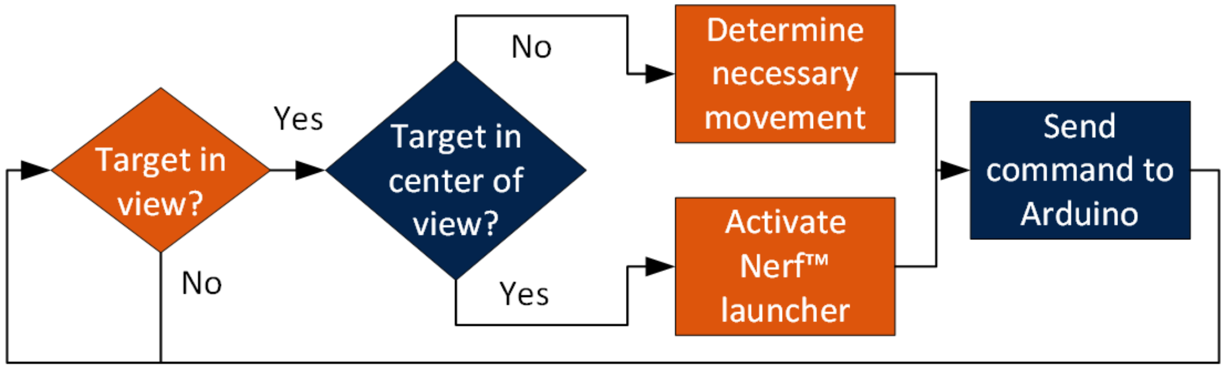


Figure 2: Flowchart of robot software operation

Methodology

Presentation Structure

The presentation given to all students adhered to the following structure:

1. *Pre-Survey*
   Students were asked to complete the pre-survey questions upon entering the classroom. The surveys were waiting on desks with pencils, and students were instructed not to write their name to mantain anonymity. The presentation did not continue until all students had completed the pre-survey.

2. *Introductions and Engineering Design Presentation*
   The presenters were identified as graduate students in Auburn University's Department of Electrical and Computer Engineering, and the engineering design process for building the robot was explained. This started with a short explanation of different types of light and why using the Microsoft Kinect™ sensor to detect reflected infrared light simplified the problem of identifying a target, as there are fewer sources of interference than in the visible light spectrum. Students were involved in this portion of the presentation through answering questions and gathering around the robot to "see what the robot sees" in both the filtered infrared and visible light spectra, as in Figure 3. Next, a brief description of the decision making process of the robot was explained using examples of how a human might turn their body to look at something of interest, providing a simple analog to the pan-and-tilt's operation. Students were once again involved by providing possible steps for this task, such as "turn left/right" and "look up/down".

(a) (b)

Figure 3: Images of what the robot sees (a) in the visible spectrum (b) in the filtered infrared spectrum

3. *Demonstration of Robot Operation*
   After donning appropriate safety gear, one presenter would affix the target to their chest to demonstrate the robot's ability to aim and launch Nerf™ balls at the target. To demonstrate the robot's ability to follow a target, the launching mechanism was disengaged and the robot was allowed to track the target while the presenter carried it throughout the room and audience space. To further demonstrate the robot's ability to launch Nerf™ balls only at the target, a volunteer equipped with proper safety equipment was made to stand next to the presenter with the target in the robot's field of vision while the robot tracked only the target. Additionally, several student volunteers were given appropriate safety gear and allowed to hold the target while the robot tracked and launched Nerf™ balls at it.

4. *Post-Survey*
   Time was next allotted for students to complete the post-survey on the back of the pre-survey which they had previously filled out.

5. *(Optional) Volunteer Participation and Further Questions*
   With the permission of the present teachers, any remaining time was spent allowing students who volunteered to put on safety gear and hold the target while the robot operated. Additionally, questions were fielded from students on the robot's operation or general engineering concepts. Students were also asked questions such as "How can we improve this robot?", "What could we possibly use this robot for?", and "What do you think could be a problem with this robot?" to encourage participation.

Targeted Approaches for Different Age Groups

Special attention was given to adapting the presentation content to the targeted age groups of elementary, middle, and high school students. For students in elementary school, most of the in-depth scientific explanations of the electromagnetic spectrum were replaced by interactive questions and demonstration of how each part of the robot works in a simplified manner. For students in middle school, in-depth scientific explanations were given when possible by leading students through questions and further supporting interactions; additionally, emphasis was placed on the availability of open-source materials, such as the Arduino platform, in an effort to inspire students to attempt projects of their own. For students in high school, in-depth scientific explanations were given when deemed necessary by student inquiry, and a large portion of time was allocated to answering questions related to STEM fields in practice and as a career path.

Figure 4: Picture of demonstration in progress at Title 1 Middle School

Survey Structure

Assessment of impact on students' interest levels in engineering and robotics was evaluated via the distribution of pre-demonstration (pre-surveys) and post-demonstration surveys (post-surveys). A copy of the surveys distributed to the students can be seen in the appendix. Each survey consisted of five questions related to the students' past experiences in robotics-like and engineering-like activities as well as their interest in future activities pertaining to robotics and engineering. Two questions on both sets of surveys evaluated the students' interest levels in robotics and engineering on a Likert scale. A third question, which asked the students about their comfort level with robots, was also evaluated on a Likert scale. Two Yes-or-No questions were included in the survey. The pre-survey Yes-or-No questions asked students if they had ever tried to write code before and if they had ever built anything on their own or with friends. Students were encouraged to provide examples if they answered yes to either question. For the post-survey Yes-or-No questions, students were asked if the presentation gave them any ideas of things to build themselves and if they would be interested in working on a similar project on their own or with friends. For both questions, students were encouraged to provide examples if they answered "yes".

Survey question selection addressed four primary goals:

1. Quantitatively define students' change in interest level in engineering to establish the efficacy of the demonstration

2. Estimate how many students had prior exposure to STEM related activities
3. Establish the efficacy of the presentation and demonstration in inspiring new ideas in students
4. Quantitatively define the change in students' interest and comfort level in robotics to establish the efficacy and accessibility of this demonstration

Data Analysis

In total, 521 responses to the surveys were collected. The schools selected for outreach were within 45 minutes of Auburn University and located in Lee County, Alabama. Yarbrough Elementary School was selected in the Auburn City School system. Beauregard High School, Sanford Middle School, and Beulah Elementary School were selected in the Lee County School System. Both Sanford Middle School and Beulah Elementary School are Title 1 systems [15] and comprised over 85 percent of the surveyed students. Table 1 shows the number of responses by age group, with elementary school age defined as grades 1-5, middle school age defined as grades 6-8, and high school age defined as grades 9-12. It should be noted that all high-school age students surveyed were in advanced level AP Chemistry and AP Physics courses.

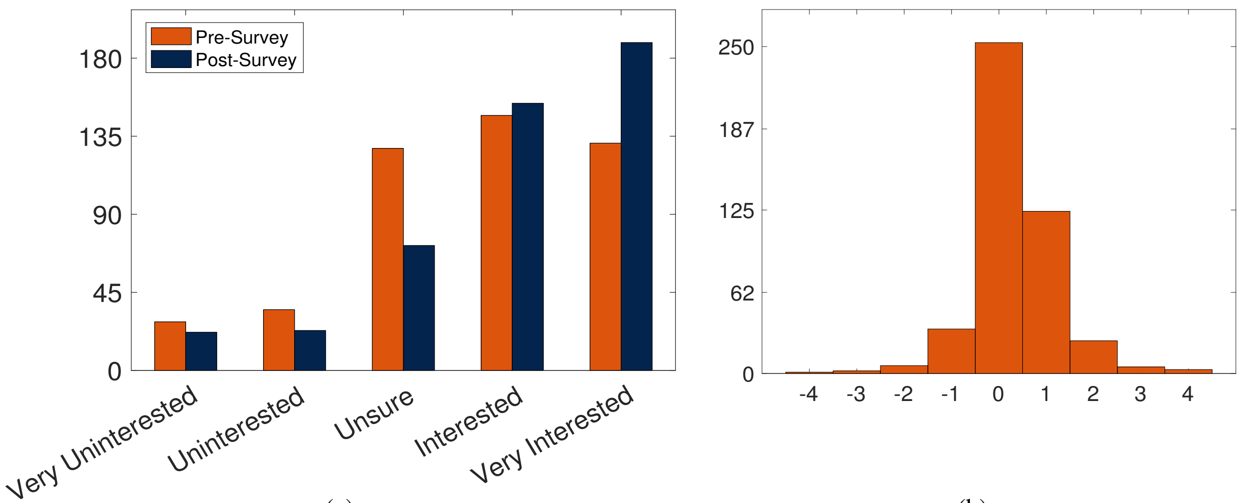
Elementary School Age	Middle School Age	High School Age
130	367	24

Table 1: Number of students surveyed by age range

Interest Levels in Engineering

Question 1 on both the pre- and post- survey asked students how interested they were in engineering; the responses were compared to determine the efficacy of the presentation in raising engineering interest levels. We found that a significant portion of students, roughly 36%, reported increased interest levels, and that students were almost four times as likely to report an increase in interest level rather than a decrease. Figure 5 shows the relevant graphs and tables of calculated values for this question, with Figure 5(a) showing survey responses and Figure 5(b) showing counts of changes in student responses. Furthermore, calculated standard deviation values of roughly one on a Likert scale indicate enough spread in responses for these results to be a reasonable interest spectrum [16], giving validity to the survey structure and wording.

These statistics prove the demonstration successful in its goal of raising interest in STEM fields, which can be attributed to several factors of the presentation: the "wow" factor of a robot, the enthusiasm with which the material was presented, and the accessible nature of the robot as a high-tech children's toy. The basis for these statements is the consistently excited reaction from students at specific points during the presentation. No group entered the presentation space without whispers of "Look! They brought a robot!", showing that children are often excited and interested by the presence of a robot. Each group laughed and enjoyed the presentation of scientific material, as age-appropriate jokes were frequently employed to hold their interest. And finally, each group had at least one student spring out of their seat to get a closer look at the Nerf™ launcher or to simply announce that they too “have one of those at home”.



(a) (b)

	Pre-Survey	Post-Survey	Delta
Average	3.68	4.04	+0.36
Std. Dev.	1.12	1.09	-0.04

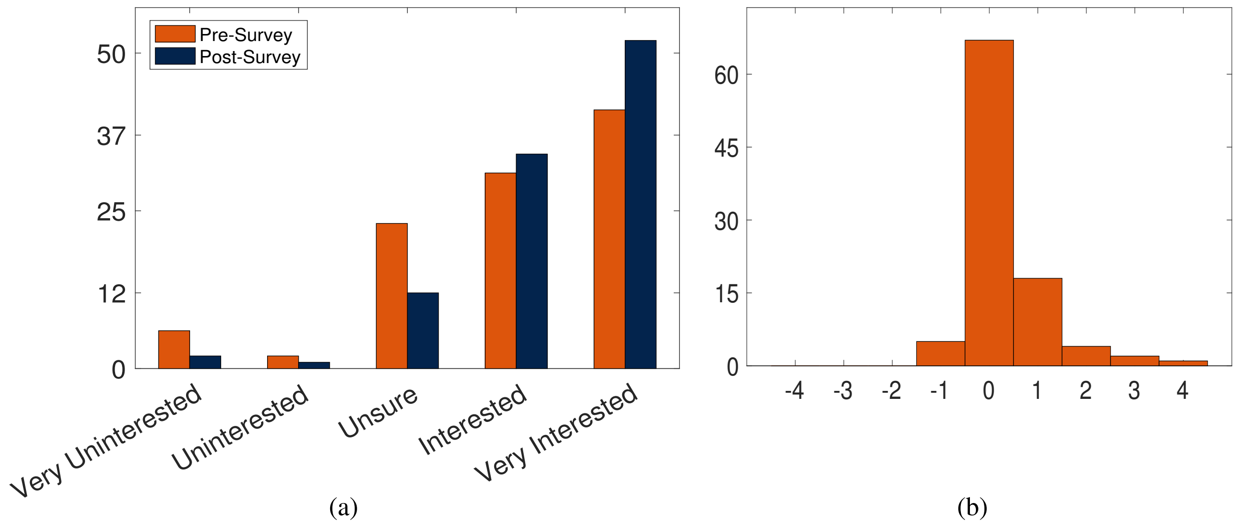
(c)

Change	-4	-3	-2	-1	0	1	2	3	4
Count	1	2	7	36	267	138	32	6	3

(d)

Figure 5: *What is your interest level in engineering?* (a) student responses on pre- and post- survey (b) count of changes in student response (c) calculated values for survey responses (d) counts of data set changes

Upon establishing the efficacy of the presentation in general, the data from Question 1 was re-examined with student responses divided into two groups: those with and those without prior coding experience. This analysis was performed in an effort to determine the value of exposing students to writing lines of code at a young age, as done in [17]. We found that students with prior exposure to writing code had significantly higher average interest levels in both the pre- and post-surveys, validating studies showing that exposing children to writing code can generate interest in STEM fields [14]. However, we also found that students with no prior exposure to writing lines of code were about four times more likely to report increased interest levels than decreased interest levels and were approximately 1.5 times more likely to report increased interest levels than students with prior coding experience. These numbers did not surprise us, as they fall in line with what one will expect for the difference between the first and subsequent exposures to a particular subject. Figure 6 shows the survey responses and changes in student responses of each group, with relevant calculated values and counts.



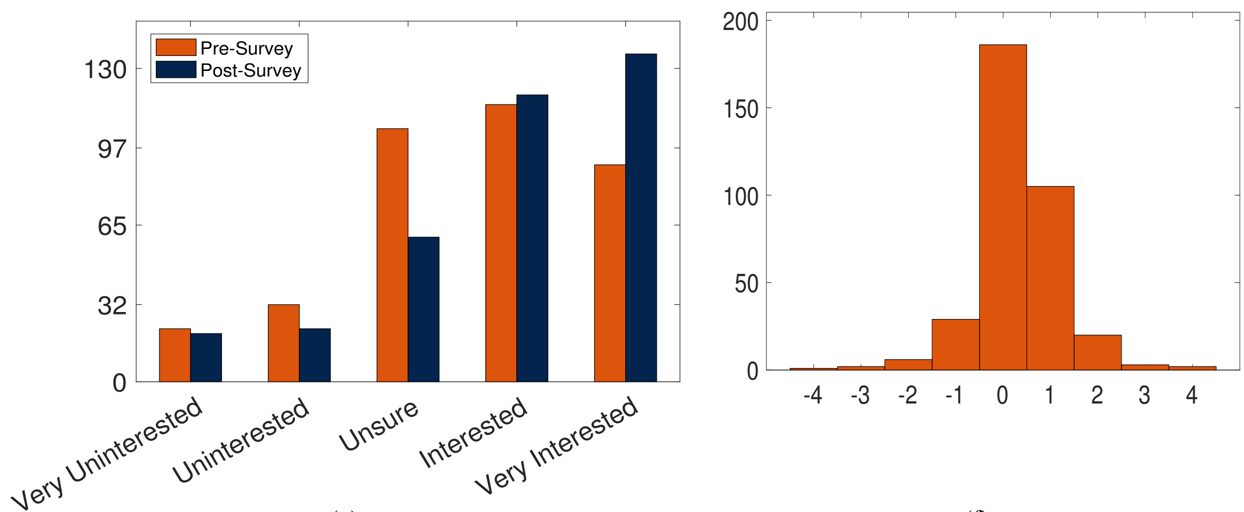
(a) (b)

	Pre-Survey	Post-Survey	Delta
Average	3.96	4.32	+ 0.36
Std. Dev.	1.11	0.87	- 0.24

(c)

Change	-4	-3	-2	-1	0	1	2	3	4
Count	0	0	1	5	70	19	5	2	1

(d)



(e) (f)

	Pre-Survey	Post-Survey	Delta
Average	3.60	3.92	+0.32
Std. Dev.	1.13	1.14	+0.01

(g)

Change	-4	-3	-2	-1	0	1	2	3	4
Number	1	2	6	31	197	118	26	4	2

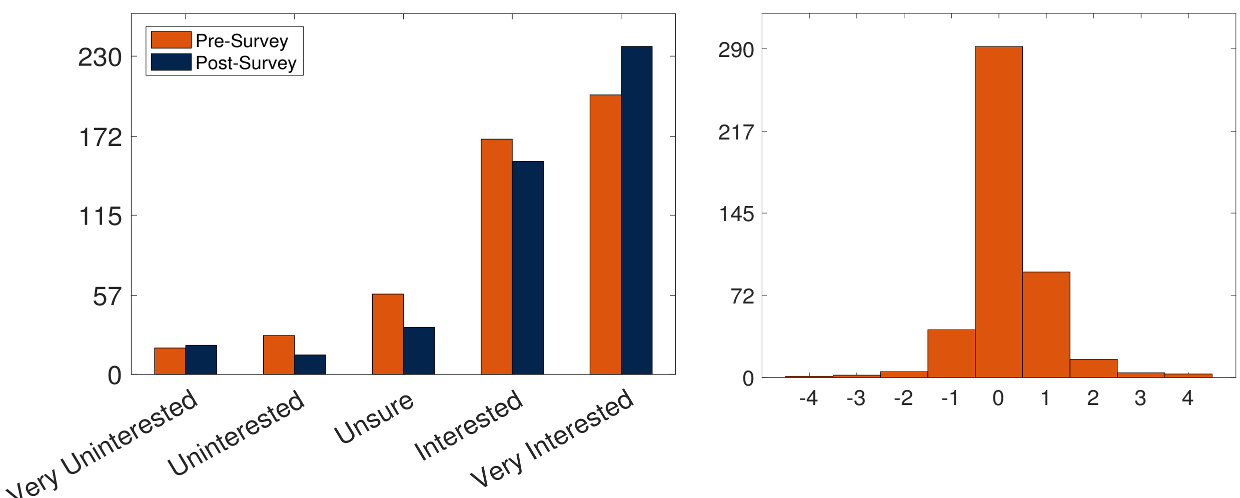
(h)

Figure 6: *(a - d) students with prior coding experience:* (a) student responses (b) count of changes in student response (c) calculated values for survey responses (d) counts of data set changes *(e-h) students with no prior coding experience:* (e) student responses (f) count of changes in student response (g) calculated values for survey responses (h) counts of data set changes

Interest and Comfort Levels with Robots

Questions 4 and 5 on the pre- and post- surveys asked students their interest and comfort levels with robots, respectively. Once again the presentation was proven a success, as both interest levels and comfort levels were between two and three times more likely to increase than decrease, with between 27% and 29% of students reporting increases on each question. Figure 7 shows the relevant graphs and calculated values for Question 4, while Figure 8 shows the same information for Question 5.

In addition to validating the presentation's efficacy, an interesting fact arose from examining the responses to Questions 4 and 5: the number of students that were "Very Uninterested/Uncomfortable" increased slightly after the presentation. The reason for this is assumed to be the connotations associated with the Nerf™ launcher, the focal point of the robot. The presenters overheard multiple students recounting stories of older siblings using these same toys against them during the course of the outreach program. Most students engaging in this line of thought followed it with something like "I could win with this robot on my side!", but some students may have seen the robot as a potential threat from older siblings instead of an ally on their side.



(a) (b)

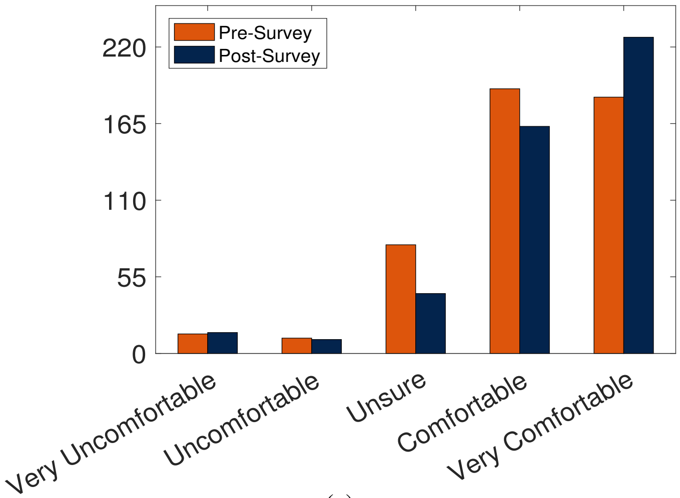
	Pre-Survey	Post-Survey	Delta
Average	4.04	4.27	+ 0.23
Std. Dev.	1.11	1.01	- 0.10

(c)

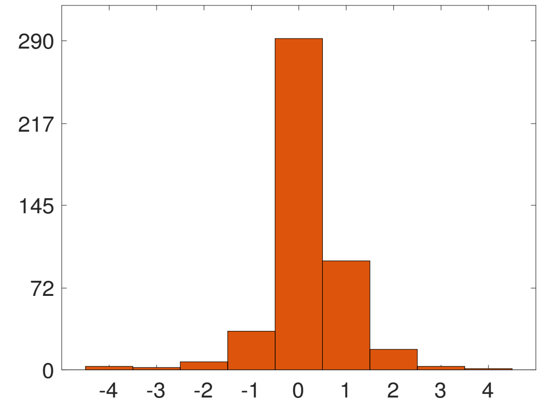
Change	-4	-3	-2	-1	0	1	2	3	4
Count	1	3	6	43	312	103	17	6	9

(d)

Figure 7: *How interested are you in robots?* (a) student responses on pre- and post- surveys (b) count of changes in student response (c) calculated values for survey responses (d) counts of data set changes



(a)



(b)

	Pre-Survey	Post-Survey	Delta
Average	4.06	4.27	+ 0.21
Std. Dev.	0.96	0.93	- 0.03

(c)

Change	-4	-3	-2	-1	0	1	2	3	4
Count	3	2	7	39	305	114	21	5	2

(d)

Figure 8: *How do you feel around robots?* (a) student responses on pre- and post- surveys (b) count of changes in student response (c) calculated values for survey responses (d) counts of data set changes

Selected Survey Responses

During the presentations and surveys, many interesting and detailed responses from the students were captured. Most students were very enthusiastic, although some were not. One middle school student wrote “You’re boring and you suck” on their survey. This was the respondent who dropped 4 interest levels between the pre- and post-surveys on all three Likert scale questions. Since the respondents were predominantly younger students, there were some fun and interesting responses. For question number 2 of the pre-survey, we received nonsensical answers like “Ultra Fire Flame,” along with serious responses that they did some programming in games such as Minecraft, participated in Hour of Code, and even that some had tried Python. With the third pre-survey question, the goal was to have a broad range of responses, and we were not disappointed. Many students denoted building simple science projects, such as cell models, baking soda and vinegar volcanoes, and marshmallow toothpick structures. Students also described many things they built outside of school, such as LEGO buildings, tree forts, and VEX robotics. Finally, some students stated they built some interesting things, such as “Ferret ration cage”, “Real life Minecraft pig”, and “Lightning catapult". The group will try to reach out to the middle school student who designed the lightning catapult, as we are very interested in this scientific advance!

In the post survey, the open ended questions gauged whether the outreach made students want to build a project on their own or with their friends. Many students desired to build a robot or device that would aide them with chores like dish washing, cleaning a bedroom, getting groceries, or doing homework. Other students wanted to build things that weren't robotic, such as: "nuclear powered armor suit", "lights that turn on when I walk into a room", "machine to collect lightning", "automated lighting system, maps out surfaces of a room to distribute light evenly", and a roller coaster. Several students were apparently hungry when the surveys were completed, as many wanted robots that would assist with getting or preparing food. One wanted to build a donut dispenser. Students often wanted to build robots that they could play and interact with, such as robotic pets, tennis ball launchers, and even a martial arts robot. Quite often students wanted to build their own automatic Nerf™ launcher, or they provided ideas and feedback to improve the robot during a question and answer session. They had several great ideas: make it mobile with wheels or treads, make it able to track multiple targets, and make it able to identify non-targets. This provided opportunity for the group to interact with the students and help them plan and discuss how such upgrades could be implemented.

Conclusions

It is typically uncommon for primary and secondary students to experience understandable engineering projects and meet engineers, particularly young engineers with whom they can relate. The demonstration of the Nerf™ launcher robot gives students a chance to see engineering as a fun and rewarding career option. Our student surveys indicated increased interest in engineering as a result of the demonstration. Some of the mystery and trepidation of engineering was removed by the demonstration and friendly explanation of the robot, and students can easily imagine this as something they can do. We also note that exposure to, and experience with, code writing also enhances student interest in robotics. We like our procedure, but hope that the ASEE community can offer suggestions to make it better!

Longitudinal assessment

This project was deemed very successful by the group, being beneficial for the students and enjoyable to the group members. Due to the success of the project, we have decided to continue developing this program. One of the significant challenges encountered when developing the outreach program was coordinating with the local school systems and getting the proper approvals. Since this step has already been completed and contacts have been made between the group and school systems, there is an interest in continuing with more outreach programs and research. More outreach projects and data are needed to further prove the efficacy of this project. We were unable to organize as many high school age events as elementary and middle school events, as high school teachers have less time to dedicate to outreach efforts. Additionally, the design of a different robot that can be presented as a more helpful, assisting robot may be created and demonstrated to the schools to compare student reactions to helpful assistant robots and deterrent robots. The students would be given a similar survey, and results could be compared to the those of the Nerf™ robot to see which type of robot has a greater efficacy to enhance interest levels in STEM and robotics, along with comfort levels around robots.

Acknowledgements

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Appendix

Pre-Survey

1. What is your interest level in engineering (applying math and science to solve real world problems)? Circle the best answer.

Very Uninterested	Uninterested	Unsure	Interested	Very Interested

2. Have you ever tried to write a program before? For Example: C, Microsoft Excel formulas, Code Block Games, hour of code, etc. If yes, give an example

Yes	No

3. Have you ever built anything on your own or with your friends before? If yes, give an example?

Yes	No

4. How interested are you in robots? Circle the best answer.

Very Uninterested	Uninterested	Unsure	Interested	Very Interested

5. How do you feel around robots? Circle the best answer.

Very Uncomfortable	Uncomfortable	Unsure	Comfortable	Very Comfortable

Post-Survey

1. What is your interest level in engineering (applying math and science to solve real world problems) after seeing this presentation? Circle the best answer.

Very Uninterested	Uninterested	Unsure	Interested	Very Interested

2. Did this give you any ideas of things to build yourself? If yes, what?

Yes	No

3. Would you be interested in working on a project like this on your own or with friends? If yes, give an example?

Yes	No

4. How interested are you in robots after seeing this presentation? Circle the best answer.

Very Uninterested	Uninterested	Unsure	Interested	Very Interested

5. How do you feel around robots after seeing this presentation? Circle the best answer.

Very Uncomfortable	Uncomfortable	Unsure	Comfortable	Very Comfortable