Generating Enthusiasm for Mathematics Through Robotics

Matthew Hoyin Jahnes, RPI Engineering Ambassadors

Matthew Jahnes is an undergraduate student at Rensselaer Polytechnic Institute studying electrical engineering with a concentration in analog design. He has had internships with both United Technologies and Bose. He is currently in his last year for undergraduate studies and works with Engineering Ambassadors.

Mr. David Joseph Glowny, Rensselaer Polytechnic Institute

David Glowny is a student at Rensselaer Polytechnic institute pursuing a Bachelors of Science in Computer & Systems Engineering (Dec. 2017) and a Masters of Science in Computer Science (Dec. 2018). He is currently an RPI Engineering Ambassador and is participating in research with Professor Agung Julius from the RPI ECSE department as well as research with the Worldwide Computing Laboratory group (https://wcl.cs.rpi.edu/) directed by Professor Carlos Varela. He has also worked as an engineering intern for Sikorsky Aircraft (Summer 2015, Summer 2016).

Timothy Andrew Spafford, Rensselaer Polytechnic Institute

Timothy Spafford is a fourth year student at Rensselaer Polytechnic Institute, pursuing both a B.S. in Mechanical Engineering and a M.B.A. At RPI he is involved in the Engineering Ambassador program, where he is a student ambassador as well as a research assistant.

Justin Lee Clough, Rensselaer Polytechnic Institute

Justin Clough received his Bachelors of Science in Mechanical Engineering with minors in mathematics and applied physics from the Milwaukee School of Engineering. As an undergraduate, he has worked on research projects with the National Science Foundation, Argonne National Laboratory, and the Stanford Linear Accelerator Center. He is working on his doctorate in Mechanical Engineering at Rensselaer Polytechnic Institute specializing in computational materials and volunteers with Engineering Ambassadors.

Ms. Elizabeth S. Herkenham, Rensselaer Polytechnic Institute

Ms. Herkenham is the K-13 Education Outreach Director of the School of Engineering (SoE) at Rensselaer Polytechnic Institute. Her responsibilities include managing the Pre-College educational programs for the NSF-funded Engineering Research Centers; LESA & CURENT ERC, and faculty-driven Broader Impact initiatives. Under Ms. Herkenham's leadership, the RPI Engineering Ambassadors undergraduate program was established in Spring 2011. This unique program has been an effective approach for disseminating cutting edge research concepts into today's 4- 12 grade classrooms.

Dr. Wencen Wu, Rensselaer Polytechnic Institute

Wencen Wu has been an Assistant Professor of the Department of Electrical, Computer, and Systems Engineering at Rensselaer Polytechnic Institute since 2013. She received her Ph. D. from the School of Electrical and Computer Engineering at Georgia Institute of Technology in 2013, and M.S. degree and B.S. degree from Shanghai Jiao Tong University in 2009 and 2006, respectively.

Dr. Anak Agung Julius, Rennselaer Polytechnic Institute

A. Agung Julius is an Associate Professor at the Department of Electrical, Computer, and Systems Engineering at Rensselaer Polytechnic Institute. He has been at Rensselaer since December 2008. He earned the Ph.D. degree in Applied Mathematics from the University of Twente, The Netherlands in 2005. In 2005 – 2008, he was a Postdoctoral Researcher at the University of Pennsylvania.

Generating Enthusiasm for Mathematics through Robotics

Abstract

This evidence-based practice paper describes the study of generating enthusiasm for mathematics through robotics. A survey of Rensselaer Polytechnic Institute undergraduate students taking the Robotics I course showed that, while many students have a great interest for mathematics, more than 1 in 4 of those same students expressed that they were not adequately prepared for the mathematics required. This is particularly concerning for those teaching engineering courses because concepts of robotics and mathematics are very much intertwined. Therefore, this inspired a study of younger middle school and high school students to i) assess preexisting notions of mathematics and robotics, ii) introduce an educational module to highlight the connection between robotics and mathematics, and iii) evaluate the students' new opinions of mathematics and robotics. Through this, the objective is to develop and validate a method for generating enthusiasm for mathematics as well as for robotics.

The method to be validated works by first giving students an oral presentation on robotics and the mathematical concepts behind it. After the presentation, the students are given a challenge that involves these mathematical concepts and pre-built LEGO NXT-based robots. The students have to complete the challenge using the mathematic concepts given during the presentation; primarily those which involves determining programming parameters by calculating distances traveled by rolling wheels. The students are encouraged to calculate these programming parameters rather than using guess-and-check methodology. The effectiveness of the presentation and hands-on activity were evaluated by comparing the differences between responses of preliminary and concluding surveys for students of Berlin Junior/Senior High School (in Berlin, NY) and Lansingburgh High School (in Troy, NY). These results are analyzed with paired t-tests to determine the significance of change for students as a whole as well as for specific genders. At the 5% level of significance, an increase was found in both schools' students' survey responses for agreement with statements such as 'Mathematics is important when learning robotics,' and 'The Engineering Design Process is an important tool for solving challenges,' ($n=103$, $p<10^{-4}$ for both statements). Overall, the results show that a majority of the paired t-tests for the survey questions had a significant improvement. Therefore, it was concluded that there was a significant improvement in the students' enjoyment, appreciation, and understanding of the concepts of mathematics within the field of robotics as a result of this educational module.

Introduction

The interest level of high school and middle school students in mathematics trails behind that of sciences for both males and females. Specifically for male students, 58.7±0.66% like mathematics whereas 69.9±1.28% of the same group like sciences; for female students, 53.2±0.58% like mathematics whereas 59.4±1.08% of the same group like sciences [1]. The two subjects are heavily intertwined and a deficiency in one will lead to difficulties in learning the other; this is especially prevalent at the college or other post-high school level of education.

As evidence of these higher-level difficulties, a survey of students in an undergraduate level robotics course at Rensselaer Polytechnic Institute was conducted. It was found that at least 27% of students who did not drop the course felt inadequately prepared for the prerequisite mathematics involved. At the University of North Dakota, the faculty recognized similar issues, but in the programming and circuitry realm. To combat this, they introduced a project in their Introduction to Electrical Engineering course (EE 101) using Lego NXT based robots. These robots helped students develop the skills needed in order to pursue their engineering degree. It was found that after implementing these devices as a learning tool, the enrollment of this class dramatically increased from fall 2007 to fall 2008. The authors of this study wrote that "the future of NXT looks very promising and the use of LEGO MINDSTORMS NXT brick is an effective way to introduce and teach the concepts of any engineering field…in areas such as robotics, logical programming, traditional concepts of mechanics, and much more," [2].

To increase student enjoyment of mathematics, the use of modern technologies has become an increasingly prevalent technique in K-12 classroom environments. An example of this is presented by Taban et al. [3]; the purpose of this study was to apply methods in the hopes of increasing understanding and interest in the science, technology, engineering, and math (STEM) fields for middle and high school students and then observe their responses based on survey results. These methods primarily used hands-on activities which included Lego Mindstorms robotics. This study spanned over two years and also incorporated the introduction of additional supporting structures including a robotics club and a robotics class. It was found that a majority of the surveyed students enjoyed and had a better understanding of the STEM fields.

A second example of using technology as a tool to convey mathematical concepts in a teaching environment was presented by Laut et al. [4]. Here, LEGO NXT-based robots again were used to demonstrate mathematical concepts, primarily those focusing on geometry. Paired t-tests of pre- and post-test responses were conducted. It was shown that, on average, the students scored significantly better on quizzes after interacting with the robots than they did before. Furthermore, the use of robotics, namely those based on the LEGO platform, to engage students has also been demonstrated by Wright [5], Lu [6], and Yuen [7].

The purpose of this study was to engage with middle school and high school students. This was accomplished through a presentation and hands-on activity designed to display the importance and exciting impact of mathematic concepts in robotics. With respect to the target audience, basic geometry and conversion equations (e.g., the rotation of a wheel to a linear distance traveled) were discussed and practiced. Student responses were collected using pre- and post-surveys at the introduction and conclusion of the school visits, respectively. The significance of the change in attitude towards mathematics, engineering, robotics, and the importance of mathematics in robotics was then quantified by the use of paired t-tests between the pre- and post-survey responses.

Method of Study

After initial preparation, a presentation was constructed that focused on essential mathematics principles in path finding robotics. This presentation explained how mathematic fundamentals, such as geometry and numerical conversions, are essential to pathfinding robotics. This also included examples of applications in the modern world. In addition, a corresponding activity was constructed that focused on mathematics and programming of LEGO NXT robots [8]; these robots were constructed before the school visits. One of these robots is shown in Figure 1.

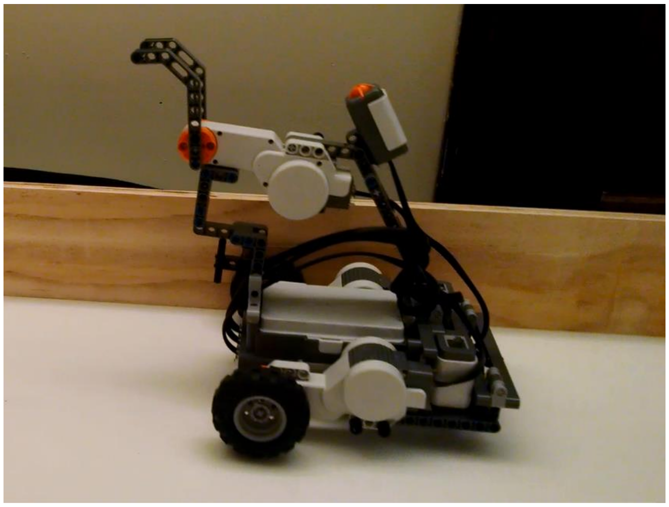

Figure 1: LEGO NXT robot. Height from wheel to top was 6 inches.

This activity guided students in understanding how the rotations of motors and wheels translate into moving a mobile robot. At the start of the activity, groups of 5 to 7 students were given a pre-measured path (shown in Figure 2) for the robot to follow on a board; the board itself was placed on a table or the floor. The robot must follow the path in order to reach a ball at the end and pick it up; success was indicated by grabbing the ball. Once the students used the mathematical principles of conversions from distance to rotations of the motors, they were then able to accurately program the robot to follow the exact path without tedious trial-and-error procedures. Thus, this activity introduced students to robotics and programming while also demonstrating applications of and expanding on mathematic concepts that they have already been taught in class.

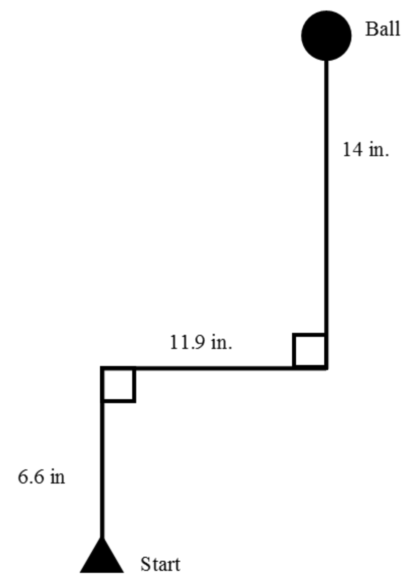

Figure 2: Path with measurements for robots to follow.

Within this activity, students were given the opportunity to apply formulaic operations to convert linear distances to numbers of wheel rotations. They were also given the opportunity to apply geometric concepts to determine the distance the wheels of the robot move during a right angle turn; then convert that distance to number of wheel rotations as well. The goal of this activity was to have the students discover how mathematics was powerful enough to guide the robot precisely through the path without lengthy and time-intensive guess-and-check methods. Thus, the students observed a more real-world example of the rewards of implementing mathematics.

The presentation and corresponding activity were delivered to Berlin Junior/Senior High School in Berlin, NY and Lansingburgh High School in Troy, NY. Within each school visit, the students were given an initial survey and a unique identifier code. The code was assigned in order to compare results with the final survey without retaining any specific personal identity information of the students. Once the initial surveys were complete, the presentation of mathematics and pathfinding robotics was given. Afterwards, the students were invited to participate in the hands-on activity with the LEGO Mindstorms NXT robots. After the activity was completed for the period, the students completed a post survey. This survey held the same statements as the initial survey and the students used the same identifier codes that were given to them at the beginning. A copy of the survey is in Appendix A.

Each survey was comprised of three sections: statement-agreement, short answer, and demographics. The first section of the survey was divided into seven statements with responses ranging from 0 to 5. The representations of the numbers were as follows:

- 0 = does not apply
- 1 = not at all
- 2 = minimally
- 3 = minimally to moderately
- 4 = moderately to extensively
- 5 = a great extent

The seven statements relating to mathematics and robotics are:

1. I enjoy doing activities within the area of robotics.
2. I enjoy doing activities within the subject of engineering.
3. I enjoy the subject of mathematics.
4. I enjoy the subject of science.
5. I enjoy doing activities like coding or computer science.
6. Mathematics is important when learning robotics.
7. The Engineering Design Process is an important tool for solving challenges.

The second section of the survey asked the student to "Write three brief descriptions on how robots are used." The final section of the survey asked for the student to specify their gender (with options of male or female), and race/ethnicity. The choices presented on the survey for race/ethnicity were as follows:

- African American
- Hispanic
- White
- Chinese, Japanese, Korean
- Other Asian
- Foreign National

There was also the option in the final section to mark "Decline to State" for gender and for race/ethnicity. Furthermore, when handing out this survey to the students, it was made clear that they were encouraged to fill out the survey to the best of their ability and were not forced to reply to every statement if they did not want to.

Once all of these school visits were complete, the pre- and post-survey data was compiled and organized by identifier codes; paired t-tests were then used to determine the statistical significance of changes between the two surveys for each statement.

Results

Data from Berlin Junior/Senior High School were collected from 101 survey responses; of the responses, 45 reported as male, 53 reported as female, and 3 declined to state gender or responded inconsistently. From the group of 101 students that were surveyed, 5 reported as Hispanic, 89 as White, and 7 either declined to report race/ethnicity or reported inconsistently. Therefore, with regards to gender, 45% reported as male, 52% reported as female, and 3% declined or reported inconsistent responses. Also, with regards to race/ethnicity, 5% reported as Hispanic, 88% reported as White, and 7% declined or reported inconsistent responses.

The data are summarized as an average and standard deviation for each survey statement, both pre- and post-, in Table 1 and graphically in Figure 3 through Figure 5. As approximately equal portions of the surveyed population reported as either male (45%) or female (52%), the means and standard deviations of these sub-populations are reported as well. On the contrary, as data from ethnic/race sub-populations were sparse (e.g., only 5 data points were collected from those who reported as Hispanic as compared to the 101 total respondents), means and standard deviations are not reported; these sparse measures were not assumed to reflect statistics of the whole population.

Table 1

Mean ±1 standard deviation for each statement calculated from both pre- and post-survey results for Berlin Junior/Senior High School.

Statement	Pre. All	Pre. Male	Pre. Female	Post. All	Post. Male	Post. Female
1	3.4±1.3	3.7±1.4	3.2±1.3	4.1±1.2	4.2±1.2	4.1±1.2
2	3.4±1.3	3.9±1.2	3.1±1.3	4.1±1.1	4.3±1.0	4.0±1.1
3	3.0±1.4	2.9±1.6	3.1±1.4	3.4±1.4	3.3±1.6	3.6±1.3
4	3.6±1.3	3.8±1.2	3.6±1.3	3.9±1.3	4.0±1.3	3.9±1.3
5	3.0±1.5	3.2±1.7	2.8±1.3	3.6±1.4	3.6±1.5	3.6±1.3
6	4.0±1.3	4.0±1.4	4.0±1.2	4.5±1.1	4.4±1.3	4.6±0.9
7	3.6±1.5	3.8±1.5	3.5±1.4	4.2±1.2	4.4±1.1	4.2±1.2

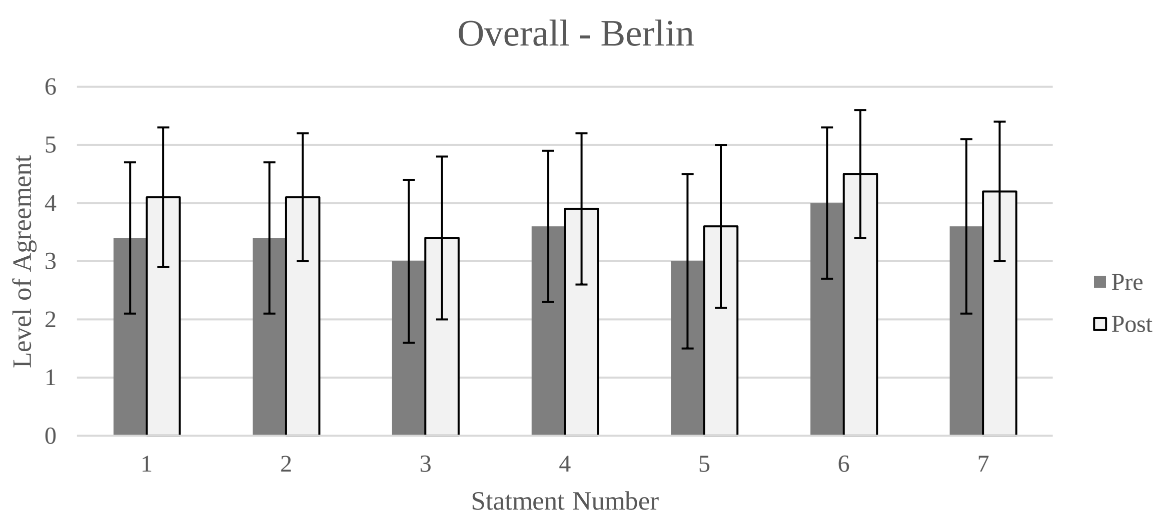

Figure 3: Graphical representation of average survey responses of all respondents for Berlin Junior/Senior High School. Error bars extend one standard deviation in both directions.

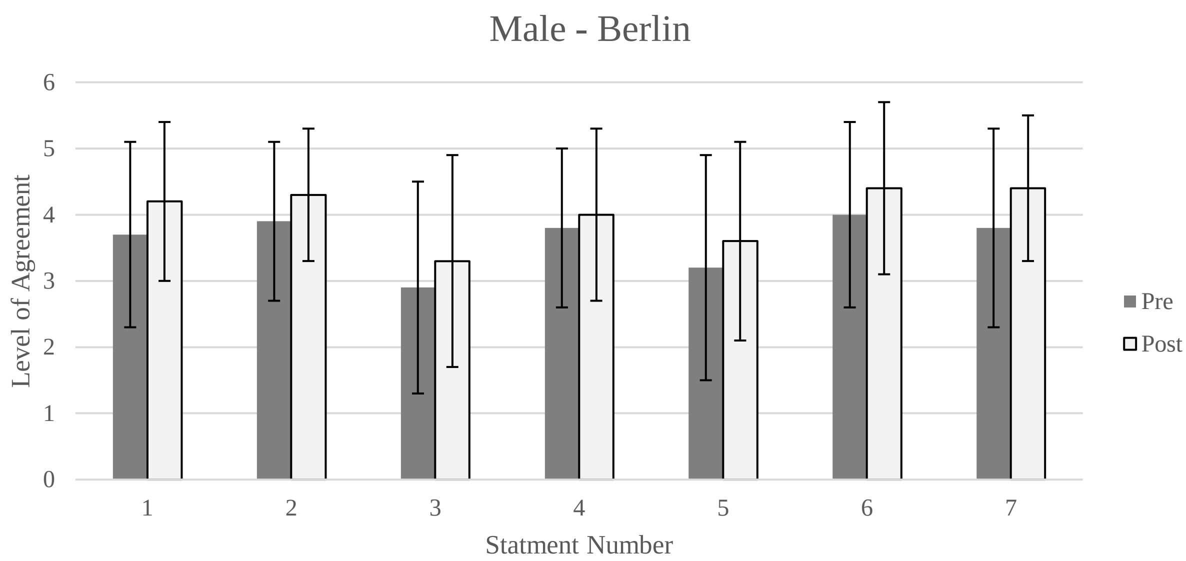

Figure 4: Graphical representation of average survey responses of males only for Berlin Junior/Senior High School. Error bars extend one standard deviation in both directions.

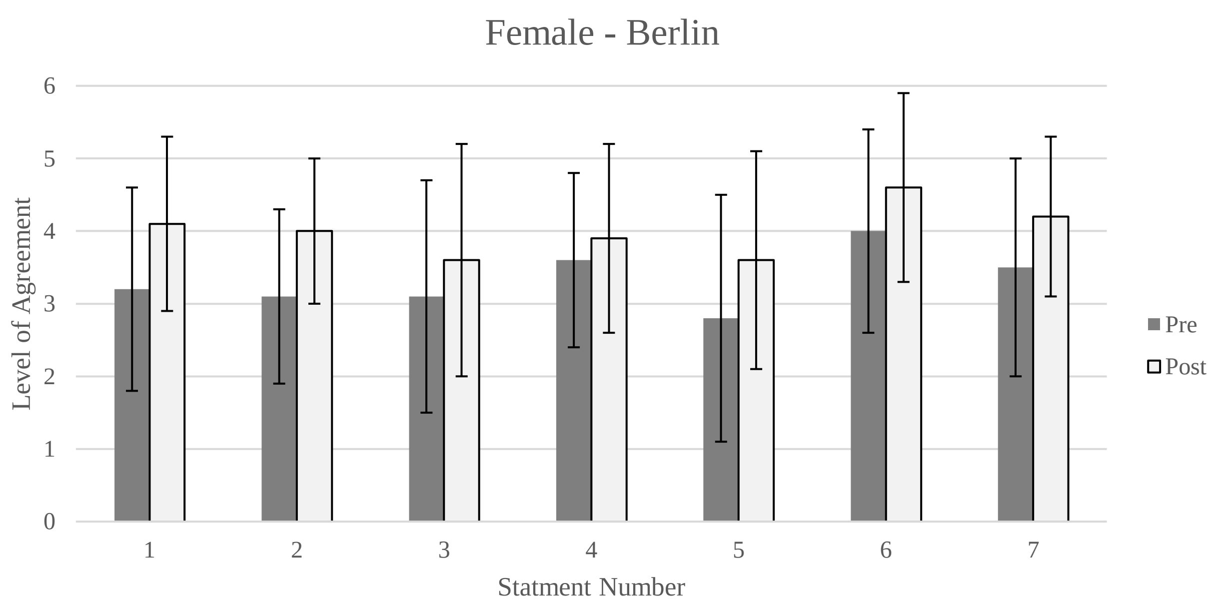

Figure 5: Graphical representation of average survey responses of females only for Berlin Junior/Senior High School. Error bars extend one standard deviation in both directions.

A paired t-test was conducted for each group's (all, male, or female) pre- and post-survey results for each statement. The null hypothesis was that the pre- and post-survey populations had equal means. This was compared against the alternative hypothesis, that the populations did not have equal means. The p-values from these tests are presented in Table 2.

Table 2

Resulting p-values from paired t-tests for Berlin Junior/Senior High School.

Statement	All	Male	Female
1	0.0000	0.0000	0.0000
2	0.0000	0.0244	0.0000
3	0.0002	0.0097	0.0055
4	0.0268	*0.2783	0.0478
5	0.0000	0.0464	0.0002
6	0.0000	*0.0684	0.0002
7	0.0000	0.0030	0.0050

Note. Only first four decimal places shown. Asterisk (*) marks p-values greater than 0.05.

As shown in Table 2, the null hypothesis failed to be rejected at the 5% level of significance for the following Statement and population sets: S4-Male and S6-Male. For the remaining statements and populations, the null hypothesis was rejected at the 5% level of significance.

Similarly, data from Lansingburgh High School were collected from 103 survey responses; of the responses, 49 reported as male, 53 reported as female, and one declined to state gender or responded inconsistently. From the group of 103 students that were surveyed, 7 reported as African American, 8 reported as Hispanic, 77 as White, 2 as Chinese, Japanese, or Korean, and 9 either declined to report race/ethnicity or reported inconsistently. Therefore, with regards to gender, 48% reported as male, 51% reported as female, and 1% declined or reported inconsistent responses. Also, with regards to race/ethnicity, 7% reported as African American, 8% reported as Hispanic, 75% reported as White, 2% reported as Chinese/Japanese/Korean, and 8% declined or reported inconsistent responses.

The data are summarized as an average and standard deviation for each survey statement, both pre- and post-, in Table 3 and graphically in Figure 6 through Figure 8. As approximately equal portions of the surveyed population reported as either male (48%) or female (51%), the means and standard deviations of these sub-populations are reported as well. On the contrary, as data from ethnic/race sub-populations were sparse (e.g., only 8 data points were collected from those who reported as Hispanic as compared to the 103 total respondents), means and standard deviations are not reported; these sparse measures were not assumed to reflect statistics of the whole population.

Table 3

Mean ±1 standard deviation for each statement calculated from both pre- and post-survey results for Lansingburgh High School.

Statement	Pre. All	Pre. Male	Pre. Female	Post. All	Post. Male	Post. Female
1	2.8±1.2	3.1±1.2	2.4±1.0	3.5±1.1	3.8±1.1	3.3±1.0
2	3.1±1.3	3.4±1.3	2.9±1.2	3.5±1.1	3.6±1.2	3.4±1.0
3	3.4±1.1	3.3±1.1	3.6±1.1	3.5±1.2	3.6±1.3	3.6±1.2
4	3.2±1.3	3.0±1.2	3.4±1.3	3.2±1.3	3.0±1.3	3.5±1.2
5	2.6±1.1	2.8±1.2	2.4±1.0	3.0±1.1	3.2±1.2	2.9±1.0
6	4.0±1.0	4.2±0.7	3.8±1.2	4.7±0.6	4.6±0.7	4.7±0.5
7	3.9±1.4	3.9±1.3	3.9±1.5	4.2±1.4	4.2±1.3	4.2±1.5

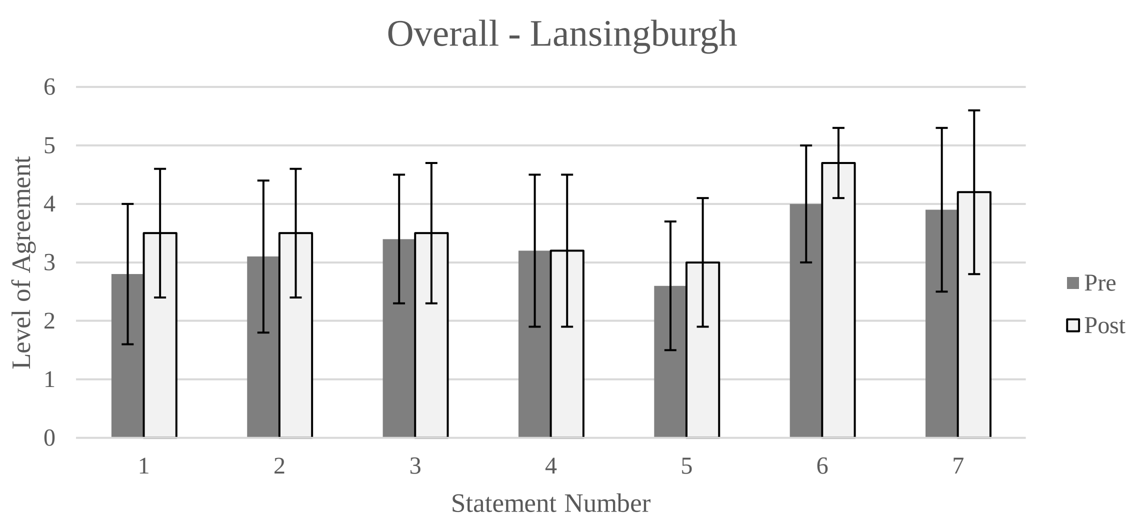

Figure 6: Graphical representation of average survey responses of all respondents for Lansingburgh High School. Error bars extend one standard deviation in both directions.

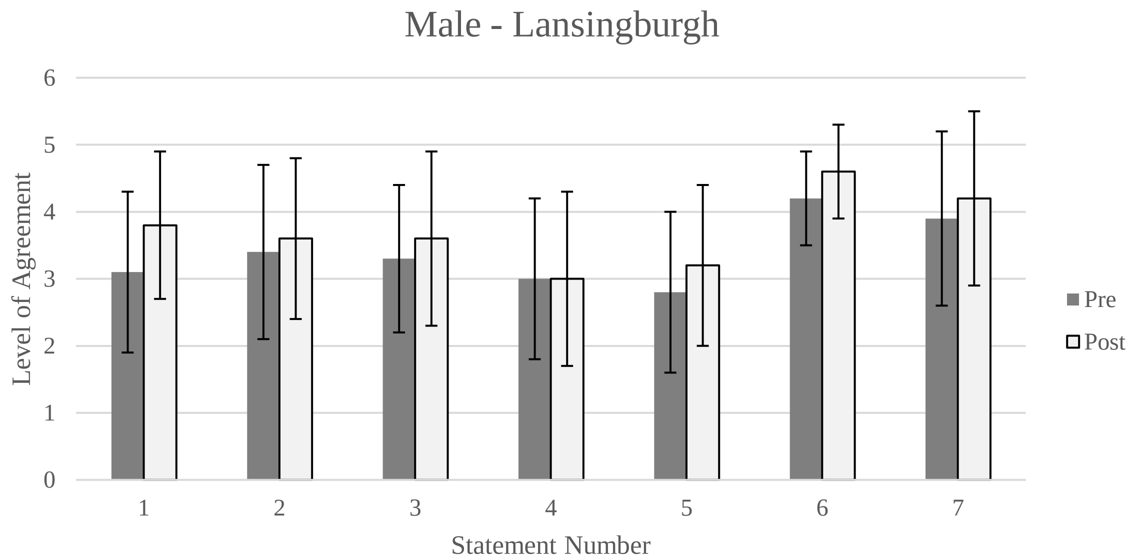

Figure 7: Graphical representation of average survey responses of males only for Lansingburgh High School. Error bars extend one standard deviation in both directions.

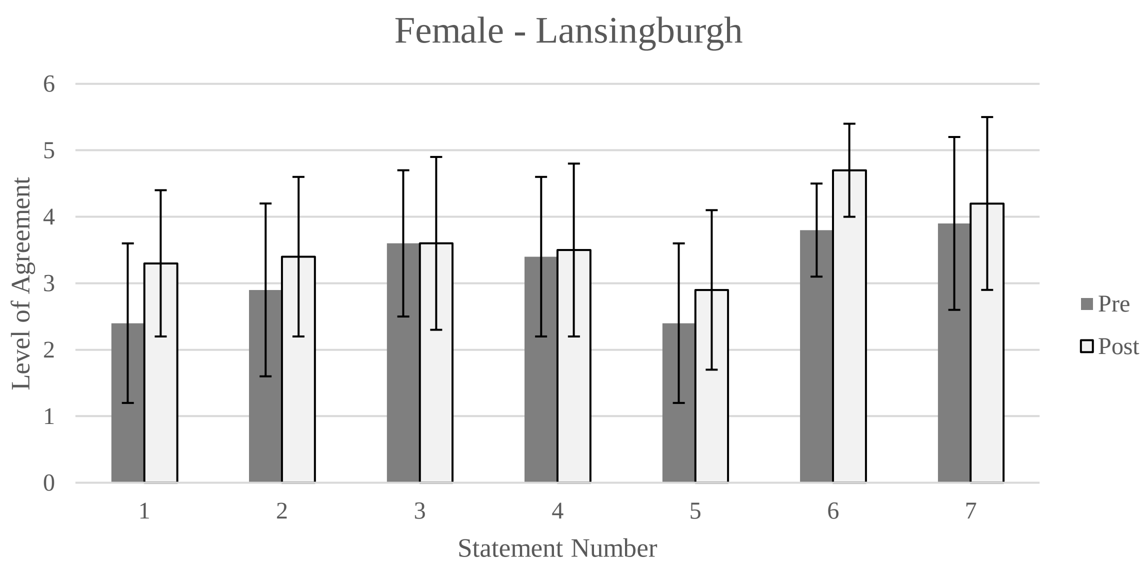

Figure 8: Graphical representation of average survey responses of females only for Lansingburgh High School. Error bars extend one standard deviation in both directions.

A paired t-test was conducted for each group's (all, male, or female) pre- and post-survey results for each statement. The null hypothesis was that the pre- and post-survey populations had equal means. This was compared against the alternative hypothesis, that the populations did not have equal means. The p-values from these tests are presented in Table 4.

Table 4

Resulting p-values from paired t-tests for Lansingburgh High School.

Statement	All	Male	Female
1	0.0000	0.0000	0.0000
2	0.0002	*0.2199	0.0000
3	*0.0638	0.0324	*1.0000
4	*0.2296	*0.8212	*0.1636
5	0.0000	0.0005	0.0006
6	0.0000	0.0004	0.0000
7	0.0000	0.0011	0.0021

Note. Only first four decimal places shown. Asterisk (*) marks p-values greater than 0.05.

As shown in Table 4, the null hypothesis failed to be rejected at the 5% level of significance for the following Statement and population sets: S2-Male, S3-All, S3-Female, S4-All, S4-Male, and S4-Female. For the remaining statements and populations, the null hypothesis was rejected at the 5% level of significance.

Differences in responses between genders for each school were also calculated for the first two statements. Namely, "I enjoy doing activities within the area of robotics," and "I enjoy doing activities within the subject of engineering," were the two statements of interest. Heteroscedastic t-tests were used to compare the responses of males to females for each question. The results of these statistical tests are shown in Table 5.

Table 5

Differences in gender response from each school t-test p-values.

Statement-School	Before	After
1-Berlin	0.0373	*0.8496
1-Lansingburg	0.0054	0.0239
2-Berlin	0.0018	*0.1092
2-Lansingburg	0.0207	*0.2778

Note. Null hypothesis was that the groups' means were equal; the alternative was that they were not. Asterisk (*) indicates failure to reject the null hypothesis at the 5% level of significance.

As shown in Table 5, the differences in responses were found to be statistically significant for both schools and both questions before the presentation. This difference was then found not to be statistically significant for all comparisons except for the first statement from the Lansingburg population.

Conclusions

As confirmed by the results, the education module had a great impact on the student population with regards to enjoyment in the area of robotics. In addition, the students showed a greater understanding of the importance of engineering and mathematics within robotics. For Berlin Junior/Senior High School, 12 out of 14 of the male and female paired t-tests rejected the null hypothesis, (i.e., it was shown that the pre- and post-survey measures are significantly different). For Lansingburgh High School, 10 out of 14 of the male and female paired t-tests rejected the null hypothesis. In addition, all of the average responses either improved or (in one case) remained unchanged as a result of the presentation and activity presented in this study.

For Berlin Junior/Senior High School, there were only two cases where the null hypothesis was not rejected (both of which were in the male sample population). Thus, these students clearly had a greater interest, appreciation, and understanding of mathematics within the field of engineering, especially for the female student population.

For Lansingburgh High School, a majority of the paired t-tests rejected the null hypothesis. However, the improvement was not very significant for the student sample as a whole and the female population on the statement “I enjoy the subject of mathematics”. Nevertheless, all gender groups rejected the null hypothesis in the statement that “Mathematics is important when learning robotics” as well as “I enjoy doing activities within the area of robotics”. This shows that although their enjoyment of math may not have been too largely affected, they understand that math is important in the subject of robotics, which they now further enjoy.

Also important is the fact that the female population group alone rejected the null hypothesis on five of the seven survey questions. In fact, for the students from Lansingburgh High School, the female population also had a large improvement in their response to the statement “I enjoy doing activities within the subject of engineering,” and scored similarly to their male counterparts in the post survey. The female population for Berlin Junior/Senior High School, as well as for Lansingburgh High School, also scored similarly to their male counterparts in the post survey. This contrasts with the pre-survey, where the female population responded significantly lower than their male counterparts. This further indicates a strong benefit to exposing the female student population to the topics of engineering as well as mathematics.

In addition to the numerical data collected, qualitative data on students’ brief descriptions on how robots are used. One of the most prominent responses was “to help people,” or simple variations of the same message such as “help sick people” or “help disabled people.” This suggests that students view robotics as a tool to help society. Furthermore, students identified the unique opportunities that robotics provides with statements such as that robots are used “to do things people can’t or don’t want to do.” Finally, one response that particularly stood out was how one student concisely wrote that robots are used “to build, to move, to connect.” Overall, these responses indicate that this student population paid attention to the messages discussed in our presentation and activity and understands how robotics are highly important in helping benefit society. Considering that the numerical results indicate that the students overall had a greater understanding of how math is crucial to robotics, this suggests that the students also had a greater appreciation for how mathematics can strongly benefit society as well.

Overall, these results validate that there was a significant improvement in their enjoyment, appreciation, and understanding of the concepts of mathematics within the field of robotics as a result of this educational module.

Acknowledgements

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Appendix A

Math in Path finding Robotics Outreach Module Survey

2 to 4 code randomly assigned to student's seats

Item	**Please answer the items below with the response that best fits your opinion.**	1. Not At All	2. Minimally	3. Minimally to Moderately	4. Moderately to Extensively	5. A Great Extent	0. Does not apply
1.	I enjoy doing activities within the area of robotics.	1	2	3	4	5	0
2.	I enjoy doing activities within the subject of engineering.	1	2	3	4	5	0
3.	I enjoy the subject of mathematics.	1	2	3	4	5	0
4.	I enjoy the subject of science.	1	2	3	4	5	0
5.	I enjoy doing activities like coding or computer science.	1	2	3	4	5	0
6.	Mathematics is important when learning robotics.	1	2	3	4	5	0
7.	The Engineering Design Process is an important tool for solving challenges.						
8 - 10	Write three brief descriptions on how robots are used below:						
	1.						
	2.						
	3.						
My gender is:		Male		Female		Decline to State	

Race/Ethnicity (please check best box)	African-American	Hispanic	White	Decline to State
	Chinese, Japanese, Korean	Other Asian	Foreign National	