Retaining Female Students in a Robotics Program

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Abstract

As we all know, the United States is short of women engineers in the work place. Many female students lose interest in Science, Technology, Engineering, and Math (STEM) at an early age. How to encourage and retain female students' interest in STEM is a challenge faced by many educators.

The paper describes our collaboration (Wentworth Institute of Technology (WIT)) with an all-girl high school to setup a robotics workshop. The high school administration is interested in bringing engineering and technology as a new component to their curriculum. From our side, we constantly seek outreach opportunities to prompt STEM and attract more girls into the STEM fields. After meeting and discussion with the high school administration, a robotics workshop was developed. The workshop was a year-long program that served as an extra curriculum activity for the girls. The program was launched in Fall 2014, starting with seven girls. By the end of the first year, there were only two students remained in the program. It was thus noticed that retention was a big problem. To increase retention rate, several changes were made in the second year when the workshop was offered, including for example, making the equipment available onsite at the high school, training a science teacher from the high school, providing more detailed step-by-step instructions, designing more individual (instead of integrated) tasks to help students understand the basic concepts, and to simply practice more. Results show that these modifications greatly improve students' learning experience since an average of six to seven girls participated throughout the entire workshop in the second year.

This paper summarizes our work and experience in setting up a robotic program at an all-girl high school during the past two years. Details about curriculum development, adjustment, and modifications for improving retention rate are described.

Introduction & Background

Nowadays, more and more scientists, engineers and innovators are needed to succeed in the global competitive economy environment. As a result, this requires quality science, technology, engineering and mathematics (STEM) education. Unfortunately, few American students pursue education and training in the STEM fields. Further, there is an inadequate pipeline of teachers who skilled in these subjects[1]. After noticing this challenge, the whole STEM society has made great efforts to increase STEM-related activities, which have the potential to promote collaborative learning and inquiry as well as to contribute to the development of the 21st century skills[2]. The US government also realized the shortage of STEM workforces. It initiated the "Educate to Innovate" program to increase student participation in all STEM-related activities. The ultimate objective of these activities is to encourage more students to choose an education in the STEM fields and pursue a STEM-related career in the future.

Extra after-school curriculum programs have been reported to be an efficient way to prompt STEM education[3]. To name a few, these programs may include science club, visits to museums & natural settings, robotics, science fairs, Science Olympiads, and Mathematics Olympiads[2]. Robotics has been widely adopted as an integrated and efficient tool to prompt STEM, since the nature of the robotics science is both multi-disciplinary and inter-disciplinary covering subjects such as Computer Science, Science, Technology, Engineering, and Mathematics. Another feature that makes Robotics suitable for the mission is that it provides a platform for students to learn, act/react, and practice. Research[4-7] shows that youth participation in the robotics activities increases their STEM knowledge, their perceived problem solving skills, and their interest and confidence in engineering careers.

Getting more students involved in the STEM education is already a challenge. Attracting more female students into the STEM fields can be even harder. Many institutions and organizations have realized this challenge and provided various activities to promote female students into the STEM fields. In addition, different strategies were developed to recruit and retain students in the STEM education[8,9]. Creating quality, attractive STEM programs[10] and using peer influence to motivate high school girls into the STEM field[11] appears to be effective ways to retain female students in STEM. AKL et. al.[12] demonstrated that ambassador and mentoring programs build up the student-to-student relationship. This helps female students to feel the support from others and thus decide to remain in the STEM program. Mosatche et. al[13] reported that facilitators play a critical role in participants' engagement, achievement, and retention in the STEM related programs. In other words, training the educators[14] helps to encourage more students into the STEM field. Lauwers et. al.[14] introduced a strategy that both speeds uptake in the community and improves the chances of the project creating an educational successful tool.

This paper describes our experience along this line to attract high-school girls into the STEM fields. The high school collaborating with us is an all-girl high school in the Boston city. In order to meet the requirement of an engineering and technology program expected from the high school, the authors and the high school administration setup a year-long robotics program. This program started in Fall 2014 and lasted for two years. Many adjustment, modifications, and improvement were made during the two-year process. Two positive outcomes were first described here. First, a new robotics club was formed at the high school. Second, one female student in the high school enrolled in the school of engineering and technology at WIT.

The rest of the paper is organized as follows. Section 2 describes several key elements of the workshop series including hardware platform, software programming languages, format of the workshop, and detailed lesson plans. During the first-year offering, several issues and challenges were encountered and these are discussed in Section 3. Based on experience and lessons learnt during the first-year offering, significant modifications were made during the second year, as presented in Section 4, which result in improved retention rate. Section 5 shows students' response to our survey. The survey results also confirm students' interests in the workshop and the selected topics. Finally, section 6 concludes the paper, summarizing our experience and knowledge gained through offering the robotics workshop.

Objective, Curriculum Development, and Format

The objective of the workshop is to make students be exposed to the exciting area of robotics and thus motivate them to pursue a STEM-related major later on. As a starting point, we aimed at introducing the fundamentals of robotics science and the basic components of a robotics system, including hardware, software, programming, sensors, and control. Students gained intensive experience working with the robots. The next step would be preparing the students to participate in the FIRST® Tech Challenge (FTC) competition, targeting towards students in grades 6 ~ 12. Since the students' ability to independently design, program, test, and debug needs to be trained, decision was made to make the workshop a year-long program, providing the students with more exercises and hands-on time. The workshop was offered as an extra curriculum activity.

Hardware: LEGO® MINDSTORM® NXT/EV3 has been widely used as a robotics outreach platform for high/middle school students. Due to its portability, versatility, low-cost, and easy maintenance, the LEGO® MINDSTORM® EV3 was selected as the robotics platform for the workshop. It allowed the students to explore engineering concepts through the use of motors, sensors, and programming in a team-driven environment. It also allowed the students to quickly design and create robots of various functions. The Lego EV3 Kits were purchased using the first author's professorship fund provided by Wentworth Institute of Technology (WIT).

Software: Among many different software, ROBOTC, developed by Carnegie Mellon University, was chosen. ROBOTC provides different ways to program the controller, i.e., graphic-based, natural-language-based, and text-based. The graphic-based programming is direct and easy for students to understand and start programming quicly. The natural-language-based programming is the "transition" from the graphic-based to the text-based programming. The text-based programming is suitable for relatively more complicated design and implementation tasks.

Format: Based on the availability of both parties, a bi-weekly workshop was setup: every other Thursday from 3:30-5:00PM. The location was first selected to be one of the labs at the WIT due to several reasons. Firstly, it was easier for the authors to manage the equipment. Secondly, it was feasible for the authors to recruit college students to help the high-school girls during the workshop. These helpers are mostly members of the Society of Women Engineers (SWE) club at WIT. Some of them were paid through work study program if they were qualified, the rest of them were volunteers. These female college students can act as the role models for the high-school girls. Thirdly, this would provide the high-school students an opportunity to work in a college lab and have an early touch on the college environment, thus gaining more confidence in pursuing a STEM-related college education in the future.

The high school assigned a science teacher as a chaperon to drive the students to WIT. Due to the limited transportation, there are seven girls registered for the workshop. This high school teacher continued to participate in the second year to work as the leader to help the students.

Lesson Plan: The following lesson plan was carefully designed for the year-long robotics workshop. Table 1 lists the lesson plans for both Year 1 and Year 2. As can be seen, many modifications were made in Year 2.

Table 1: Lesson Plan

Semester	#	Year 1: 2014-2015	Year 2: 2015-2016
Fall	1	Hardware Assembly and Graphic Programming	Overview of Robotics; Graphic Programming
	2	Introduction to ROBOTC (1): Motor Behavior	Introduction to ROBOTC (1): Motor Behavior
	3	Introduction to ROBOTC (2): Control Structure	Introduction to ROBOTC (2): Motor Behavior (2)
	4	Light Sensor: Line Following	Introduction to ROBOTC (3): Control Structure (1)
	5	Touch Sensor: Obstacle Avoidance	Introduction to ROBOTC (4): Control Structure (2)
	6	Sonar Sensor: Target Tracking	Introduction to Text-Based Programming
Spring	7	Encoder Sensor I: Translation (Going to a Specified Distance)	Touch Sensor: Obstacle Avoidance
	8	Encoder Sensor II: Rotation	Light Sensor: Line Following
	9	TETRIX™ Movement	Sonar Sensor: Target Tracking
	10	TETRIX™ Sensing	Encoder Sensor I: Translation (Going to a Specified Distance)
	11	TETRIX™ Challenges (1)	Encoder Sensor II: Rotation
	12	TETRIX™ Challenges (2)	Challenges

First-Year Offering: Observations and Challenges

We first followed the curriculum plan as those listed under Year 1 in Table 1. During graphic programming period, the students were very excited when they observed that their robots actually "listened" to them, followed their commands, and completed the tasks. However, upon transition from the graphic-based to the text-based programming, the attendance rate dropped dramatically. We then noticed that the students ranged from freshmen to juniors. Few of them took physics before. None of them had taken any programming courses ever. Obviously, introducing the text-based programming to them was extremely overwhelming. Modifications were made accordingly as we proceeded by postponing the Tetrix project and moving slowly and concentrating more on the basic components.

Challenges Encountered During Year 1:

- **Text-Based Programming**: Transition from the graphic-based to the text-based program was a huge jump for the high-school girls. Since they literally had no pre-existing programming skills, they could not understand the very basic components, structure, and syntax of a text-based program, such as color-coded keywords (task main, sleep, wait, if, while, for), the usage of punctuation marks (semicolons, curly braces, parenthesis, mathematical symbols, double forward slashes, stars), as well as robot-specific phrases (motor, port, and sensor value). Finally, when the program was written and complied, the robot may or may not perform as expected. Generally speaking, the student's programming experience was very frustrating.

- **Long Commute Time**: Long commuting time pulled the students back. The workshop was planned from 3:30 PM to 5 PM. Upon completion, it was already 5PM and the students headed right into the traffic. This issue was even worse during the winter season.

- **Lack of Practice**: Since the equipment was located at WIT, the students had no access to them while they were at their school. The workshop was carried out every two weeks. The student might easily forget what they learned/did in the previous session.

A mid-year survey was conducted. Survey results showed that the pace was absolutely fast for them. Hence, we slowed down accordingly. In addition, we modified the curriculum by increasing the time on basic motion/movement control. For Year 1, only two students completed all workshop sessions. Many of them dropped off after midyear.

Second-Year Offering: Modifications and Improvement

Modifications were made in Year 2 to retain students in the program. Ten students signed up in Year 2, with one attended last years' workshop but dropped in the middle of the year. She was a sophomore in Year 2 of the program. All others were new members ranging from freshmen to seniors. Since most students were new to the program, we decided to follow a similar curriculum, with several major modifications as highlighted below:

- **Offering Workshop Onsite**: Starting Fall 2015, the workshop was moved to the high school. The EV3 sets were stored in the science teacher's lab. Students were allowed to have access to these resources any time they needed. We traveled to the high school and met with the students right after their school was over. The workshop was set to 2:40--4 PM, students could still schedule other activities after 4 PM. This resolved two of the challenges we encountered in Year 1, i.e., Long Comminute Time and Lack of Practice.

- **Increasing Meeting Time**: In Year 2, weekly meetings were required for students who participated in the program. The workshop was still offered bi-weekly by the authors. In the other week, students worked on additional challenges under the guidance of their science teacher. Smaller tasks were assigned to the students after each lesson by the authors. Completion of these smaller tasks helped the students to improve their skills step by and step, thus becoming more experienced and confident.

- **Emphasizing the Role of the Science Teacher**: The science teacher who helped the workshop taught physics and chemistry at the high school. At Year 1, she was only the chaperon without helping the students to solve the challenges. However, she did participate in the workshop from the beginning to the end. With her STEM background, it became easier for her to understand the materials. At Year 2, she became the facilitator for the robotics workshop. She met with students on a weekly basis in her lab to supervise the students to finish the tasks assigned by the authors.

All lesson plans and solutions to challenges were shared with the science teacher. Based on the first years' experience of going through the entire workshop sessions, the science teacher was capable of helping the students with their assigned tasks. She bridged the gap between us and the students. The girls were very happy to have extra help from their teacher at school. For problems that she could not solve, we helped the students the next time we met.

A research conducted by Mosatche et. al.[14] approved our observation. Their research concluded that teacher participation was key to the success of afterschool programs. They also demonstrated the importance of having facilitators who were comfortable with both STEM and the participating girls. There phenomenon was observed and confirmed in our workshop.

- **Gradual Transition to Text-Based Programming**: We still began with the graphic programming language. We used this as an opportunity to expose students to programming logics, sensors, and motors. We then gradually proceed towards text-based C programming when tasks became complicated and hard to be implemented using the graphic way.

- **Making it More Interesting by Incorporating Art-Flavored Exercises**: Music and dance are what most girls like. Two art-related tasks/challenges were included in Year 2, where one was a spin art activity and the other was a dancing robot with different movements. These two activities were first demonstrated at the beginning of the workshop. Students show great interest in these activities. These helped to attract more girls to enroll in the workshop.

- **Adding Challenges that Connect Robotics, Math, and Science**: Robotics is an interdisciplinary subject, with math, science, and engineering naturally embedded. After training the students with understandings of the basic components, challenges that connect robotics, math, and science were introduced to the students. Following shows one example. Considering robot turning and motor synchronization, students were asked to command/program the robot to move along a circular path, as shown in Figure 1 below [15]. The project had several objectives: a) To understand that a robot with two driving wheels and a trailing coast wheel (tri-bot) can be controlled to follow a circular path by driving its two wheels at different rates; 2) To calculate the ratio of the rates; 3) To design a structure to attach a marker to the tri-bot so that the robot's trajectory can be displayed.

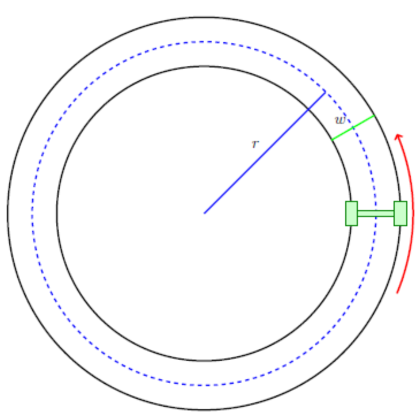

Figure 1: Two-wheel drive robot following a circular path of radius r and track width w.

It might not be obvious about how to draw an arc with a given radius of curvature and a given arc angle. However, a simple geometric calculation can determine the relative rates at which the two drive wheels should turn in order to move along a circular path with the given radius. Assuming that the tri-bot goes through the circular path in t seconds. The distances traveled by the left wheel (inner circle) and the right wheel are: $2\pi(r - \frac{w}{2})$ and $2\pi(r + \frac{w}{2})$ respectively. The speeds of the two wheels can then be calculated as:

$$v_L = \frac{2\pi\left(r - \frac{w}{2}\right)}{t} \quad \text{and} \quad v_R = \frac{2\pi\left(r + \frac{w}{2}\right)}{t}$$

Hence the ratio of these two wheels is obtained:

$$\frac{v_L}{v_R} = \frac{r - \frac{w}{2}}{r + \frac{w}{2}}$$

As long as the ratio is preserved, the tri-bot will move a circular path of radius r.

The students were then asked to design a structure to be attached to the tri-bot to show the robot's trajectory. This challenge served as an integrated example that requires problem solving and engineering design skills.

With the above-mentioned modifications made in Year 2, regular attendance of 6~7 students was achieved every week. The science teacher took attendance every time. Though some students were absent due to reasons such as sports team practice and driver's lessons, as an average, there were about 6~7 girls participated in the program every week. Therefore, a much better retention rate was achieved in Year 2.

Student Survey Results

We conducted surveys to evaluate outcome of the workshop and to obtain feedback from the students. In the survey, we asked questions about students' interest level, workshop materials, workshop's ability to engage student, whether we met the objectives originally set, and the favorite (and the least favorite) part of the workshop. Some of the survey results are shown in Figure 2.

The survey results indicated that students' favorite parts of the workshop include: doing challenges and testing of the robot to see that the robot actually carried out their commands. The least favorite parts include: the text-based programming, the math behind, and remembering/typing the codes.

The survey results assured us that the workshop was interesting to the students and proper topics were selected.

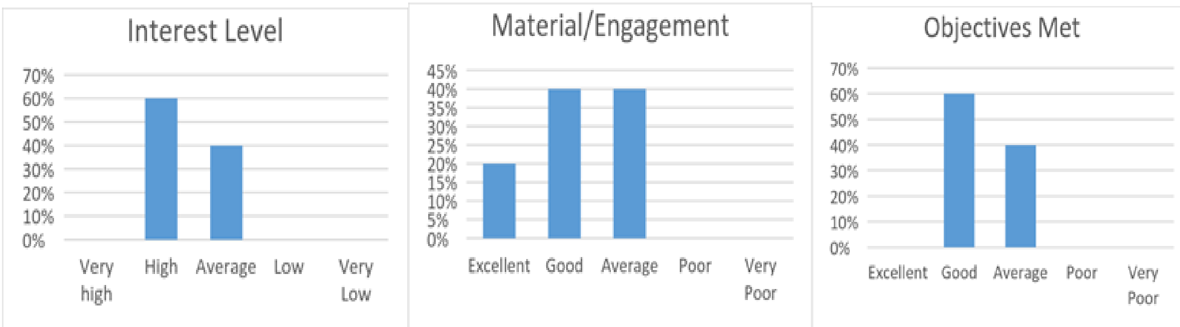

Figure 2: Survey results on students' interest level, material and engagement, and objectives met or not.

Conclusion

This paper describes our work in organizing a robotic workshop for an all-girl high school. This workshop was motivated by the high school's intention of introducing science and technology into their curriculum, as well as our long-term objective of recruiting more female students into the STEM-related career. The workshop was designed to be a year-long program to suit the students' limited STEM background. The workshop was first conducted at the WIT, but then moved to the high school to provide the students with onsite and thus more frequent access to the hardware and equipment. With this modification, along with several other significant improvements made during the second-year offering, retention rate was increased from only two students remaining in the workshop to generally 6~7 students in each session. Further, a new robotic club was formed at the high school as a result of this workshop. One female student who participated in the workshop enrolled in the college of engineering and technology at WIT.

We believe that making the robots available to the students any time they need is certainly a crucial step in obtaining this improvement. Involving high school teachers, for example, the science teacher in our case, also helps tremendously. Another aspect that we believe critical is to run the workshop sessions with a reasonable (most likely a reduced) pace. The last but certainly not the least part is the constant improvement and modification of the lesson plans by incorporating exercises, tasks, and challenges that connect naturally among STEM areas and are also interesting to the members.

This paper documents the results of our findings, obtained via discussions with the high school administrators, via interactions with high school teachers, and via feedbacks from the high school students. The experience gained during this process will certainly help us to be more prepared and creative in organizing similar workshops in the future. We believe these experience would also benefit other educators and researchers with the common goal of increasing the number of female professionals in the STEM fields.

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