Lessons Learned from a High School Robotics Workshop

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Abstract

Statistics data show that there is a huge gender gap in science, technology, engineering, and math (STEM) workforces in the United States. In order to encourage more women to work in the STEM fields, the first step is to attract women to pursue the STEM majors. Robotics provides an easy, fun, and exciting environment for young minds, while exposing them to technologies at the same time. This paper describes our collaboration with an all-girl high school in offering their students a year-long robotics workshop. The motivation of this collaboration is two-folded. On one side, the school administration is interested in bringing engineering and technologies to their curriculum, which is currently missing. From our side, we would like to motivate and recruit more female students to the STEM fields by showing them the emerging and multidisciplinary aspects.

Our collaboration with the local high school started in Fall 2014 by offering their students a year-long robotics workshop. Our objective is to utilize the robotics workshop to introduce STEM concepts to high school students, and encourage them to be interested in an engineering and science career. A sequence of workshop topics were given to introduce the fundamentals of robotics science and the basic components of a robotics system, including hardware, software, programming, sensors, and control. The students would gain intensive experience working with the robots. In addition to introducing the fundamentals, we planned to prepare the students with the necessary knowledge and skills to participate in national robotics competitions, such as FIRST® Tech Challenge (FTC) and FIRST® Robotics Competition (FRC).

At the time of writing, the robotics workshop has been offered for one year and a half. Workshop lessons were offered bi-weekly. At the end of year 2014, a survey was conducted to collect feedbacks from the students. At the end of Spring 2015, we also had direct conversation and discussion with the teachers in the high school to gather their opinions. Continuous and constant modifications and adjustment were performed to give the students an easy yet fruitful learning experience.

This paper presents our curriculum development, implementation and modifications of the lesson plan, feedbacks from students and their high school teachers, and the lessons we learned from offering this workshop.

1. Introduction and Background

Engineering is a profession to solve problems. Statistics data show that there is a big gender gap in the STEM field in workplaces. It has been found that women make up 46% of the workforce, but hold only 24% of jobs in STEM fields\(^1\). The challenge lies in how to attract the students into the engineering field. Many institutions and organizations have realized this challenge and have provided various activities to promote female students into the STEM field. For example, the Intel “She Will Connect” program helps young women expand their understanding and use of technology; Microsoft “DigiGirlz” gives middle and high school girls opportunities to learn about careers in technology and participate in hands-on computer and technology workshops.
Generally, robotics is considered to be one of the most effective way, because it is inherently multidisciplinary. It also provides an environment for students to learn, act/react, and practice. Research\textsuperscript{1-5} shows that youth participation in the robotics activities increases their STEM content knowledge, their perceived problem solving skills, and their interest in engineering careers.

Among these efforts, many robotics-related outreach programs have been developed for school teachers\textsuperscript{6} and students\textsuperscript{7-10}. To name a few, FIRST\textsuperscript{®} provides a platform to attract students to participate in robotics competitions. Carnegie Mellon University (CMU) offers a program to teach robotics to middle and high school students using the LEGO\textsuperscript{®} MINDSTORM\textsuperscript{®} NXT/EV3 platform and the TETRIX\textsuperscript{TM} platform\textsuperscript{11-12}. Tufts University Center for Engineering Education and Outreach (CEEO) provides year-long workshops for kids. Various institutions offer robotics summer camps to pre-college students with different emphases on mechanical design, electronics, and coding. Some institutions also regularly arrange Robotics Open Houses, such as the USC Viterbi robotics open house and the UPEN GRASP national robotics week open house.

This paper describes our experience along this line to attract high-school girls into the STEM fields. Using the LEGO\textsuperscript{®} EV3 as the robotics platform, we began to offer a robotics workshop to a group of high-school girls in a local all-girl school starting in Fall 2014. At the time of writing, we have offered the robotics workshop for one year and a half. During this process, we have encountered a couple of challenges and problems, both technical (for example, selection of programming software) and non-technical (i.e., where to host the workshop, what time to offer the workshop, availability of workshop instructors, and equipment). Despite these issues, the overall experience is very rewarding. We identified several female students who have proper backgrounds and long-term interests. For example, one student also participated in other STEM events held by the authors. One student continued to participate in the workshop again this year, and another student in the high school enrolled in our institute of engineering and technology. A new robotics club was also formed at the high school.

The high school that we collaborated with is a catholic school, whose curriculum includes English (I, II, III, IV), Mathematics (Algebra I, Geometry, Algebra II), Science (Biology, Chemistry, Physics), Social Studies (World History, Modern European History, U.S. History I and II), and Spanish (I, II). In the school's current curriculum, there are no engineering or technology related courses. The robotics workshop is of mutual interests. The school's administrators are interested in adding the engineering/technology components to their curriculum. From our side, we want to use this opportunity to expose the high school students to the STEM fields, with the objective of recruiting more female students into STEM fields starting from their college education.

Regarding management, the high school assigned a teacher to lead the students. This turned to be very helpful since the high school teacher, with proper science background, could understand the material quickly and help the students when the instructors were not available. Regarding the location of the workshop, we first offered the workshop at our institute. We thought this would provide the students with an opportunity to sit in a college lab and experience the college environment earlier. However, this did not work well since the transportation for the students to come to our institute and then return back home took quite long. The second year, we changed
the location from our institute to their school. This led to an increased student enrollment and a newly-formed robotics club. We believe that this arrangement and the year-long effort will help to continue recruiting more female students into the STEM fields in the future.

The paper is organized as follows. Our detailed curriculum development, including hardware platform, software languages, and lesson plan are described in Section 2. Implementation of the lesson plan is given in Section 3. Section 4 presents the survey results, from where the lesson plan was modified and adjusted to better suit the students. Section 5 concludes the paper.

2. Curriculum Development

The objective of the workshop is to expose students to the exciting area of robotics and thus motivate them to pursue a STEM major. 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, which is targeted for students in grades 6 - 12. In FTC, each team is responsible for designing, building, and programming its robot in ten weeks to compete in an alliance format against other teams13. Therefore, the students' ability to independently design, program, test, and debug needs to be trained. This is one reason to make the workshop a year-long process since it provides students with more exercises and guidance.

Details of the robotics platform, software, and lesson plans are presented next.

- **Robotics Platform:** LEGO® MINDSTORM® NXT/EV3 (Figure. 1) 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.

![Figure 1: EV3 system and its sensors](image1)

- **Software:** Among various programming languages that were compatible with EV3 (for example, ROBOLAB, Easy C, and ROBOTC), ROBOTC was selected due to the following features7:
− It is a cross-robotics-platform programming language for popular educational robotics systems.
− It is the premiere programming language for robotics competitions.
− Though essentially a C-based programming language, it also provides graphical programming ability.

For beginners, graphical natural language can be a good starting point since it is simple and easy to understand. Figure 2 shows an example of using graphical language to command the robot to stop once the touch sensor is pressed. We used ROBOTC graphical programming in the first lesson to introduce the students to the entire process of hardware design/construction, software programming, and the robot's motion in action.

![Figure 2: An example of using ROBOTC graphical programming language.](image)

For complicated tasks, the C-based language is used instead. Figure 3 shows the C code that achieves the same task as the example in Figure 2.

![Figure 3: An example of using text-based ROBOTC programming.](image)

• **Workshop Format and Lesson Plan:** The workshop was a year-long program, which was offered bi-weekly on Tuesday or Thursday from 3:30PM-5:00PM (determined by instructors' availability). Students worked in groups of two or three. In the beginning, basic concepts were introduced through examples and demonstrations. Then students were asked to achieve certain small tasks (also called mini-challenges) under supervision. Some of the tasks were
designed by the instructors, others were sample tasks from CMU online resources. The following topics were addressed, as listed in Table 1.

<table>
<thead>
<tr>
<th>Semester</th>
<th>#</th>
<th>Topic</th>
</tr>
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<tbody>
<tr>
<td>Fall</td>
<td>1</td>
<td>Hardware Assembly and Graphical Programming</td>
</tr>
<tr>
<td>Fall</td>
<td>2</td>
<td>Introduction to ROBOTC (1): Motor Behavior</td>
</tr>
<tr>
<td>Fall</td>
<td>3</td>
<td>Introduction to ROBOTC (2): Control Structure</td>
</tr>
<tr>
<td>Fall</td>
<td>4</td>
<td>Light Sensor: Line Following</td>
</tr>
<tr>
<td>Fall</td>
<td>5</td>
<td>Touch Sensor: Obstacle Avoidance</td>
</tr>
<tr>
<td>Spring</td>
<td>6</td>
<td>Sonar Sensor: Target Tracking</td>
</tr>
<tr>
<td>Spring</td>
<td>7</td>
<td>Encoder Sensor I: Translation (Going to a Distance)</td>
</tr>
<tr>
<td>Spring</td>
<td>8</td>
<td>Encoder Sensor II: Rotation</td>
</tr>
<tr>
<td>Spring</td>
<td>9</td>
<td>TETRIX™ Movement</td>
</tr>
<tr>
<td>Spring</td>
<td>10</td>
<td>TETRIX™ Sensing</td>
</tr>
<tr>
<td>Spring</td>
<td>11</td>
<td>TETRIX™ Challenges (1)</td>
</tr>
<tr>
<td>Spring</td>
<td>12</td>
<td>TETRIX™ Challenges (2)</td>
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From Table 1 we can see that the robot’s basic motion and sensing are first introduced. In the end, students will move to TETRIX™ Challenges, making preparations for robotics competitions.

3. Implementation

In Fall 2014, the high school recruited seven girls to participate in the workshop. The high school also assigned a dedicated science teacher to lead the group and drive the students to Wentworth Institute of Technology (WIT). The teacher's science background helped her understand the workshop materials and supervise the students at their school. The number of students was limited due to transportation to WIT.

After a couple of lessons, the number of students decreased from seven to three. We then conducted a survey to understand the possible reasons causing this change. Findings of the survey will be described in detail in section 4. Based on the survey results, lesson plans were adjusted and the TETRIX™ content was temporarily postponed. We modified our lesson plan to spend more time on helping the students obtain a hands-on experience working with the robotics platform, including basic programming, implementation, testing, and task execution. Additional challenges were added so that the students would gain more confidence and hands-on experience.

The following describes each lesson topic in details. Typically, we would discuss one topic in one lesson period, assign two or three mini-challenges for the students to practice by themselves, and adjust our pace accordingly for the next time based on the completion of the assigned challenges.
Hardware Assembly and Graphic Programming: Students were first introduced to LEGO® MINDSTORM® EV3, including its hardware and software. Literature\textsuperscript{15-19} showed that problem solving and creativity and design were two main areas that could attract more girls into STEM field. Some researchers\textsuperscript{20} re-focused STEM including the arts, recognizing that creativity and innovation skills were necessary in STEM fields. To motivate girls interested in STEM, an example that combined art and engineering was implemented. More specifically, a spin art activity was performed at the end of the lesson. After playing with the spin art device, students were excited to see how technology can be used to quickly generate an art piece.

![Spin art with LEGO®](image)

Figure 4: Spin art with LEGO® \textsuperscript{14}.

Introduction to ROBOTC: The objective of these lessons was to introduce students to text-based C programming. The challenge we did was adopted from the ROBOTC online curriculum website\textsuperscript{6}, requiring the students to be able to control the robot's motion such as going forward/backward and making turns. More specifically, assuming that the robot works in an orchard, students were asked to program the robot to move from its starting area through three rows of fruit trees (denoted by the yellow blocks in Figure 5). The robot may take any path, as long as it passes along both sides of each row during its run.

![Illustration of the “orchard tree” mini challenge](image)

Figure 5: Illustration of the “orchard tree” mini challenge\textsuperscript{11}.

Light Sensor - Line Following: The use of light sensor was illustrated by the line-following challenge, where students were asked to program their robots to follow a straight line painted on a white background. Through this lesson, students understood that the light sensor provides
different values for black and white surfaces. Regarding the robot's motion control, a simple zig-zag manner was used based on a single light sensor.

**Touch Sensor - Obstacle Avoidance:** The touch sensor was used in the obstacle avoidance challenge, where students were asked to program their robots to turn randomly at any angle (for example simply 90 degree) upon the detection of a touch sensor press-down. In this scenario, the touch sensor was installed in the front of the robot. When the robot moved forward and hit an object, the touch sensor would be triggered, signaling a stop followed by a turn.

**Sonar Sensor - Target Tracking:** The sonar sensor is a very important type of sensor on the LEGO® EV3 since it provides range information between the sensor and a detected object. In this lesson, we first introduced the characteristics of a sonar sensor, including sending out a sound wave to detect objects, reflection of the wave from a nearby object to the sensor's receiver, and the calculation/estimation of the distance based on the speed of sound and the sound's one-way travel time. For students' mini-challenge, they were asked to program the robot to track/follow a moving target based on the collected sonar data between the robot and the target. Students were very happy to see that their robots were able to follow a target moving in a straight line.

**Encoder - Translation and Rotation:** We also introduced the encoder sensor and discussed the relationship between the encoder reading and the distance the robot travels when moving straight. In challenges, students were asked to program their robots to go to a specified distance and to rotate a specified angle based on encoder readings (instead of simply based on a timer).

4. **Survey Result, Lessons Learned, and Modifications Made**

As mentioned earlier, after a couple of lessons in Fall 2014, the number of students who attended the workshop decreased from seven to three. We then conducted a survey to evaluate the outcome of the workshop and to obtain timely feedback from students. In the survey, we asked questions about students’ interest level, workshop materials, workshop's ability to engage student, class length, whether we are meeting the objectives originally set, and the favorite (and the least favorite) part of the workshop. Some of the survey results are shown in Figure 6.

Other survey questions were in the form of question-answering and cannot be presented graphically. In terms of the favorite part, results indicated that students liked to do challenges, enjoyed testing the robot to see if the robot actually carried out their commands. The least favorite part is the text-based ROBOTC programming, the math behind the activity, and about remembering/typing the codes. Some students commented: "This has been a great experience."
While the survey results assured us that the workshop was interesting to the students and proper topics were selected, we investigated the situation further and realized the following might be the reasons for the decrease in attendance:

- No Access to Hardware and Software: Since the workshop was originally offered in WIT, the high school didn't buy any equipment from their side. The students did not have any access to the robots outside of the workshop. Thus, it was very hard for the students to retain the knowledge they learned at the workshop.
- Long Commute Time: The high school students got out of school at 2:35 PM. It usually took them 45 - 55 minutes to drive to our WIT for the workshop. The workshop was planned from 3:30PM to 5PM (due to instructors' availabilities). Upon completion, it was already 5PM and the students headed right into the traffic. When they finally arrived home, it was very late. This issue was even worse during the winter season.
- Difficulty in C Programming: Students did not have any programming experience before. The text-based C programming language was hard for beginners and took longer for them to use.

To solve these issues, we no longer offered the workshop at WIT. Instead, starting from Fall 2015, we went to the high school to offer an on-site workshop for the students. We also left the LEGO® robots at the high school so the students could have access whenever needed. These arrangements basically resolved the first two issues mentioned above. For the last one, we made
modifications to our lesson plans to postpone the TETRIX™ portion. More challenges and mini-tasks on LEGO® EV3 were added to practice basic programming, sensing, and motion control. These arrangements and modifications were very helpful in retaining students' interests. An increase in the enrollment was observed. For example, ten students enrolled in the workshop this year and in each session at least six students regularly showed up. This also helped to expose the robotics workshop to other students. As a result, a new robotics club was formed at the high school. We believe that keeping these efforts in long term will help attract and recruit more female students into the STEM fields.

5. Conclusion

This is the pilot study of a robotics workshop offered to a group of high-school girls. The program achieved its objective by exposing the high-school girls to the interdisciplinary STEM fields, boosting students' interests and giving them a more hands-on experience. It also directly recruited new students into our institute of engineering and technology, and resulted in a newly-formed robotics club at the high school. Based on these rewarding aspects, we believe that the program is successful. We also believe that it will keep attracting more female students into the STEM fields in the future.

The pilot workshop also provides us with valuable feedback and a guideline for future improvements:

- Offering the workshop on-site to the local high school would attract more girls into the program. It proved very beneficial to train a high school teacher to work with these students. The workshop sessions can be offered bi-weekly; however, the workshop students should meet every week. Their high school teacher can help them work on challenges.
- Making small progress each time, since the students did not have any priori engineering and programming experience. Taking small steps would increase their confidence level and as a result keep them interested.
- Incorporating some flavors of arts to the program. The spin art activities attracted many girls. Another example was a dancing robot with different movements. Girls could dance together with the robot by following its movements. Beginning with the graphical natural language programming for simple challenges. Proceed gradually towards text-based C programming for complicated tasks.
- Considering the possibility of offering the workshop as a credit course, or an extracurricular activity, to recruit more students and keep them interested.

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