A Human-Interactive Robotic Program for Middle School STEM Education

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***Abstract*—The use of human-interactive robots in industry and daily life has become more prevalent throughout society as more people are using collaborative, and assistive robots to accomplish a task. To demonstrate the utility and importance of assistive robots to middle school students, a unique educational platform called Neu-pulator (neurally-controlled manipulator) was designed and fabricated to introduce their application in improving the quality of life. This robotic manipulator consists of low-cost components, which reflect the characteristics of a human arm, and is actuated by signals from the students neuromuscular system. During summer 2016, a 5-day program introduced students to the engineering design process as they designed, programmed, manufactured, and tested the Neu-pulator robot. A series of surveys and group interviews were performed to understand how each students attitude and opinion towards different STEM-related topics evolved throughout the course, both quantitatively and qualitatively. We observed that the students confidence, attitude, and excitement towards STEM improved over the course of the week, especially when they could see the robot they developed in action. With the use of this unique educational platform, a bridge can be made from learning fundamental STEM concepts to real-world application of human interactive and assistive robots.**

***Keywords*—Assistive Robotics; Active Learning; STEM; Middle School; Interdisciplinary Education; Student Assessment**

I. Introduction

Within the past 20 years, the robotics industry has seen many changes, one of which includes a tremendous increase in the demand for collaborative and assistive human-interactive robots to be able to work alongside humans. Applications of this field of robotics can be found almost anywhere; ranging from the manufacturing industry, to service robots, autonomous cars, health care, entertainment, public safety, and disaster relief. One of the key driving factors for the development of these robots has been the ability to improve the overall quality of human life [1].

As a result of this, assistive human-interactive robotics has become increasingly prevalent in the rehabilitation and health care industry, where advancements have caused the market to expand 10-fold between 2010 and 2016 [2]. Some examples of these robots include the da Vinci®Surgical System (Intuitive Surgical [3]), which has helped doctors perform efficient and minimally invasive surgeries; the MIT-Manus and its clinical version InMotion ARM [4], developed for robot-aided therapy of upper extremity; the Lokomat™ exoskeleton (Hocoma [5]), used to improve the success of gait rehabilitation in stroke patients; the Nao™ humanoid (Aldebaran Robotics [6]), which promotes social interactions in autistic children; and the EDAN robot arm [7], controlled using signals produced by muscle activations, to allow wheelchair users to reach objects in their environment. Assistive robots have improved the lives of many, but there is a continuing need for new research and for improvement upon these already existing technologies. It is important that the next generation of engineers and scientists are prepared to take on these challenges.

Therefore, engineering and robotics need to be introduced to students at an earlier age to better draw their attention into the pursuing careers in the fields of STEM. New educational standards and initiatives require that science and engineering be brought to classrooms in all grade levels [8]. The underlying goal is to improve the attitude and confidence levels of future generations toward STEM learning [9]. Some of the most popular educational platforms being implemented include the LEGO®Mindstorm® [10] and the VEX IQ™ [11], [12]. In addition, low-cost educational platforms, such as Arts & Bots [13] and AERobot [14], bring a different level of creativity to robotics education. Although these platforms and programs are designed to introduce hands-on and exciting STEM-related materials to young students, they don't introduce students to the field of assistive robotics; where, the robots augment human capabilities through direct interaction with the human body to improve human performance in their activities. This is significant because middle school and high school students, especially female students and underrepresented groups, exhibit a higher appeal to engineering and robotics when presented with a theme of helping society [1], [15]–[18].

This paper describes a low-cost educational robotics platform, called Neu-pulator, that was designed to show pre-college students firsthand how an assistive robot can be used to improve human life. Developed by the Human-Interactive Robotics Laboratory (HIRoLab) at Michigan Technological University (Michigan Tech), this neurally-controlled manipulator reflects the characteristics of a human arm and provides students with hands-on experience as they learn to program, design, and assemble their robot. The "helping humans" theme of this platform will demonstrate the importance of assistive robots within our society and create new levels of creativity, interest, and excitement towards learning about robotics and STEM (science, technology, engineering, and mathematics).

The unique design of the Neu-pulator and its ability to be

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actuated by signals from the student's neuromuscular system offers a new perspective about human-robot interaction. The Neu-pulator introduces concepts from biomechanics, computer science, electrical engineering, and mechanical engineering. Through a project-based program, students learn how assistive, human-interactive robots and engineering can be used to protect and help improve human life [16].

To evaluate its effectiveness, the Neu-pulator platform was tested during the 2016 Michigan Tech Summer Youth Program (SYP). Over the course of one week, 31 middle school students, grades 4 to 6, learned the "engineering design process" as they brainstormed, designed, manufactured, and tested their Neu-pulator. A series of surveys and group interviews were performed to understand how each student's attitude and opinion towards different STEM-related topics evolved throughout the course, both quantitatively and qualitatively.

This paper describes the implementation of the Neu-pulator platform in the following sections: Section II describes the Human-Interactive Robotics Program, including the Neu-pulator design, participants, instructors, and evaluation techniques. Section III presents the integration of this program, and Section IV discussed the impact and assessment that this program had on middle school students. Finally, Section V presents the conclusion and future for this work.

II. Human-Interactive Robotics Program

A. Program Overview

The main theme for this program is how to build a robot that can help to improve human life. At the beginning of the course, students were introduced to the field of robotics and how robots are currently being used around the world to help improve human life. Examples, such as modern-day human interactive and assistive robots were presented to spark interest in how the robots work. This discussion led to the explanation of the engineering design process and how it could be applied to build and design robots that can help people.

This project-based program was founded to mirror the engineering design process using the Neu-pulator platform that iterates 5 steps to encourage students to: (1) *ask* questions and *identify* a problem, (2) *imagine* workable solutions, (3) *brainstorm* a plan to address this problem, (4) *create and build* a prototype, (5) *test and iterate* their prototype to improve their current designs [16]. This program was designed for pre-college students to build Neu-pulators through hands-on activities implementing these steps in a 5-day program (Table I). These activities were defined as small projects building upon each other to increase the students' knowledge gradually and prepare them for the final challenge.

B. Neu-pulator Platform

The students build a Neu-pulator platform over the course of the week. The platform design is split into three groups: mechanical structure, electrical assembly, and the human neuromuscular interface. Each group is composed of low-cost, off-the-shelf components that are easily replaceable.

The mechanical structure of the Neu-pulator resembles the elbow, shoulder, and torso of a human body. As shown in Fig.1, the elbow and shoulder are two low-cost MG995 servomotors (MG995, TowerPro™, Taiwan) that are mounted between wooden linkages (15 x 4 x 1cm) to form the arm and forearm. The arm is attached to a wooden adapter (8 x 6 x 1cm) that acts as the shoulder blade, connecting the arm to the torso. Finally, the torso is composed of a vertical T-slot aluminum frame (2.5 x 2.5 x 40 cm) that is supported by the wooden base plate (30 x 20 x 1 cm).

TABLE I: Overview of the daily activities to demonstrate the engineering design process and integration of assistive robotics.

	Day 1	Day 2	Day 3	Day 4	Day 5
Objective	***Engineering Design Process: Ask, Identify, Imagine, Brainstorm, Create, Build, Troubleshoot, Test, Iterate, Build Programming Skills***				
Main Activities	Intro to Human-Interactive Robotics Learn how to Program Engineering Design	Learn how to Program Engineering Design	Mechanical Assembly of the Neu-pulator	Human Body Instrumentation with EMG	Neu-pulator Testing and Challenges

For the electrical assembly, the servomotors are powered with an external power supply, such as a wall socket. This power supply is connected to a power safety switch which allows the power to the motors to be turned on and off. A breadboard (8.4 x 5.4 x 0.9cm) is used to connect both motors to the external power and ground sources. In addition, each motor is connected to an easy-to-program Arduino Uno (A000099, Arduino™, Italy) microcontroller. The Arduino can be programmed to calculate the required angle that each motor should move to while the Neu-pulator is in motion. In addition, the Arduino program can be modified to make the motors move based on the sensory data, such as the signals received from muscle activation levels that help it move as the user intended.

The neuro-muscular system of the students' arm controls the motion of each servomotor joint. To measure electrical changes in the muscle's activation levels, two electromyography (EMG) sensors (13723, SparkFun™, USA) are placed on the bicep and forearm muscles in the arm. When the muscle is relaxed, the EMG sensor measures very little electrical changes in the muscle activity. As the muscle is flexed, the muscle activity and the EMG sensor measurements increase, resulting in a higher EMG signal. To process the EMG signals, the EMG sensors are read and powered by the Arduino microcontroller. The Arduino is programmed to use the EMG signals to control the motion of the servomotors.

C. Participants

During the summer 2016 program, a total of 31 middle school students participated during two sessions. This age group was particularly important because developing interest towards STEM at this level has been shown to be influential in selecting high school classes and future career paths [15]. The first session, called SYP Robotics, was available for any student interested in learning about human-interactive robots, and consisted of 20 middle school boys. The second session, called Women in Robotics, was designed specifically for female middle school students, and 11 middle school girls participated. Depending on the activity throughout the week,

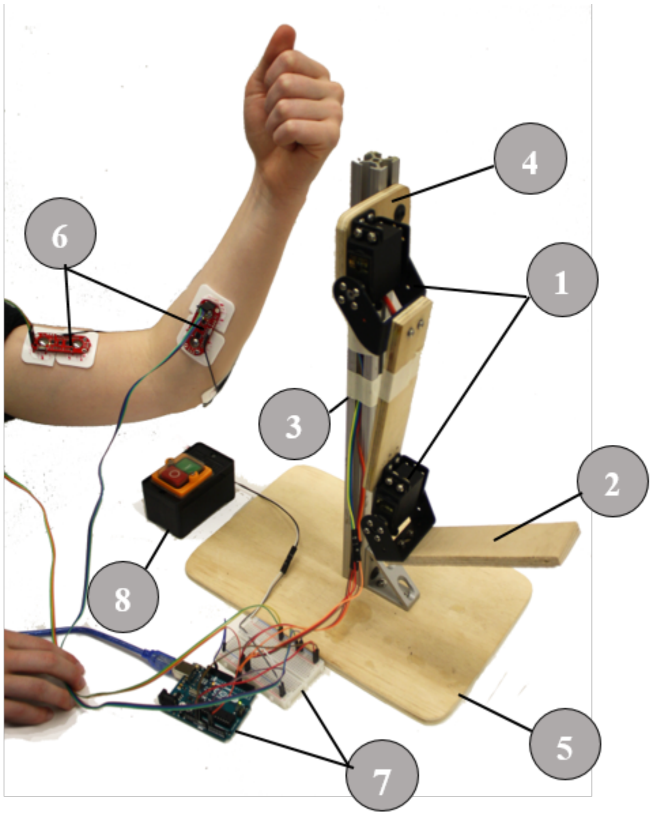

Fig. 1: Assembly of the Neu-pulator. (1)"Shoulder" and "Elbow" servomotor joints, (2) Wooden "Arm" Linkages, (3) T-slot Aluminum Frame, (4) "Shoulder Blade" Adapter, (5) Base Plate, (6) EMG Sensors, (7) Arduino and Breadboard, (8) Safety Power Switch.

students worked independently or in self-selected groups of 2-3 people. Grouping students into small teams gave them more opportunity to gain hands-on experience, while also promoting student collaboration and communication among the class.

D. Instructors

The program was led by a team of two graduate students (1 male, 1 female), who were enrolled in the mechanical engineering department at Michigan Tech and had backgrounds in robotics. Both graduate students completed an educational training course, offered through the university that focused on incorporating objective-based high-engagement activities into classrooms and assessing student learning. These instructors also received training to understand how to interact with the middle school age group. To ensure that there was enough help answering questions during each of the activities, two undergraduate mechanical engineering students (1 male, 1 female) also provided assistance each day. This allowed the teacher to student ratio to be 1:5 for the first session, and 1:3 for the second session.

E. Evaluation and Survey Method

To evaluate the students, instructors, and course content, four different assessment methods were used: pre-course and post-course surveys, daily surveys, group interviews, and observation [19]. These surveys were composed of Likert 5 point and 7 point questions (quantitative) as well as written response questions (qualitative) to determine the students' level of interest in robotics, computer programming skills, comfort working in a team, and attitude toward STEM learning.

Students completed a four-question daily survey at the completion of activities. Daily surveys were used to evaluate the students' incremental learning and their feedback about each day. In addition, an independent observer monitored each session to study student-student interaction, student-instructor interaction, and overall behavior and responses to different activities. These observations provided insight about the strength and shortcomings of the program.

At the end of the course, students also participated in a group interview, which captured their overall experience with the course. This method of evaluation was age appropriate and necessary to obtain valuable feedback from the students.

The results of all four assessments were used to evaluate the success of the program in changing the students attitude and confidence toward STEM learning and robotics.

III. Neu-pulator Program Implementation

The program was designed so that each day of the week reflected new parts of the engineering design process and to provide students the skills they needed to build the Neu-pulator. The following section describes the day-to-day activities that the students performed.

Day 1. The students were introduced to the application of robotics, with emphasis on assistive robotics. Next, the Neu-pulator platform was introduced and students were encouraged to imagine and brainstorm how the assistive technology could be used in the real-world and, more specifically, which tools and resources they would need to build, control, and improve the Neu-pulator. The discussion extended to multidisciplinary concepts, such as mechanical modeling, electronics, and programming, that were later practiced though introductory projects. As a practical introduction to mechanical modeling, the students learned how to use a Computer Aided Design (CAD) program to model the Neu-pulator (Fig. 2). In addition to demonstrating how the robot is assembled, the CAD program allowed them to test new ideas and modify their Neu-pulator as imagined during the brainstorming session. For example, some students changed the length of their robot's arm, or added new joints to increase reach and the dexterity of the robot.

To introduce electronics and programming, students learned the basics of circuits and how to use an Arduino to control these circuits. Small projects introduced students to electrical elements, such as an Arduino, a breadboard, connecting wires, resistors, switches, and LEDs. Each group experimented on example codes from the Arduino Integrated Development Environment (IDE) program starting with a light-blinking project building to Spaceship Interface project.

Day 2. The students were introduced to the most common robotic components, servomotors (actuator) and potentiometers (sensor). The students learned how these components work, where and how they are used, while applying the information in simple Arduino projects. The projects included controlling a servomotor with a potentiometer, and controlling a servomotor with an automatic sweep motion. Similar to Day 1, the students

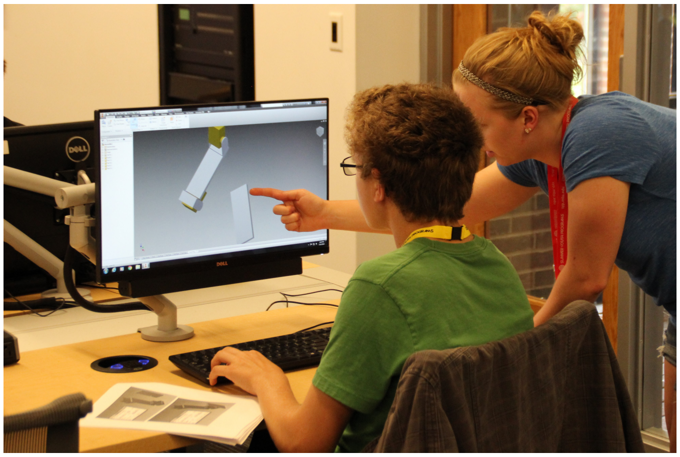

Fig. 2: Student working with computer design software to model the Neu-pulator components.

Fig. 3: Students working together to assemble the Neu-pulator.

based their program off example codes from Arduino IDE to facilitate coding.

The students practiced their programming and wiring skills to build a "mock" or "mini" Neu-pulator using the same components as the previous project and popsicle sticks. Like the Neu-pulator, the "mock" Neu-pulator has a shoulder and elbow joint that are controlled by two independent signals. However, unlike the Neu-pulator the controlling signals are generated by the potentiometers rather than receiving from the EMG sensors.

Day 3. The students learned more advanced concepts of mechanical components and, with these new concepts assembled the mechanical part of the Neu-pulator as a team project. Each team received the robot components and illustrative instructions with the technical terms that were taught during the introductory lesson. The students' comprehension of these technical terms during assembly demonstrated the importance of learning the correct technical nomenclature.

First, the students learned about the structural components of the Neu-pulator, such as the arm links, base, and fasteners. Specifically, they learned the differences between screws, bolts, nuts, and washers, and the appropriate tools and method to tighten and loosen them. The practical skills were tested during the assembly of the Neu-pulator.

Working together, students communicated with each other to take turns and divide the work (Fig.3). For example, one person would build the base frame for the arm, while other students in the group worked to build the motor modules and connect the arm linkage.

Day 4. Teams experimented with EMG sensors and, together with the servomotor wiring, completed the electrical circuit of the Neu-pulator. To control the robot with the EMG sensors, the code previously written for the "mock" Neu-pulator was adapted. The teams extensively tested the code, the wiring, and the structure of the robot to troubleshoot failure modes.

Students learned how small electrical signals generated by their muscles are related to the contraction level of the muscles and how biomedical sensors, such as the EMG sensors, measured these signals. To measure the best signals, students learned how to appropriately attach the sensor on the center of their muscle.

To better visualize how the signal changed when the muscle was flexed, an EMG activity called "EMG Hero" was introduced. "EMG Hero" is a game where players try to follow a trajectory or path displayed on the screen. The better they follow it, the higher they score. Instead of pressing controller buttons, the students had to contract and relax their muscles to make their cursor follow the path. Not only were students excited about this game, but they also were able to better understand how the EMG sensor worked. If they were not getting a clear, strong signal, they quickly realized that they needed to adjust the sensor placement on their muscle.

The students applied this practical understanding to operate the Neu-pulator. Students modified the code from the "mock" Neu-pulator to work with the EMG sensors. To assist the students, the instructors provided an extra piece of code that calibrated the system to the student's muscle signals. Each team of students worked together to test their Neu-pulator with the EMG sensors and modify their assembly, if needed (Fig. 4).

Day 5. This day was the highlight of the week for most students. To continue with the engineering design process, students tested the functionality of their Neu-pulator with two challenging games: The Reaching Challenge and Balloon Volleyball. For the Reaching Challenge, students learned to control the Neu-pulator function with their muscles to try to move the robot to specific positions within the reach of another robot arm. The more positions that were successfully reached within a certain amount of time, the higher the students scored.

For the Balloon Volleyball challenge, students designed a cardboard hand for the Neu-pulator and played against each other in a mini-volleyball tournament. The ball was a balloon, hanging from a string, and the net was paper. During this activity, students could modify their code to improve their volleyball performance, such as increasing the speed of the motor joints, or changing the direction of the joints to be able to spike the ball as they flexed their muscles.

IV. Neu-pulator Assessment Results

A. Daily Survey Results

The daily activity survey results showed that majority of the girls and boys rated this program with positive factors with

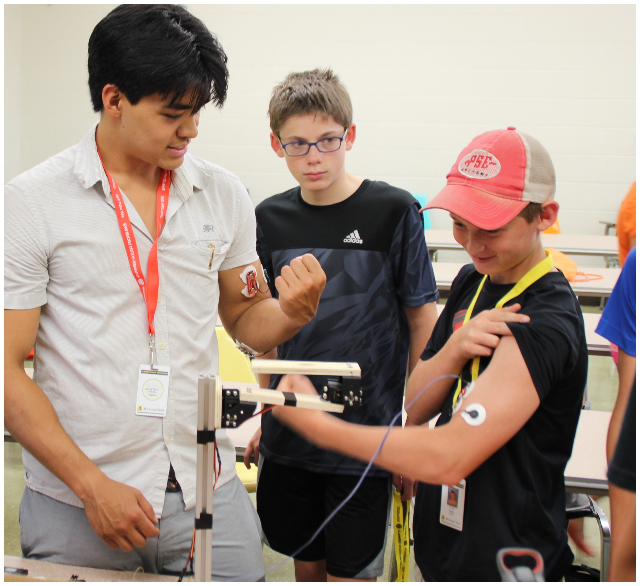

Fig. 4: Student working with instructor to control the motion of the Neu-pulator by flexing his muscle.

the top reasoning being “It was fun”, “It was interesting”, and “I have gotten a lot better at it”. These results showed that most students enjoyed the activities and found them helpful in their learning.

The surveys evaluated the confidence of all the students throughout the week. The starting confidence for girls had an average of 4.3, while the average confidence for the boys was 4.7. However, the average ending confidence for the activities was approximately the same for both girls and boys, with values of 5.6 and 5.7, respectively. This suggested that even though the girls had a lower confidence to start, this program helped increase the overall confidence of all students in the activities that were performed during the week.

An additional worksheet survey asked the students what the three most interesting applications for the Neu-pulator could be. Most students expressed that the Neu-pulator could be used for “helping people with disabilities”, “performing surgery in the medical field”, and so “people can have arms even when they lost one”. Other notable answers included the idea to use the Neu-pulator to “do things humans cannot do”, “get muscle information”, and “do things humans get tired from doing”. These responses showed that students recognized the human-interactive and assistive potential for the Neu-pulator through their own interactions with the device.

B. Pre- and Post-Survey Results

When comparing the pre-survey and post-survey results, we observed that student’s confidence, attitude and excitement towards STEM improved over the course of the week, especially when they could see the Neu-pulator in action. From the 1-7 point Likert survey results, the girls reported a 17 percent increase in their interest in robotics and the boys reported a 6.2 percent increase in interest towards robotics (Table II). Other interests, such as programming, using computers, and designing things, remained consistently high over the course of the week.

TABLE II: Results of students’ interest in STEM-related topics from the pre-survey and post-survey.

	Girls (n=11)		Boys (n = 20)	
Interested in:	**Pre-**	**Post-**	**Pre-**	**Post-**
Robotics	5.5	6.5	5.65	6.0
Programming	5.4	5.5	4.7	5.1
Using Computers	6.0	6.1	5.55	5.8
Designing/ making things	6.55	6.2	6.0	5.9

Students reported on their favorite activity of the week. The majority of students stated that their favorite parts of the week were the activities related to programming and building. One student said his favorite part was “programming with Arduino and seeing the program interact with real life objects”. Another student said her favorite part was “building and programming the robotic arm” because she thought “it was cool that it could copy movements when we put the sensors on our arms. I really liked programming and all of the things we did”. We observed that when the students were presented with a challenging task, such as programming, they showed higher interest in learning when it was integrated with hands-on activities. Accomplishing these tasks showed to be very rewarding to the students. Out of 31 students, only three girls and seven boys stated that they did not enjoy programming because it was “difficult” and that they were “not good at it”.

Additionally, students were asked how their ability to contribute to their teams changed from the beginning to the end of the week. Approximately 85 percent of students stated that their ability increased because they “could help more with programming”, “got better at building”, “got better at wiring”, or “got better at working with others”. When students were asked what they learned from this program, the most common responses were programming, wiring, and how to build a robot.

C. Interviews and Observation Results

The interviews and observation captured students’ opinions about their experience and provided a complementary data in addition to the survey results.

Observation focused on students and instructors’ interaction and behaviour during the daily activities. A series of guidelines were suggested to improve the quality of the teaching environment including:

- Instructors should be more attentive towards the quieter students, even if they are not raising their hand for help.
- Instructors learn all the students’ names.
- Some students have a limited attention span, so it is important to limit the time on activities and offer parallel projects in order to regain their attention.

Interviews were performed after the activities of the fifth day by independent evaluators, who had little to no interaction with the students over the course of the week. The questions asked mostly pertained to understanding the students’ attitude, confidence, and overall interest toward STEM after participating in this program.

Students were asked about the overall expectation of the program. Responses in general were positive and included: "I was excited to try something new. I didn't know what I was expecting, but then when I came, it blew my expectation away." and "I expected it to be really frustrating, because other robotics classes I've taken were very frustrating, but this one was better." A few students had prior experience working with robotics, and they stated that this program was different from other robotics programs because they "got more in depth with programming" and that they learned "a lot about different capabilities of robots".

The interviews also showed that the program increased the confidence of students, especially in topics related to computer science. During the interview, students reflected about what they learned over the course of the week. Many students responded that during the programming activities they "did not know how to do it at first, but after this week I learned how to do it". Another girl stated "when we were first trying to program, I thought I could not do it. But when I started to get into it, I was like Oh wait! I can do it!". In addition, as the confidence of the students grew, they were able to enjoy the activities even more. For example, a student stated that he initially did not like programming because he did not know how to do it, but "once I learned, it is a lot more fun!".

Students were asked to express their memorable moment of the program. They emphasized that the most memorable parts of the week were during the programming activities. For example, "I thought programming would be really hard and confusing, and that it would take loads of effort to do it, but it was actually kind of easy once you learned how to read it". Another student mentioned that their most memorable moment was "when we were programming the arm to move with the potentiometers, and the program worked - I figured out that I could do it". Last, one group of students' favorite moment was when "we finally figured out the code, and it worked! We moved the arm!".

In addition, students reported that this program made them more interested in continuing to learn about robotics and STEM. When asked how the experiences during the week would change their lives, students replied that they are "definitely more into robotics now". One student reported, "I was always kind of thinking I would do something with science, and I have more of an interest now that I actually know how some of this stuff works". Other students said they knew they always wanted to pursue engineering in the future and that "knowing more about it makes me more sure of my choice".

V. Conclusion and Future Work

The Human-Interactive Robotics Program was developed to promote robotics and STEM learning with the theme of helping human life. In 2016, 11 middle school girls and 20 middle school boys - grade 6 to 8 participated during a week-long summer camp. This program was built around a unique hands-on educational platform called Neu-pulator, or neurally-controlled manipulator. Designed and fabricated at the Michigan Tech's HIRoLab, this low-cost robotic manipulator reflects the characteristics of a human arm, and is actuated by signals from the student's neuromuscular system.

During a 5-day educational program, students learned different topics within Science, Technology, Engineering, and Mathematics by implementing the engineering design process. Each day students participated in multidisciplinary hands-on activities as they *brainstormed*, *designed* a 3D model, *programmed* a microprocessor, and *assembled* and *tested* the Neu-pulator arm.

Surveys and interviews were performed to understand the students' attitudes and interests towards STEM and robotics. The survey results revealed an increase in the level of interest towards robotics among the students, with a significant increase for girls. In addition, the results determined that young students are capable of learning more complex STEM-related topics, such as programming, sensors, actuators, and human biomechanics, through fun hands-on activities. Based on the daily survey results, students showed an increase in their level of confidence as they learned new concepts and practiced their skills throughout the week.

Future work will broaden the impact of this program by reaching out to 60 middle school students in summer 2017, while targeting more female students. The Human-Interactive Robotics Program will offer full scholarship to female students supported through National Science Foundation grant. In addition, the goal of this program it to introduce Neu-pulator to school classrooms. Recently, a pilot teacher workshop was conducted to receive preliminary feedback on the teaching training material content. A series of workshops will educate and train middle school teachers on how to conduct the Neu-pulator project activities independently in their classrooms and afterschool programs.

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