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Board 176: Summer Robotics Program for High School Students

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Summer Robotics Program for High School Students

Abstract

Our university started a pre-college program for the summer, called ImpactLab. ImpactLab was offered in the summer 2022 for the first time. It was a two-week residential summer experience for rising juniors and seniors in high school, that let them experience a college environment and explore a field of study. Various programs were offered to expose students to different professional fields, including arts, science, architecture, and engineering. Introduction to Robotics was one of the programs and eight students enrolled the program. The students were introduced to college life by a residential experience including social activities in the evenings and weekends.

The objective of this study was to measure the impact of the Introduction to Robotics program on the students' affective and learning experience. To this end, a survey was administered to the eight students who participated in the program, after completion of the projects. All students participated in the survey, and the results revealed that 62.5% of the students reported being extremely satisfied with the robotics program, including working with their peers and interacting with the faculty. The students expressed that they found the academic program experience enjoyable and useful in helping them to identify their future college interests and majors.

Introduction

Educational robotics offers a stimulating and enjoyable environment for young individuals, while simultaneously introducing them to technological advancements. A growing number of studies have delved into the impact of educational robotics on the academic and social skills of young learners [1]. Anwar et al. [1] conducted an analysis of 147 studies on educational robotics and found that youth participation in robotics activities enhances their knowledge in STEM fields, their perceived problem-solving abilities, and their interest in pursuing engineering careers. Several outreach programs for both students and teachers have been developed in this regard [2-9]. FIRST® is an example of a program that offers a platform for students to engage in robotics competitions. Carnegie Mellon University (CMU) offers a robotics education program for middle and high school students utilizing the LEGO® MINDSTORM® NXT/EV3 and TETRIX™ platforms [6-7]. Additionally, many institutions provide robotics summer camps for pre-college students, with various focuses on mechanical design, electronics, and coding [8-9].

Our pre-college experience ImpactLab was a two-week residential summer program for rising juniors and seniors in high school. ImpactLab let students try out a college experience while living on-campus and collaborating with new friends. This immersive learning program gave students a chance to explore science, engineering, design, or business. From the opportunity to get a sneak peek of college life, to learning in the labs and studios, students were able to explore 14 of various engaging topics.

ImpactLab was open to rising juniors and seniors in high school. All interested students were required to submit the application form, a current high school transcript and an essay detailing their interest in attending a pre-college program. Students were reviewed based on their interest in the program and potential admissibility to our university. There were 183 applicants for the program and 80 students attended. The Introduction to Robotics program represented 10% of the total attendance at ImpactLab. ImpactLab is a tuition-based program. The majority of students paid tuition to attend the program. However, in the Introduction to Robotics program, two of the eight participants had received full tuition assistance to attend the program.

The ImpactLab program was designed as a non-credit bearing exploratory program of STEM disciplines. Participants in the two-week program had approximately 48 hours of academic instruction. The balance of their time on campus was dedicated to college preparation programming, social programming and field trips around the city.

Table 1. A typical daily schedule at ImpactLab

Time	**Activities**
7:30/8:00 AM	Breakfast
9:00 AM	Course Time (Built in Lab & Project Work)
12:00 PM	Lunch
1:00 PM	Course Time (Built in Lab & Project Work)
4:30 PM	Optional Activities & Recreation
5:30 PM	Dinner
7:00 PM	Evening Activities & Recreation
10:00 PM	Residence Hall Check-In

Table 1 shows a typical daily schedule at ImpactLab.

One of the programs was Introduction to Robotics, and the students who selected this program did all their course time in the Robotics program.

Program Implementation

Introduction to Robotics was one of the programs and eight students enrolled in the program in Summer 2022. The academic portion for the selected field took place during the day, Monday through Friday, six hours a day, except only two hours on Friday. The main goal was to expose students to the robotics discipline through active learning.

The summer program was developed and conducted by five faculty from the School of Engineering's programs in electrical, computer, and mechanical engineering. Each faculty shared with students their own experience in the robotics field. Basic knowledge related to robotics was introduced and followed by hands on activities.

Three projects were undertaken by the students. The first was setting up and programming an autonomous vehicle controlled by Arduino. This project included sessions and lab activities that covered electrical theory and safety, benchtop pulse width modulation, Arduino pulse width modulation, Arduino with ultrasonic sensor, and ended with a SumoBot competition. The second project involved modeling robots using SolidWorks. The students learned about CAD and built their own models. Finally, the third project used Vex Robot equipment. Sessions and labs included an introduction to industrial robotics, building a Workcell, testing its movements, and picking up/dropping off/transporting objects using the Workcell. The laboratory work was carried out by the students in groups of two. The school of engineering provided complete support in terms of equipment and software required for the program.

The weekly plans of the robotics program are shown in Table 2. Students worked on Autonomous Vehicle for four times (12 hours), Robotics modeling for five labs (15 hours), and eight labs for VEX Robot (24 hours). One of the challenging factors that we encountered was faculty involvement. Since the participating faculty already had a full teaching load during the Summer, it was difficult to arrange lab content in a way that was both meaningful and coherent. As a result, the program schedule had to jump around from project to project, which may have created a lack of continuity that could have negatively impacted the students' learning experience. Table 2 illustrates some of the issues that we encountered as we tried to navigate this challenge.

Table 2. Weekly Plan

		Monday	Tuesday	Wednesday	Thursday	Friday
week 1	morning	Project 1 – Safety Lecture, Lab 0: Wet Hands, Lab 1: Benchtop PWM Motor	Project 2 – Introduction to Robotics, SolidWorks	Project 3 – Intro Robotics and Kinematics Lecture, Start Vex Lab 1: Vex Assembly	Project 2 – Modeling Robot in SolidWorks	No Lab
	afternoon	Project 1 – Lecture Intro Arduino Software, Lab 2: Arduino PWM Motor	Project 1 – Lecture Sensors and Software if-then statements, Lab 3: Sensors, and start Lab 4 Car Rotate	Project 3 – Continue Vex Lab 1 - Vex Assembly	Project 1 – Finish Lab 4: Car Rotate, Lab 5: SumoBot, Competition	No Lab
week 2	morning	Project 3 – VEX Lab 2: Safety of the Robot, Emergency Stop, Vex Lab 3: Manual Movement	Project 2 – Modeling Robot in SolidWorks	Project 3 – Vex Lab 7: Dropping Off and Transporting Objects	Project 2 – Modeling Robot in SolidWorks	Project 3 – Vex Lab 9: Conveyor Systems and Sensors
	afternoon	Project 3 – VEX Lab 4: Programming Movement	Project 3 – Vex Lab 5: Using variables, Vex Lab 6: Using an End Effector	Project 3 – Vex Lab 8: Build Conveyor Systems	Project 2 - Modeling Robot in SolidWorks	No Lab

Project 1 Autonomous Vehicle

The autonomous vehicle project included sessions and lab activities for electrical theory and safety, benchtop pulse width modulation, Arduino pulse width modulation, Arduino with ultrasonic sensor, and ended with a SumoBot competition. The main goal of this project is to familiarize students with benchtop instrumentation and microcontroller programming. It is designed to be accessible for individuals with no prior experience.

Pulse Width Modulation: the students were introduced to the basic benchtop instrumentation, including the function generator, oscilloscope, digital multimeter, and power supply.
The challenge was to generate pulse-width modulation (PWM) periodic square waves to control the two continuous stepper motors. This exposed the students to basic electrical engineering concepts of time-course signals, voltages, frequency and manipulations of periodic signals. Use of the bench top instruments and observation of how their different signals would control the motor allowed the students to develop some insight and confidence [10-11]. Figure 1 shows square wave generated and measured by bench devices.

Arduino Pulse Width Modulation: instead of using the bench top instrument of a function generator to make the PWM signal, the students needed to write software on an Arduino microcontroller. With software and the microcontroller board, the students generated the same PWM signals that they had previously made with the function generator. This lab exposed students to the process of writing computer programs, downloading to hardware, running and testing that hardware. The trial and error experimentation and control of the motor allowed development of insight and confidence [10-11].

Arduino with ultrasonic sensor: sensor input to the microcontroller was introduced. Students activated sensors, set up analog-to-digital conversion on the microcontroller, and utilized the new information to generate the PWM signals controlling the motors. Using a digital multi-meter (DMM), they observed the change in voltage from the sensor as the measurand (color on the floor observed by the sensor) changed. Following analog-to-digital conversion on the microcontroller board, they observed the number from the sensor as used within the software program. Based on what they learned, they set up a threshold within the software.

Autonomous Vehicle: the students utilized their prior skills to develop a target behavior for their car. The goal was to have the car generally move forward, but to stay within an arena defined by the border of a white line ring around a black floor in the interior of the ring. Figure 2 shows the hardware connection of the autonomous vehicle.

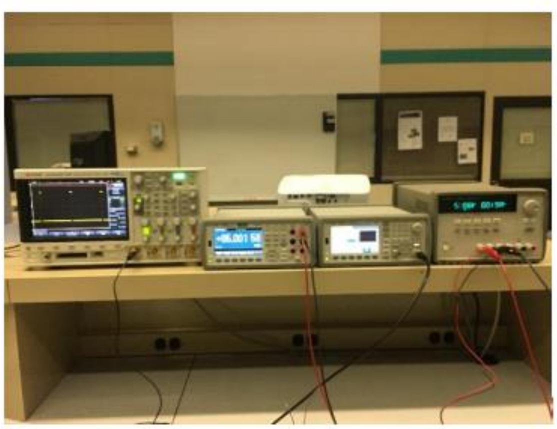

Figure 1. Square wave generated and measured by bench devices

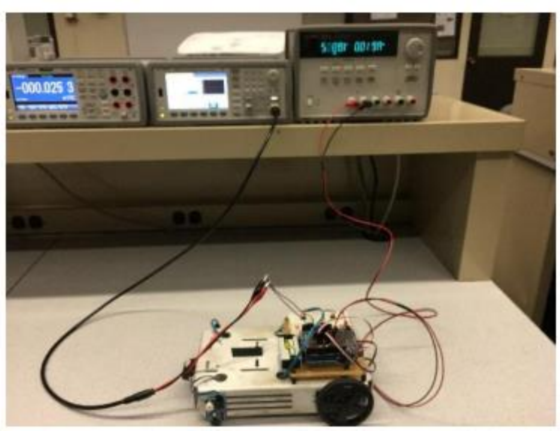

Figure 2. Hardware connection of autonomous vehicle

Project 2 Modeling of Robots using SolidWorks

The series of sessions for Robot and SolidWorks began with the topic *A Brief History of Robotics*, and the key concepts in modeling of a robotic system:

- Degrees of Freedom of a Joint
- Representation of Joints
- Degrees of Freedom of Series and Parallel Robotic Systems
- Robot End Effector
- Robot Teaching

Then, in the topic *Classification of Robots*, the students were introduced to several types of robots which have been built over the years for a variety of industrial applications:

- Cartesian Coordinate Robots
- Cylindrical Coordinate Robots
- Spherical Coordinate Robots
- Horizontal and Vertical Revolute Articulated Robots
- Mobile Robots

Then the focus switched to *Applications.* The students learned about *Robot Kinematics* and *Simulation and Design of a Robotic System Using SolidWorks.* SolidWorks is a trademark of Dassault Systèmes SolidWorks Corporation. Each student built their own models. The students were provided with the components, and they built two assemblies. One assembly was for a planar with Translation-Rotation-Translation joints (TRT), shown in Figure 3 and the second for a spatial with Translation-Rotation-Rotation-Translation joints (TRRT), shown in Figure 4.

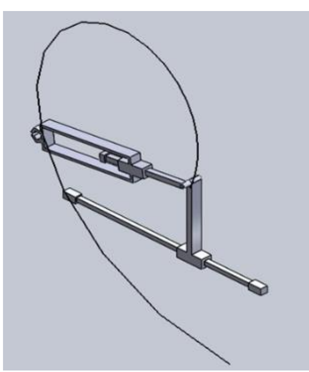

Figure 3. Planar TRT manipulator

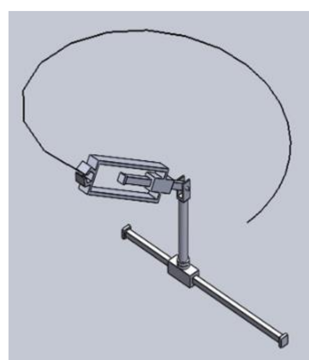

Figure 4. Spatial TRRT robotic system

For each assembly, the students assigned motor actuations to observe the output trajectory of the end effector.

Project 3 VEX V5 Robotics Arm

The main aim of this undertaking is to familiarize students with the concept of using robotic arms in automation, helping them understand the construction and functioning of a robotic arm. This project is designed to be accessible for individuals with no prior experience, although possessing programming skills would be advantageous.

Any robotics system contains mechanical components, programming, and sensors. Among the many different robotics platforms available, the VEX V5 Workcell was selected for this project. The assembly of the Workcell is shown in Figure 5. workcell offers a highly valuable robotic automation system, which can enable students to broaden their understanding of industrial robots and automation. VEX is a well-established partner in the classroom for STEM education and robotics, utilizing metal-based construction kits. The VEX V5 Workcell goes beyond just featuring a robotic arm and incorporates a complete factory automation workstation with a conveyor belt, allowing the robotic arm to pick and place objects. By centering on autonomous vehicle operation in Project 1 and delving into the modeling of the robotic arm in Project 2, this Workcell offers a highly valuable robotic automation system, which can enable students to broaden their understanding of industrial robots and automation.

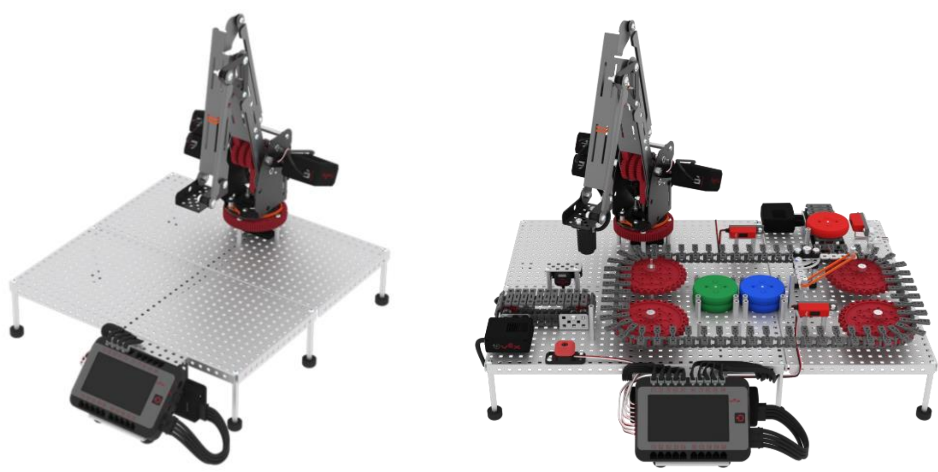

Figure 5. Vex V5 Workcell

The VEX V5 Workcell is a smaller and safer industrial robot model that is versatile in its building capabilities. It provides students with a more independent hands-on learning experience compared to professional-grade robotic arms [12]. It also allows students to engage in a building experience. Students who are engaged with professional-sized robotic arms gain experience programming them, but may not understand how they move and operate. Being involved in the building process gives students the opportunity to make a stronger connection between the hardware and software, and allows them to gain more foundational knowledge of how the robot physically works. When designing the robotics program, we decided to let the student team experience the building process so that they can explore various mechanical components and observe and learn how they work. During this process, they can better understand how the mechanical system works and gain the ability to fix any potential mechanical problems they might encounter in the future.

Regarding programming, the VEX V5 provides the VEXCode V5 software platform, which helps users overcome the barrier of programming. It supports scratch, block-based coding, and can also be easily converted to a C++ or Python text-based project. A sample scratch code and text-based code is shown in Figure 6. The scratch method was chosen to program the robot by the students.

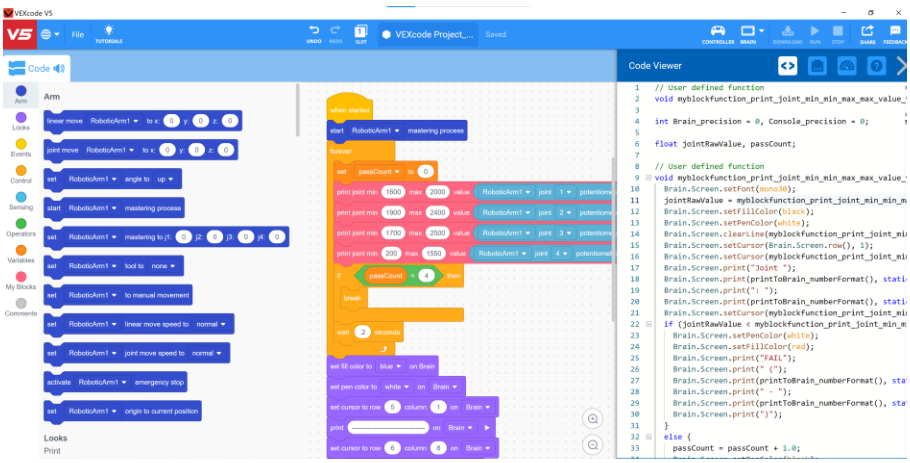

Figure 6. A sample block-based code and text-based code

VEX provides a series of lab instructions to teach students about industrial robots. We followed the lab sequence and made some modifications for our use. The curriculum of the Robotic Arm is shown in Table 3.

Table 3. Curriculum of VEX V5 Robotics Arm

Lab 1	Building the Industrial Robotic Arm	Explore Industrial Robotics and learn about the components and application of industrial robots.
Lab 2	Safety - emergency stop application	Add the Bumper Switch to the Workcell and code it to simulate an E-Stop, explore safety standards in Industrial robots.
Lab 3	Manual Movements	Manually move the arm mounted on the VS Workcell to learn about the Cartesian coordinate system.
Lab 4	Programming Movements	Observe and compare the difference between linear movements and joint movements.
Lab 5	Using Variables.	Learn how variables are used to store values
Lab 6	Using an End Effector	Explore how to store (x,y,z) coordinates in a 2D list to draw different shapes.
Lab 7	Dropping off and transporting objects	Add the Electromagnet and program it to pick up and drop off colored disks. Add Optical Sensors and sort disks based on their color.

Lab 8	Using a conveyor System	Build a conveyor system to sort colored disks in an expanded Workcell to explore material handling systems in manufacturing.
Lab 9	Conveyor System and Sensors	Utilize sensors with the conveyor system and learn how manufacturing processes incorporate sensors into the material handling

The students spent approximately six hours building the robotic arm and setting its home position to ensure that it could reach specific locations. They also received instruction on industrial robot safety protocols. Figure 7 shows the students working on the VEX V5 Workcell. Once the arm was assembled, the students learned how to manipulate it manually and using programming, including using variables and lists to draw different shapes.

The students also explored using an electromagnet and sensor feedback to pick up and release objects. Finally, they built a conveyor system to simulate a production line in manufacturing. Through these activities, the students gained hands-on experience in building and programming a robotic arm, as well as an understanding of the various components and subsystems required to create an automated manufacturing system.

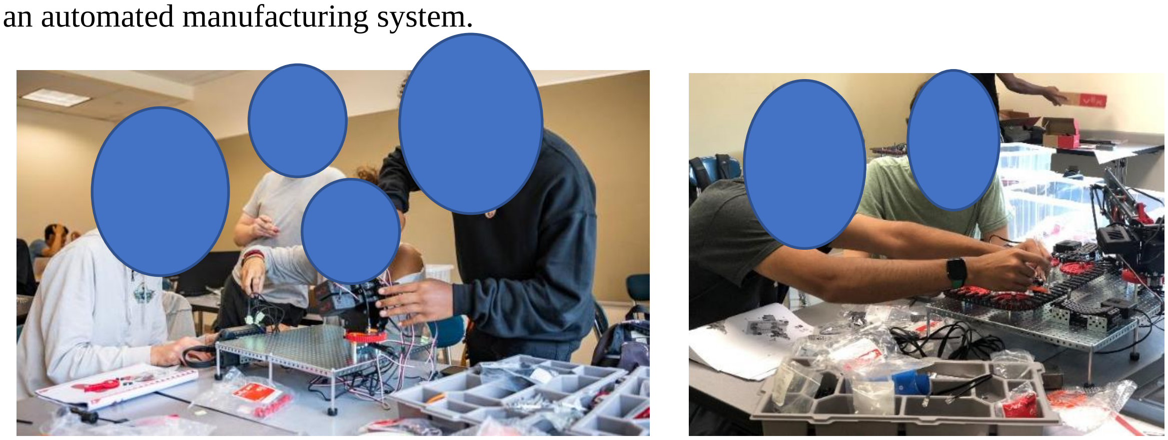

Figure 7. Working on the Robotic Arm and Conveyor System.

Survey Results

A survey was sent out to participants after they completed the robotics program, and Figure 8 shows the level of satisfaction among the eight students. Of these, five students reported being extremely satisfied with the robotics program, working with peers, and interactions with faculty.

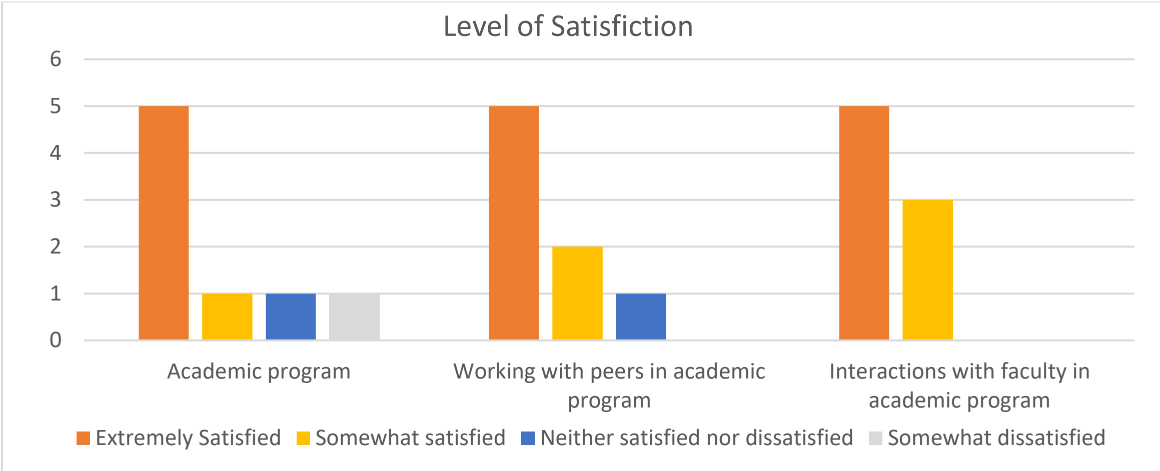

Figure 8. Survey result – Level of Satisfaction

When students were asked "what do you think was done well? What do you think could be improved?" Six out of eight students commented:

- *The professors' being helpful was done well, and nothing should be improved.*
- *The teaching was done well.*
- *The amount of lecture time and lab time was well balanced.*
- *Building and programming the vex and Arduino robot were great.*
- *I think having a final project for the robotics program would be an enriching way to end the program.*
- *More tools for working on the projects.*

Overall, the feedback from students was positive and the suggestions were valuable. A final project is under development for next year's program.

Conclusions

The pre-college summer program Introduction to Robotics Program was motivated to expose students to STEM fields, boost students' interests and give them actual hands-on experience. This program could also in the longer-term recruit new students into our university and fulfill our long-term objective of recruiting more students into the STEM-related career.

Three projects developed and conducted by Electrical, Computer, and Mechanical Engineering faculty were presented in this paper. Positive feedback was received by the participants as well as their parents. The survey showed that most participants were satisfied with the robotics program, working with peers, and interactions with faculty.

The experience gained from this program will help us to be more prepared and creative in organizing a similar program this year. We believe these experiences would also benefit other educators and researchers with the common goal of increasing the number of professionals in the STEM fields.

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