

Preparing the Next Generation Advanced Manufacturing Workforce Using Collaborative Robots and Experiential Learning (Work in Progress)

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Abstract

The widening skills gap and shrinking workforce in advanced manufacturing is a critical national problem. One solution is to open the minds of schoolchildren to the joy of robotics in manufacturing to stir their enthusiasm, with a larger goal of generating future career interest. This paper describes the application and assessment of a 7-week long after-school experiential learning program using collaborative robots that introduced 16 middle school students from underrepresented and underserved groups to robotics and advanced manufacturing. Through pre- and post-surveys, students reported feeling better informed about collaborative robots, how they are used in manufacturing, how to program them, as well as how to operate industry standard machine tools. This work in progress study may serve as a valuable guide for K-12 STEM educators and policy makers interested in developing programs which inspire and equip pre-college students to pursue engineering careers. Future work will enlarge the sample size of participants through additional offerings and include quantitative evaluations of instructional effectiveness in addition to the student surveys.

Introduction

Global manufacturing is undergoing a paradigm shift towards flexible automation in the form of internet-enabled machinery and collaborative robots (cobots) [1]. Previously, due to cost and scale, large manufacturers were the primary users of this technology [2]. However, with plunging technology costs and rising need for increased productivity, adoption of factory automation by small and medium-sized manufacturers (SMEs) is on the rise [3]. This influx of advanced technologies and automation into the traditional manufacturing industry has led to significant workforce skill shortages. The recent trend of skilled worker retirements in industrialized economies further exacerbates the need for technically savvy employees in the modern factory [4]. In fact, about 2.4 million manufacturing jobs are estimated to be left unfilled by 2028 in the United States [5]. The top skills required by the manufacturing workforce include computing and robot programming skills [5]. Reskilling the existing manufacturing workforce is ongoing, however, the needs of industry are outpacing the growth of newly trained and qualified workers [6]. Hence, to further bridge the skill gap, there is a need for an expansion of the pipeline of future manufacturing talent. This requires building a pool of current K-12 students interested in pursuing a career in manufacturing and engineering and primed with the industry-relevant skills listed above. Within this student age group, existing programs have focused primarily on high school students [13], with limited attention to pre-high school student groups, although studies have shown that those age groups are critical for interest and career choice-making [12].

This paper contributes toward filling this skills gap through the description and application of an after-school experiential learning program, *Cobots for Kids*, for middle school students. The program goal was to develop an age-appropriate, hands-on learning experience to introduce collaborative robotics and advanced manufacturing to middle school students in an engaging way to gain their interest in the manufacturing field. The Cobots for Kids program, led by Worcester Polytechnic Institute (WPI), particularly involves students from underrepresented (i.e. from minority groups based on gender, race or ethnicity) and underserved (i.e. from low-income communities) student groups, who may lack access to such educational programs and resources due to cost, or availability constraints. This paper presents a

description of the program and curriculum developed and preliminary evaluation results from a pilot cohort. Motivating students to engage with and learn about manufacturing and robotics while still in middle school, would help shape their perception about the field, inspire their interest for continuous learning, and thus prepare them to be part of the next generation advanced manufacturing workforce.

Program and Curriculum Design

Program Overview

The first offering of the program was launched in the Fall of 2019. The program sought a well-diversified student cohort, with special attention to attracting students from under-represented and underserved groups in the community. Student enrollment was conducted by the WPI Office of Pre-Collegiate Outreach via emails to middle schools in the Worcester public school district. Within 24 hours of registration opening, student applications far surpassed the available program participant slots. Hence, slots were filled on a first-come, first-served basis with consideration of the diversity criteria. Sixteen middle school students from Worcester public schools were enrolled to participate in the program – half of them were female; three identified as African American, four as Hispanic or Latino, one as Asian or Asian-American, seven as White/Caucasian, and one as Native Hawaiian. The schedule of the after-school program comprised seven weekly sessions. Sessions were held on Wednesdays for two hours at the WPI Manufacturing labs. The suite of machine tools and equipment used to run the activities in this program include the following: two Universal Robots (UR) collaborative robots (UR5e) with Robotiq Gen 2 Two-finger Adaptive grippers, two 3-axis Haas CNC Milling machines, one Haas CNC Lathe machine, and two Universal Laser Systems Laser Cutter machines.

Pedagogical Approach

The pedagogical approach of the Cobots for Kids program is grounded in the experiential learning theory. The theory argues that learning is a continuous process resulting from a cumulation of experiences and information gathered [10]. Thus, the program activities were crafted to provide students with practical experiences working on real-world manufacturing applications with industry standard equipment. Specific attention was given to guiding students to make connections between their practical experiences and prior knowledge, especially in math and science. Also, reflection is crucial to learning and understanding, hence, to encourage students to reflect on their experiences and learning, each session ended with a debriefing time where students were asked to reflect and evaluate their experience. To assist in facilitating activities, WPI student instructors with requisite background in manufacturing and robotics were employed, trained, and supervised by the program team to assist in facilitating the class activities. Specifically, two undergraduate student instructors were recruited for the program.

Curriculum

The Cobots for Kids curriculum comprised a series of experiential learning activities designed to gradually guide students in understanding the role of robots in manufacturing and developing skills on how to work with these technologies. The student learning outcomes were that at the end of the program, students were expected to: (1) understand why cobots are relevant in today's manufacturing, (2) be able to program cobots to perform fundamental industrial tasks, (3) understand how advanced machine tools work, (4) operate machine tools to make different items, and (5) perform basic 2D and 3D designs using Computer-Aided Design (CAD) software. To achieve these learning and experience outcomes in a fun, engaging, and

impactful way, the curriculum adopted an activity-based, hands-on, experiential learning approach. Table I shows the schedule of activities in the program. The activities are broken down into two categories: (1) Collaborative robot programming and (2) Machining. These activity categories are described below.

Collaborative Robots (Cobots) Programming:

Students learned what cobots are and how to program and work with them. In the first week, students received an introduction to cobots and learned to move the robot via manual control (called robot jogging). Here, they were exposed to concepts and terminologies such as robot degrees of freedom, coordinate systems, and joint and end-effector motion. In the hands-on activity, students performed two tasks using manual control: a cube stacking task and a trace-a-maze task using a board marker on a sheet of paper placed on the table. Robot programming was introduced in the second week. Students learned basic programming functions for moving the cobot, setting waypoints, and operating the robot gripper (to open and close). The practical activity involved writing a program to automate the cube stacking task performed manually in the previous week. In the subsequent weeks, to ensure that students build intuition about how cobots are used in manufacturing, two practical projects were formulated with strong relevance to real-world manufacturing processes: (1) *automated part assembly* and (2) *machine tending*.

i) Automated part assembly: The manufacturing process of all sorts of items/equipment involves one or more steps of part assembly. The use of robots enables the automation of this labor-intensive, repetitive, and oftentimes, dangerous process. In this project, students were tasked to develop a LEGO vehicle (truck) assembly station (see Fig. 1). With the respective vehicle parts precisely arranged on a pallet, students were required to program the robot to pick and assemble the different parts together to form a truck. The project was completed in three weeks. Along with learning to work with and program the cobot, this project enabled students to harness critical thinking skills for problem solving, learn to work and collaborate with others on



Fig 1: Students working together to program the cobot to complete the truck assembly task

Week	Activities
1	<ul style="list-style-type: none"> • Tour of the manufacturing workshop • Introduction to Cobots: Manual control
2	<ul style="list-style-type: none"> • Introduction to Cobots: Programming basics • Introduction to Machining • Introduction to Laser cutting
3	<i>Part Assembly Task I</i> <ul style="list-style-type: none"> • Cobot programming with LEGO • Part dimensioning using measuring tools
4	<i>Part Assembly Task II</i> <ul style="list-style-type: none"> • 2D design of assembly mat in CAD software • Cobot programming for assembly
5	<i>Part Assembly Task III</i> <ul style="list-style-type: none"> • Cobot programming for assembly II
6	<ul style="list-style-type: none"> • Machine tending • Machining: Fidget spinner, Christmas Tree
7	<ul style="list-style-type: none"> • Machining: Snowman, Snowflake • Concluding session

TABLE 1



Fig 2: Student tightening the vice on the CNC milling machine after inserting the workpiece

a shared task. students to harness critical thinking skills for problem solving, learn to work and collaborate with others on a shared task.

ii) *Machine tending*: Machine tending is another labor-intensive, repetitive task performed by machine operators in industry. It involves feeding, manipulating, and then removing workpieces from the machine tool. Robots, specifically cobots, have become well suited to automate this process. In this activity, students are required to program the robot to pick up a workpiece from the vice (face up), rotate it, and place it back into the vice in face down orientation (typically for another machining operation).

Machining: Machining involves creatively processing materials into a finished product using machine tools. This category strived to build students’ intuition about the machining process; how CNC machine tools function and how they are used to make simple everyday items. In the first week, students took a tour of the manufacturing labs at WPI and were exposed to the different CNC machine tools and equipment in the facility. In the second week, the students engaged in two experiential learning activities on the machine tools: (1) keychain engraving: using a CNC milling machine and (2) making a chess pawn using the CNC lathe machine. Through these activities, they learned the basics of CNC machine operation and explored basic machine setup procedure. Fig. 2 shows a student in action on the CNC machine tool. The last activity in the second week was an introduction to laser cutting. In the sixth and seventh weeks, students learned to operate the CNC machine tools to make different items such as a fidget spinner, a snowman, and a Christmas tree.

Preliminary Program Evaluation

To evaluate the impact of the program on the knowledge base of participants, a survey questionnaire was administered electronically via an online form at the beginning and the end of the program. The questions enabled (1) a quantitative assessment of objective knowledge about collaborative robots and advanced manufacturing tools, and (2) a qualitative analysis of student feedback about the program. The pre and post surveys were administered to 16 middle school students that participated in this program. Of these, 12 students completed both the surveys (a 75% response rate). These 12 students comprised of 50% females, an average age of 13.67 years, and 50% students were in the 7th grade while 50% were in the 8th grade. Students were asked to indicate how informed (knowledgeable) they were about seven topics on a scale of 1 (Not informed at all) to 4 (Very well informed). Table II presents their responses before (pre) and after (post) the program. It is clear from the pre and post average scores and Wilcoxon matched-pairs signed-rank test that their overall knowledge after the program had significantly improved ($z = -2.8, p <$

How informed (knowledgeable) are you about these topics. (1 – Not informed at all; 4 – Very well informed)	Pre	Post	Gain
Collaborative Robots (Cobots)	2.5	3.3	32%
Programming a Robot Arm	1.8	2.9	61%
Types of Robots	2.3	2.9	26%
Operating a CNC machine/Laser cutter	1.5	3.1	106%
Programming a cobot to perform a variety of simple industrial tasks	2.1	2.7	28%
Programming/Interfacing a cobot with a machine tool for a task	2.2	3.2	45%
Safety measures while working with a Robot	2.3	3.3	43%
Total Average	2.1	3.0	45%

TABLE II

.005) as compared to what it was before attending the program. They learned the most about collaborative robots and the safety measures while working with a robot (post average of 3.3). The difference between their pre and post knowledge was the highest (over double) for learning about CNC machine/ Laser cutter operation (percent gain of 106%).

Furthermore, in the post survey, students were asked two open-ended questions: (1) “Did this program meet your expectations, if Yes, tell us how?”, (2) “What new things did you learn from this program?”. The students stated that they learned about programming a cobot and basic usage of machine tools. They found this experiential learning and doing different activities to be fun, and that they developed skills that might help them in the future [16]. The following quotes depict students’ feedback about the program:

“...it taught me how to program a cobot and I learned how to use fusion. the programming helped me learn how to move the cobot around...”

“...we got to do a lot of really cool stuff in the program that I probably wouldn’t be able to do at school. I am really glad I did this program. It was fun.”

“...we got to use a lot of machines and learned some basic stuff about how to use them etc. We got to do different things every week and learned skills that might help us in the future.”

Overall, the results indicate that students learned about safely working with and programming cobots, and operating CNC machines and laser cutters. They also enjoyed the program and thought it met or exceeded their expectations.

Discussion & Conclusion

The preliminary evaluation, based on survey responses, suggests that the program succeeded in improving students’ knowledge about basic concepts of operating collaborative robots and manufacturing machine tools. This result reveals that experiential learning-based, pre-college engineering education programs, can be an effective learning opportunity appropriate for, not only high school students, but also middle school students [16, 17]. This program provided the middle school students with hands-on activities which were well-aligned to real-world manufacturing situations in an engaging and age-appropriate way.

Furthermore, involving undergraduate engineering students as instructors in the program provided a valuable mentorship opportunity to the middle school students. Research has shown the importance of student role-modeling and mentorship, especially towards ethnically minority groups [8, 14]. Also, the involvement of undergraduate students as instructors served a second purpose of building an “immediate” cohort of future manufacturing workers. By serving as program facilitators, student instructors can deepen their knowledge of the field, improve self-awareness [15] and sharpen their industry relevant skills which would make them more attractive to manufacturing firms as they graduate and enter the labor market. Further studies may investigate the direct impact of teaching responsibility on knowledge, skill, confidence, and attitude of undergraduate student instructors.

In conclusion, this work in progress paper presented the design and implementation of an age-appropriate after-school program for middle school students. Our experiential learning-based approach provided students with a unique opportunity to learn fundamental concepts about advanced manufacturing in an engaging way. This pilot offering served a small, but diverse cohort from the Worcester public school district. Plans for subsequent offerings are in place to extend its reach to more students, in underrepresented communities.

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