Using Robotics and 3D Printing to Introduce Youth to Computer Science and Electromechanical Engineering

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Abstract
We describe the design and implementation of a learning experience to introduce high school students to electromechanical engineering and computer science education. We used a series of hands-on collaborative group learning activities to engage participants. Our interdisciplinary team designed the experience in a way that gradually introduced the youth to topics in robotics, 3D modelling, printing and assembly, through collaborative group activities. The workshop culminated in the real-time fabrication and display of a functional 3D printed robotic hand, which was designed and customized by the participants.

Author Keywords
Youth; Prototyping; 3D Printing; Robotics; Engineering Education; Making; Design.

ACM Classification Keywords
K.3.1 Computer Uses in Education (e.g., Collaborative Learning).

Introduction
The importance of outreach activities, including summer camps, after-school programs, and workshops in introducing and engaging participants from different

socioeconomic and ethnic backgrounds to Science, Technology, Engineering and Math (STEM) topics is well-recognized and studied [3, 7, 9, 11, 12, 14, 15]. Many of these programs incorporate project-driven learning and Maker activities to provide an engaging hands-on experience to participants [7, 15]. "Making" refers to a wide range of activities that involve tinkering, customizing, designing, and fabricating small-batch artifacts that usually require some degree of technical (or craft) skills, which are usually accomplished by amateurs in self-directed projects [2]. Recent technological innovations in the areas of rapid prototyping—especially 3D modelling and printing—as well as, robotics and embedded computing, especially low-cost microcontrollers and sensors [7, 13], have supported this approach to learning and practice. Making is not only about the tools used; it is more of a mindset and practice that values collaboration, knowledge sharing, and creativity [6].

Previous research has demonstrated the relevance of making and project-based learning in different contexts, such as in primary schools [11], high schools [7, 14], universities [9, 12], special education classrooms [4], and informal learning environments [8, 16]. There is a need to further investigate what can happen at the intersection of different learning contexts—when these spaces meet and boundaries are crossed. We are interested in using Maker approaches to introduce youths to a university-level engineering and computer science education. We were interested in the following questions: how can we design hands-on Maker activities to provide a taste of interdisciplinary research and practice to youth? How can we design memorable and meaningful activities for large groups of students (who are on a short university visit) to introduce them to current topics in engineering and computer science?

In this case study, we present the design of a Maker workshop to introduce high school students to electromechanical engineering and computer science topics when visiting York University. The workshop consisted of three independent modules that were followed by an entrepreneurship pitch session. Each of the modules introduced participants to cutting edge topics in digital design, rapid prototyping, and robotics. During the workshop, the participants worked together to design 3D printed fingers, which were assembled onto a robotic hand. The workshop ended with an entrepreneurship pitch session in which undergraduate engineering students presented their ideas in front of the workshop participants. The pitch session allowed participants to witness the application of digital literacy and engineering skills toward real-world contributions.

Designing a Hands-on Group Learning Experience for Youth

The youth workshop was a deliverable of a large interdisciplinary academic-industry partnership government research grant for research commercialization, knowledge transfer, and entrepreneurship. The goal of our one-day workshop, was to introduce high school students to electromechanical engineering and computer science topics via a series of hands-on activities by using current technologies. Our aim was to demonstrate the endless possibilities in the fields of engineering and digital media by incorporating interactive student-centered learning activities [5].

We formed a multidisciplinary team of academic-industry partners with expertise in 3D Computer-Generated Imagery (CGI) modeling, 3D printing, human-computer interaction (HCI), mechanical engineering, electrical engineering, computer engineering, robotics, and project management. The challenge involved creating an engaging learning experience that would actively engage youths, encourage new creative interests, and be complex enough to give them a feeling of accomplishment.

Workshop Design Process

The research grant's project manager came up with the concept of 3D modeling and printing a robotic hand with movable fingers as a three-hour workshop exercise for youths to learn about university-level electromechanical engineering and computer science programs. She assembled the interdisciplinary design team, secured corporate partners as contributors, facilitated high school student attendance, and managed the workshops.

In designing the exercise, she drew upon her prior experience of attending interactive do-it-yourself (DIY) workshops in which she had used sensors and Arduino microcontrollers to create a sensing human prosthetic finger. In the prior workshop, teams of two people each created a life-sized model of their own fingers by using hot wax that was poured into a mold. Once the fingers were cooled and formed, small-scale heat, moisture, or sound sensors could be attached to the wax finger to allow it to "feel". The finger sensors were wired to an Arduino microcontroller mini-circuit board—which was connected to a computer with pre-programmed code—that could read and translate the sensor data to create a "smart" prosthetic finger.

She modified this idea for the youth workshop described here, so that the fingers were 3D printed instead of being molded in wax. Creating a 3D printed finger would provide more transferable knowledge and skills about additive manufacturing than a wax finger. It would also eliminate the risk of using a hot and messy molding process. If the finger could be connected to a microcontroller and actuators—and demonstrate motion—the whole exercise would demonstrate a concrete application of rapid prototyping, robotics, and computer programming. The process would be simple enough to engage the participants, inspiring them to create customized and unique fingers in the 3D design and printing process. In short, it could allow the students to gain first-hand experience on how prototypes are created.

Early in the concept design stage, the plan was for the robotic hand to have a similar appearance to a human hand. Five fingers (including a thumb) would be connected to servos that were embedded in a hollow hand palm. This would allow each finger (excluding the thumb) to move independently of the others. However, given the complexity of designing and prototyping this object, the increase in the probability of failure, and limited time and resources, we determined that full dexterity was not a requirement. Although four fingers moving independently would be more interesting and versatile to have, they were not practical for the current workshop. Therefore, we decided that all of the fingers would be fitted onto a single rotatable bar, which would connect (via a gear) to a servo embedded inside the palm of the hand (Figure 1). The decision to limit the scope of the project by favoring simplicity over a more functional (yet complex) design provided a more straightforward mechanism, which was easier to model and produce (thus, saving us time during the workshop). In the end, the final product was both portable and easy to assemble.

Preparing the 3D Printed Robotic Hand
Initially, the team chose to build and assemble a pair of hands with 3D printed components. To provide the most realistic representation and the movement of the human hand, our design incorporated both electrical and mechanical components. Since there are many ranges of motion in a realistic human hand, we designed our robotic hand to only facilitate the flexion and extension of the digits to avoid excessive complexity. In the weeks leading up to the workshop, we iterated on the robotic hand design two times for a total of three completed prototype versions before we were satisfied with the outcome.

The design of the robotic hand was done in advance of the workshop and consisted of (1) the hollow hand palm base; (2) the servo motor container and stand; (3) the gears and gear bar; (4) the fingers and pegs; and (5) the thumb (see Figure 1). All the test components in the hand—other than the servo motor (i.e., the shell of the palm, the finger, the thumb, the supports, and mechanical parts)—were 3D printed.

To test and calibrate the hand's movement (i.e. flexion and extension), the servo motor was connected to a potentiometer, which allowed us to adjust its speed and identify a range of movement speeds that could be demonstrated at the workshop.

Two final hollow hand palms with pegged gear bars were 3D printed, and servo motors were installed prior to the workshop. This would make the final assembly with the fingers that were created by the youth participants quicker in the time allowed.

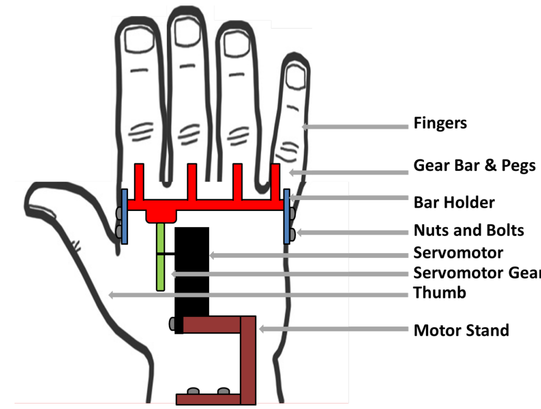

Figure 1: The moving mechanism of the 3D printed hand.

Workshop Description

The workshop was hosted by the Lassonde School of Engineering at York University. It received 70 youth participants from five participating high schools in the Greater Toronto Area (GTA). The students were in grades 10 and 11 (between 15 to 17 years of age) and were accompanied by their teachers. The workshop consisted of three independent modules that were taught sequentially in a computer lab with 24 workstations. The module lasted approximately 30–40 minutes. The participants were divided into teams for the modules. Each module had pre-assembled kits and USB jump drives with prepared support material for the teams.

Module 1: Introducing 3D Modelling and Printing
This module introduced the participants to 3D modeling and printing through computer graphics design. Firstly, the participants were given a presentation—which included a short video—on the concept of additive manufacturing. They were also introduced to the Thingiverse platform (Thingiverse.com) and the

Figure 2: Preparing 3D printers for printing the multiple fingers designed by the participants.

Meshmixer 3D computer graphics modeling program (Meshmixer.com). They were assisted by the instructor and student volunteers. Next, in teams of 3–4, the participants were given template model files on a USB jump drive for each of the five fingers. The finger templates included small holes in the bases of each finger so that the participants could fit the fingers onto the gear bar of the hollow palm. They had to load the models into Meshmixer and collaborate with one another to customize the fingers in a way that would include a team logo and additional stylistic changes (e.g., different colors), but still be small enough to be 3D printed within one hour for the final assembly. The teams then converted the computer graphics files to the STL (STereoLithography) format for 3D printing. At the end of Module 1, each team chose and submitted one of the fingers that they had designed to be 3D printed and assembled onto the robotic hand. The computer-designed finger models were transferred to an array of seven MakerBot 3D printers (see Figure 2) in a separate lab. Lastly, the 3D printing supervisors printed the fingers while the students moved on to the next module (after a short break).

Module 2: Introducing Robotics with Arduino and Servo Motors

For the robotics workshop module (see Figure 3), a short presentation was given to introduce participants to robotic motion. Teams of 2–3 participants were provided with kits, which contained a servo, Arduino, wires, and wire cutters to assemble. Various types of actuators were presented such as solenoids, linear actuators, DC motors, stepper motors, servo motors, muscle wire, and electro active polymers. The basic theory behind each technology was explained along with examples of real world applications.

An overview of the Arduino hardware was given, including an overview of its microprocessor specifications, hardware pins, and communications protocols, as well as, the details of interfacing with servo motors. The communications protocol to the servo motor was *pulse width modulation* (PWM), which is a method of specifying the desired angular position to the servo.

Each student team was then tasked with connecting the Arduinos to the computers, running the Arduino *integrated development environment* (IDE), modifying the sample code that was provided on the USB jump drives and uploading the code to the Arduinos. The participants were then asked to cut and strip wires for connecting the Arduinos to the servo motors. They were subsequently tasked with controlling the servo motors through a software interface.

Module 3: 3D Hand Robotic Build

Once all the models of their collaboratively created fingers were ready, we started to print them in view of the participants. For participant safety, we displayed the 3D printers in a room with glass windows through which the printing process could be observed.

Once the fingers were printed, they were installed on the life-sized hand base (see Figure 4). The 3D printed finger prototype included a small hole in the base of each finger to be able to fit the finger onto the pegged gear bar of the assembly. This feature required some customization to size of the hole so that the fingers could properly be assembled on the gear bar. As mentioned previously, the assembled hand was connected to Arduino microcontrollers and servo motors for finger actuation. Thus, the participants could see how their designs were combined as part of a concrete installation.

Figure 3: Youth teams experimenting with microcontrollers and servos motors.

Entrepreneurship Pitch Session

The successful robotic hand build was followed by a 30-minute lunch break, during which the participants could interact with the 3D printed hand (e.g., change the movement speed of the fingers, take pictures, etc.). After the break, the participants attended the final module of the workshop, which was a juried entrepreneurship pitch session (approximately one hour).

In this session, competing undergraduate engineering teams presented their innovative ideas and received feedback from a panel of judges. This format gave the youth participants exposure to how the tools and engineering skills that they had just experienced in the previous workshop modules could be utilized in an entrepreneurial context. They witnessed post-secondary students apply their training to develop their own creative business plans to solve real-world problems with real-world parameters.

This is particularly relevant for engineering capabilities, which usually function with inputs of resources and presentation skills in regulatory and multiple stakeholder contexts [17]. The youth participants could observe engineering students (who are their slightly older peers) present business plans and promote their ideas by using entrepreneurial concepts and techniques. The former had participated in the team group learning and collaboration experience, which simulated the use of similar team-based skills in entrepreneurship and multi-stakeholder production in engineering and science professions. Thus, they discovered how continued learning can contribute to the world and assist them in their own endeavors.

Figure 4: The 3D printed hand with customized movable fingers. Each finger was modified from a base model template by each participant team.

Lessons Learned

The experience of designing and conducting the workshops provided several observations and lessons that we will share in this section.

Value-Added Learning

One of our goals of the project was to create a self-directed learning experience for the participants that was special and distinct from other learning experiences (an approach that is sometimes used in internship programs) [1]. We viewed this opportunity as a one-time chance to make youths (and their teachers) interested and curious in the topics that we presented. We learned that providing basic parameters (such as finger templates, limiting printable size, color options, pre-loaded USB jump drives, and assembly kits) gave the participants creative freedom, helped them to make cooperative decisions, and offered the immediate satisfaction upon seeing their creations printed and combined with the work of their peers (an experience different from completing making activities on their own). The cascading activities in the modules created a sense of anticipation and excitement as their learning activities culminated in an assembled robotic hand. The self-directed—yet guided—workshop can create a positive and relaxing atmosphere, which will promote learning. We also extended the end use of the workshop by offering each participant a USB jump drive, which was pre-loaded with software, templates, and files that were used during the workshop. These USB jump drives would allow the participants to continue to learn and experiment on their own after the workshop ended.

Figure 5: After the workshop, participants interacted with their collaborative project, the 3D printed robotic hand, that was placed on a table (center).

Constrained Creativity

A collaborative creativity challenge for the participants was how to balance constraint and freedom in the 3D finger modeling task. We addressed this challenge by reflecting and discussing how a base 3D finger model could be tweaked within certain parameters. We also discussed how it could be augmented with different premade shapes and still be printable by the end of the workshop. In similar workshops, it is important to see the creative components as a balancing act between giving the participants agency while adhering to the technical and logistical constraints of the workshop.

Sharing of Ideas

An important dimension of the workshop—which can be relevant to other workshops—was to introduce the participants to the idea of knowledge sharing (a key Maker practice and aspect of student-centric learning). The hand model was a starting point for the design and participants also learned about Thingiverse. It encouraged participants to try out other models from the repository after the workshop, allowed them to experience firsthand how sharing ideas and designs can be beneficial to others, and simulated team-based professional practices.

Variations on a Theme

It was important for the participants to have similar experiences to one another, but, at the same time, be given a degree of freedom and agency. We achieved this by having the participants work in small groups on tasks that were similar (i.e., designing a finger); however, these tasks were also different in that they were impacted by dynamics of each team. At the end, combining a finger from each team in a functional prototype solidified the experience of a big team collaboration.

Moments of Celebration

We found it important to have moments of celebration in which the efforts of the participants paid off in tangible outcomes. Given the short amount of time for the workshop, it was necessary for the participants to have a rewarding emotional lesson to take home. The rapid prototyping of 3D printing the fingers allowed the students to watch their designs come to life. The creation and display of the mechanical robotic hand (which applied the robotic motions skills that they had just learned) at the end of the workshop (see Figure 5) served this purpose. This plan served as a "moment of celebration" [9] in which all the pieces of the puzzle came together (i.e., the 3D printed fingers and actuated hand were assembled and moved on command).

Learning Together

Finally, an important aspect of the workshop was that it exposed the participants to the underlying collaborative process of higher learning and professional practice. The project required experts from different fields to work together and—with the participants—to reach a final goal. Engineering and science disciplines are increasingly interdisciplinary. Thus, it is imperative that we present this aspect to young participants at the very outset. By the end of the day, the workshop was designed to emphasize that the participants and organizers were all learners, who benefited from collective collaborative expertise and achieved a specific goal.

Conclusion and Future Work

Maker approaches that promote collaborative project-driven learning and hands-on fabrication experiences are being recognized as effective ways to support youth engagement and interest in STEM topics. We described how we used a Maker approach in a multidisciplinary context to design an engaging group-learning experience for youth that introduced them to engineering and computer science topics in a university context. We believe that this approach has great potential for creating interest in higher education and collaborative work practices in youth. Many tools are emerging that make 3D modeling and printing easier to use and available to more users; we believe it is equally important to investigate what are the *processes* that can employ these technologies to motivate collaboration, engagement and creativity in users.

In future research, we aim to include youth participants themselves in the experience design process. Additionally, we plan to measure the impact of participation in these workshops on the knowledge and attitudes of participants towards engineering and entrepreneurship topics.

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References

1. Yvette Alex-Assensoh and Mary Ryan. 2008. Value-added learning. *Peer Review*, *10*(2/3), 34.
2. Chris Anderson. 2012. *Makers: The New Industrial Revolution*. Random House, New York, NY, USA, p. 20.
3. Paulo Blikstein. 2013. Digital fabrication and “making” in education: The democratization of invention. *FabLabs: Of machines, makers and inventors*, 1-21.
4. Erin Buehler, William Easley, Samantha McDonald, Niara Comrie, Amy Hursy. 2015. Inclusion and Education: 3D Printing for Integrated Classrooms. In *Proceedings of the SIGACCESS Conference on Computers & Accessibility,* ACM, New York, NY, USA, 281-290.
5. Clayton M. Christensen, Michael B. Horn, & Curtis W. Johnson. 2011. *Disrupting Class: How Disruptive Innovation Will Change the Way the World Learns*. McGraw Hill, New York, NY, USA, p. 101.
6. Christina Hobson Foster, Micah Lande, and Shawn S. Jordan, 2014. An ethos of sharing in the maker community. In *American Society for Engineering Education Conference. Indianapolis, IN. Jun,* 15-18.
7. Glen Bull, Hossein Haj-Hariri, Rosa Atkins, and Pam Moran. 2015. *3D Printing and Additive Manufacturing* 2, 2: 42-49.
8. Foad Hamidi, Karla Saenz, and Melanie Baljko. 2014. Sparkles of brilliance: incorporating cultural and social context in codesign of digital artworks. In *Proceedings of the 2014 conference on Interaction design and children*, ACM, New York, NY, USA, 77-84.
9. Cindy K. Harnett, Thomas R. Tretter, Stephanie B. Philipp. 2014. Hackerspaces and engineering education. In *Proceedings of the Frontiers in Education Conference* (FIE), IEEE Press, New York, NY, USA, 1–8.
10. Gillian R. Hayes. 2011. The relationship of action research to human-computer interaction. *ACM Transactions on Computer-Human Interaction (TOCHI)* 18, no. 3 (15).
11. Nathan Holbert. 2016. Bots for Tots: Building Inclusive Makerspaces by Leveraging "Ways of Knowing". In *Proceedings of the The 15th International Conference on Interaction Design and Children* (IDC '16). ACM, New York, NY, USA, 79-88.
12. Beth Kolko, Alexis Hope, Brook Sattler, Kate MacCorkle, and Behzod Sirjani. 2012. Hackademia: building functional rather than accredited engineers. In *Proceedings of the 12th Participatory Design Conference* (PDC '12), ACM, New York, NY, USA, 129-138.
13. Silvia Lindtner, Garnet D. Hertz, and Paul Dourish. 2014. Emerging sites of HCI innovation: hackerspaces, hardware startups & incubators. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14). ACM, New York, NY, USA, 439-448.
14. Selena Nemorin. 2015. A critical perspective on ‘Making’ in school: The implementation of 3D printing in high- school settings. In *Proceedings of Fablearn’15*. Stanford University: Palo Alto, CA.
15. Papavlasopoulou, Sofia, Michail N. Giannakos, and Letizia Jaccheri. 2017. Empirical studies on the Maker Movement, a promising approach to learning: A literature review. *Entertainment Computing* 18: 57-78.
16. Irene Posch and Geraldine Fitzpatrick. 2012. First steps in the FabLab: experiences engaging children. In *Proceedings of the 24th Australian Computer-Human Interaction Conference* (OzCHI '12). ACM, New York, NY, USA, 497-500.
17. Daniel Yergin. 2011. *The Quest: Energy, Security, and the Remaking of the Modern World.* Penguin Books, New York, NY, USA, p. 75.