An Undergraduate Engineering Service Learning Project Involving 3D-Printed Prosthetic Hands for Children

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ABSTRACT

This paper describes a service-learning project in our mechanical engineering program in which students 3D print and build prosthetic arms and hands for children in need within the community. Three engineering students worked with three faculty members to adapt 3D models currently available through the E-NABLE organization's website. The children involved typically have a limb missing either below the wrist or below the elbow. The 3D printed device provides a low cost prosthetic with functional fingers for gripping that are actuated by wrist or elbow movement. The educational goals were to provide learning opportunities in the areas of community engagement, project scope definition, advanced CAD modeling and design, 3D printing, and project management. The project also helps teach the students that as engineers, we should try to give back to the community using our skills. Project outcomes and perspectives from the children, students, and faculty are presented in this paper.

INTRODUCTION

Eastern Washington University is a regional, comprehensive university offering primarily undergraduate education, with some master's degrees and one applied doctorate. Our mechanical engineering program offers a BSME, with elective tracks in robotics & automation, thermal sciences, and materials. While most of our graduates plan to enter the local job market following graduation, an increasing number are going on to earn master's and PhD degrees. With no graduate degree in our ME program, service learning projects provide a good opportunity for both faculty and students to engage in scholarly work and service activities. These types of projects are particularly well-suited for our program, as our students are often very hands-on and enjoy working on practical solutions within their community.

The focus of this project is building 3D printed prosthetic hands and arms for children in need. The impetus was a one-off project in which a nearby elementary school teacher who, after seeing an article in The New York Times on 3D printed hands [1], reached out to our department in late 2017 seeking assistance in building a prosthetic for her 5th grade student, who was a congenital amputee, missing an arm just below the elbow. A 3D arm was printed from a model on the e-Nable website [2] and fitted to the student, who was more than thrilled. The new hand provided the ability to grasp with fingers by flexing the elbow joint. This allowed the child to hold small objects, such as a water bottle, fruit, a book, and even a basketball. With this success, and learning of this need in the community, the project was expanded with funds from a small grant to build ten more limbs for children in the area. This paper is a presentation of our work.

PROJECT NEED AND GOALS

Need – While prosthetics are commonplace today, a primary challenge is cost, which can be in the tens of thousands of dollars for a custom-fitted device. The cost for children is amplified by their growth, and hence need for a new device each year or so. 3D printed prosthetics are a relatively new idea with the benefits of being easily customizable and very inexpensive, at less than $40 in material.

Goals – This project fits well as a service learning project for our students, as it involves common aspects of mechanical engineering education, such as CAD modeling, design, and project management, while also filling an important need in the community. The goals for this project are two-fold:

1. <u>Engineering Design</u> – provide undergraduate mechanical engineering students an opportunity to gain real hands-on experience in 3D printing, advanced CAD modeling methods, and project management.

2. <u>Community Service</u> – provide a needed service to children in the community who otherwise would not have the resources to acquire a prosthetic arm.

SIMILAR PROJECTS

The popularity and ease of use of 3D printers today has made the generation of low cost prosthetics viable. While this application for 3D printing is relatively novel, two similar projects over the past few years were found.

Engineering students at Penn State used the same e-Nable CAD models for a class project in 2016 called Prosthetic Kids Hand Challenge (handchallenge.com). Throughout their Intro to Engineering Design course, students worked on designs, selecting materials and styles based on user needs, and then donated them to organizations for distribution [3].

Advancing the e-Nable technology further, Yagli and Hsieh [4] worked with a high school STEM group to modify the models in order to equip them with sensors and servo motors for muscle-controlled actuation. The goal for their project was proof-of-concept and also to present for STEM outreach activities. Their mechatronics design was from Talbot [5], who first developed a myoelectric prosthetic system using the Arduino microcontroller.

Our project is similar to Penn State's above, but with greater emphasis on extracurricular service learning rather than a course-wide student learning activity.

STAKEHOLDERS

The three stakeholders for this project are the clients (children in need), the engineering undergraduate students, and the faculty. Details for each are as follows:

Clients (community members) – Our intended clientele is school-aged children within the local community in need of prosthetics. This rationale was based on perceived need and opportunity and therefore formed the basis for our solicitation efforts. However, anyone in need of a prosthetic would be served. Demographics of our community are as follows: total metro area population of 500k, with roughly 87% White, 2% African American, 2% Native American, 2.5% Asian, and 5% Hispanic, and an overall poverty rate in the region of 20% [6].

Engineering Students – Three mechanical engineering students participated in this project. The faculty gave only small administrative support and structure, allowing students to organize and manage their project completely. Students met with faculty approximately weekly for small updates and feedback. The project duration spanned three academic trimesters – Fall, Winter, and Spring. The first trimester consisted of the typical engineering design processes – defining the problem, organizing the team, and generating CAD files. The second and third trimesters consisted of meeting with candidate children in need and fabricating their prosthetic devices. Grant funds provided a small stipend of $500 for each student (however, students were not made aware of this stipend prior to joining). The three students originally signed up for the project with the understanding that this was solely extracurricular. However, one student later opted to enroll in an Independent Studies course and was able to use the project for course credit, replacing a required technical elective. In terms of demographics, all three students were entering seniors, with one being female and the other two males.

Faculty – Three mechanical engineering faculty members served as mentors for the students. One mentor assisted in CAD and 3D printing, one assisted with the community outreach aspects, and one assisted with the administration of the grant. Faculty did not receive stipends and contributed roughly an hour a week towards the project.

PROJECT DETAILS

The main efforts for this project were the initial design following by community engagement. Following are details for these two major project phases.

Design Process

CAD Design and Modeling – Designing and modeling a 3D printed arm is a sizable project. The e-Nable organization has taken on this challenge and provides several options available freely on their website. All CAD files can be easily scaled to fit a particular child's arm (or adult) and then downloaded and printed. The interface is relatively easy and intuitive, and the designs have been tested and revised several times, resulting in a fairly robust process. Figure 1 below shows the measurement process for fitting a child.

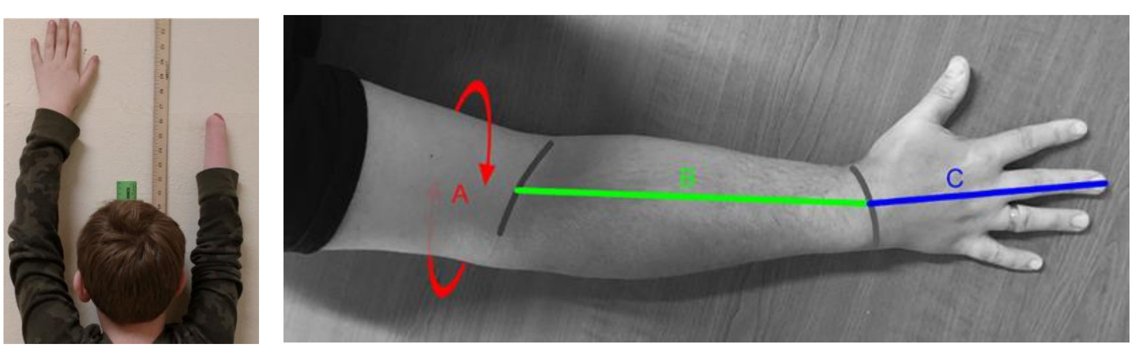

Figure 1. Measurement process for prosthetic fitting. Values A, B, and C from intact arm are used to scale CAD files

For this project, the students used the free e-Nable models as base model, and then built their own CAD models in SolidWorks using a top-down design approach, making the models easily scalable with a few input dimensions from the child; this was done only as an educational endeavor for the students' benefit, and in most cases the e-Nable files were used entirely. The modeling involved advanced techniques often not touched on in the basic CAD classes in an ME program, such as advanced lofting, design tables, and scaling. Figure 2 below gives images from the e-Nable site of three hand and arm options available.

Figure 2. 3D Printed prosthetic hands and arms (from e-Nable website)

3D Printing – A large Fusion 3D printer (Fig. 3) was purchased for this project with a bed size of approximately 14 inches wide x 14 inches deep x 12 inches in height, to accommodate the full size of the prosthetic arm. This allowed the large-size parts to be printed as a single piece, versus printing half parts and bonding together, as is done with a smaller printer. Students experimented with various materials (PLA, ABS, FLEX, PETG, and others), orientations, and settings (temperatures, speeds, feeds, etc.) for optimal strength, surface finish, manufacturability, and print time. Lessons learned included design for manufacturing, tolerancing, and the myriad of details involved in 3D printing.

Figure 3. Fusion3 F410 3D printer

Community Engagement

The goal for this project was to print ten prosthetic hands for children in the community. The students developed a plan to reach out to local school districts. They drafted and submitted all introduction letters and legal forms for university approval and emailed each of the school district superintendents in the area. The superintendents filtered the solicitations to their schools and teachers. Replies came back to the students, who then coordinated the introductory meetings at the schools with the teacher, child, and parent. At the meeting, the child’s measurements were taken along with other pertinent information, such as desired colors and potential issues. The students then produced the CAD files, printed the arm, and arranged for a second meeting to present and test the arm with the child. Some post processing on-site is needed to make the final fit. Students coordinated all aspects of the community engagement, with faculty providing input and assistance when requested.

RESULTS

Following the solicitation letters, we immediately received around fifteen replies expressing interest and requests for more information. Students then began coordinating interview meetings with clients and building the prosthetics. Currently we are in the midst of building devices for three clients, and the first child fitted is shown below with his new hand and arm. The project will continue over the 2018-1019 academic year until all hands are complete. And while our goal was set at ten hands for this initial project, we would complete all requests beyond this target as well from those expressing interest from our solicitation. Perspectives on the project from the Students and Clients are presented below.

Figure 4. First 3D printed arm fitted to child

Client Perspectives

By and large, recipients were excited to obtain the prosthetic, and particularly interested in being involved in the process. Their input was sought for color, special features they may want, straps, comfort issues, and any other “cool” ideas they may have. Children were especially interested in viewing the CAD models in SolidWorks of their future hand, asking lots of technical questions and showing genuine interest in STEM fields overall. One of our adult clients, a special education teacher herself, used the new hand to assist in riding her road bike, which allowed her to grasp the handlebar on both sides, for better control and balance. Although we are less than halfway through the project, feedback from these recipients and their guardians and/or teachers has been very positive and inspirational. A quote from one teacher regarding her student getting the arm:

> *“Isaiah was bouncing up and down today like Tigger…he’s so excited! I called his grandmother to let her know where we are in the process and his family is beyond grateful.”*

Student Perspective

While the e-Nable site provided all needed files, the students took it upon themselves to remodel the files for their own learning and experience. This gave them a lot of experience they would not have gained in the traditional CAD class. Similarly, in terms of project management, they gained experience in managing their time and resources, and also in being resourceful through challenging and new problems.

For this paper, the three students were asked to provide a small blurb on their perspectives of the project to their education in general, with prompts to be completely candid with no limitations. Below are their verbatim responses.

> Student #1:
>
> *As a non-traditional student with two children, this project touches close to home. Also, I believe students in their last year of college should be focusing on projects to assist in honing their skills and individuals should spend time bettering their community. So, when the opportunity presented itself to assist youth, I could not refuse. However, before diving in, I reflected on my availability and the perceived requirements this project would entail. As important as this project is, it deserves a fair bit of time, energy, and attention. The fact that I am a part of this paper, reveals my decision.*
>
> *This begs the question: If I were to go back, would I still agree to take on this project? The answer to that question is yes. However, there are things I wish I would have known before starting the project, some of which are specific to this project, and others that have been learning lessons I can take onto future projects.*
>
> *As a team, we spent the first quarter working out a plan to identify individuals, working on legal documents, and setting up and learning how to 3D print. We spent considerable time altering existing legal documents for our specific purpose and formulating a letter to send to our targeted audience. After submitting those documents to the universities legal department, we received a shell of our former documents. In retrospect, I would bring them in earlier in the hopes we would generate better documents for less work.*

The next largest struggle came from the 3D printer itself. None of our team had experience with 3D printing, but everyone possessed an eagerness and desire to learn the process. There is a wealth of knowledge on the internet in regard to 3D printing, and it is an exceptional technology. However, it is still a very new technology. Finding answers to specific problems takes experimentation and research, much more than I or either of my teammates could have fathomed before taking on the project. There is an element of artistic ability and experience required to obtain quality prints, engineers are not particularly known for these traits.

Outside of learning how to print and develop good prints, the printer itself developed mechanical issues. At this point in the project, our printer has been down 2 months out of the 5 months we have had it, for various reasons. The latest reason and probably the most significant was the manufacturer changed the nozzle material to a copper alloy that gains and loses heat quickly, without letting clients know. It took them months to find a solution to this problem and multiple emails and phone calls for them to finally resolve the issue with us.

Overall, there were delays in our project we expected, and multiple delays we did not expect. This is true to any engineering project, and good experience. Having a reliable group of individuals working on a project helps to mitigate issues and minimize delays. Engineering students taking on projects of this caliber should do so with a strong sense of their available time and the time expected to complete this project (expected and an estimated unexpected). The ability to remain flexible as the project progresses will also serve them well.

<u>Student #2:</u>

Since this project was based on open source files, there was no actual CAD work necessary; however, the team wanted to take that open source design and develop a newer version of that arm that could also provide a baseline for future teams to develop more complex 3D printable prosthetic arms here at EWU. The development of our Talon III arm, while still a work in progress, has resulted in massive gains to my CAD modeling skill. I am coming out of this project with a significantly greater understanding of the SolidWorks Lofts and Sweeps as well as Top Down Driven functionalities and how to leverage equations and Global Variables.

One thing that this project has highlighted for me is the importance of a solid Project Manager at the helm. I have also realized through this project that big part of being a manager is knowing your people, knowing their strengths and weaknesses and seeing how all those pieces fit together into a cohesive team. This requires a sense of the big picture and the steps to get there that I have not developed but plan to as my career develops. In my case, I was asked to join because of my previous experience with SolidWorks. Through this project my experience with CAD modeling has increased significantly and it happened because the Project Manager knew me, knew my skill set, and thought I would be a good fit for the team. I am very appreciative of the opportunity *and believed in the project enough to take on an additional $4,000 in student loans so that I could give this project the time and focus it needed.*

One of the things I saw in this project from the start was an opportunity to be involved with an outreach type project. Typically, I don't think of engineers as having much value in community outreach because I can't build a house or heal what's broken so my value is less than those who can. This project has helped me realize that an engineer can be valuable in outreach projects, the projects will just looks different. This has also opened a door for me into the prosthetic realm that I otherwise would not have explored. I hope going forward that as opportunities arise, I can take advantage of them to leverage my skills for the betterment of those around me.

Student #3:

For this project, most of our learning process has been through a trial-and-error process, both with the physical printing process as well as slicing models on the computer. Most of the time, it's small details that affect the quality of the print; misaligned bed leveling, a bad filament extrusion modifier, and printing at too low a temperature can compound into a poor-quality print that is unusable for our project. Virtually every time one of the prosthetic arm pieces are put through a slicer program, we would have to create custom supports as auto-generated supports tend to fill in areas that are small enough that supports aren't necessary or supports would be generated in areas that are inaccessible, effectively filling in the space. The way models are oriented in the slicing program is also important. Having a flat surface on the model you are printing is incredibly useful as odd, organic shapes being printed on supports results in a rough surface. My advice for those who are just starting out with 3D printing is to completely ignore the more specialist filaments and experiment purely with PLA filament. PLA should generally be the baseline for printing at first, being easy to print with relative to other filaments, heat moldable, and having a low enough melting temperature that any off-the-shelf 3D printer can accept it without modification. The benefits of being inexpensive relative to most other filaments allows for lots of experimentation with printing as every company creates their PLA with slightly different chemical makeups, so these tests are vital to dialing in the optimal print settings.

Faculty Perspective

Students were given less direction in this project than in a traditional lecture class or lab. Given this, it was impressive to see them take ownership in their project and learning, opting to do more than was necessary for their own understanding. The three students on the project completely managed themselves – setting roles and responsibilities, communication standards, and schedules for deliverables. The "pull" vs. "push" learning strategy [7] was evident as they were motivated to learn in order to solve immediate, real challenges, and hence "pulling" needed information/knowledge.

CONCLUSIONS

While this project is still ongoing, our experiences so far have been very positive. As a service-learning academic endeavor, the project gave students the opportunity to develop skills in areas they were interested in. All three students detailed significant learning, gained through open-ended challenges with limited assistance from faculty. Their eagerness to participate and go above the requirements was impressive, particularly considering it was their senior year with lots of demands from other classes and projects. After completion, we will assess whether there is sufficient need and opportunity in the community for continuing the project.

ACKNOWLEDGEMENTS

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