Adjustable Platform for Exploring Soft Robotic Gripper Design

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Abstract - **The growing importance of STEM careers and the imbalance of the demographics of people who pursue them have resulted in a myriad of outreach activities and platforms to expose students to key concepts in fun and interactive ways. Robotics is one of the primary themes of these outreach activities due to the combination of disciplines (e.g., mechanical and electrical engineering, computer science). Specifically, soft robotics, an emerging field, has become a popular topic as it is outside the expectations and experiences of most students, making it more universally accessible. In this work, we present a tendon-driven, soft-robotic gripper platform with multiple adjustable design features in order to emphasize the iterative nature of design. Students can choose the number of fingers, their distance apart, and their length and number of joints. After designing and molding the fingers themselves, threading the tendon and installing them on the base, they have the opportunity to test and iterate their design. Eleven high school girls and their teachers participated in a pilot activity, filling out a survey on the design of the platform. The surveys indicated the students found the activity a fun, interesting, and valuable learning experience, one they would recommend to their friends.**

Index Terms - K-12 Engineering Education, Soft Robotics, Engineering Design, Project-Based Learning.

INTRODUCTION

The careers that students choose are correlated in part with interest in related topics at a younger age [1]. When comparing bioengineering and computer science, the associations students have with careers can influence their choice based on what is important, such as whether they would be helping people and interacting with others or building new skills [2]. Many of the existing outreach and robotics K-12 events center around LEGO and robotics competitions, utilizing traditional rigid building strategies often thought of as encompassing robotics [3,4]. These platforms succeed in creating project-based learning with introductions to many prominent areas in STEM, including mechanical and electrical engineering, and computer science [4,5], and emphasizing the engineering design process [6].

Other methods have been used to draw in a larger diversity of students, such as partnering computer science and art students to create unique art installations in their Artbotics course [7]. Incorporating robotics applications in unique environments with emerging technologies has also been effective, such as with underwater robotics projects [8].

Soft robotics is another subfield of robotics that has shown successful outcomes in shifting student interest. When utilized as a supplement to LEGO and other rigid platforms, soft robotics has shown unique and valuable outcomes [9]. In one program designing and fabricating pneumatic soft grippers, female students saw improvements in their self-efficacy scores and identification as tinkerers [10]. In another with elementary students, they were asked to draw a picture of a robot before and after a soft gripper design activity that included brainstorming grippers in the natural world such as in elephants, opossums, and octopi. The pre-test showed traditional boxy humanoid robots, however the post-test showed a larger variety of forms, some with themselves building the robots [11]. Soft robotics is an emerging subfield that undermines student expectations and is able to appeal to a larger audience.

STUDENT ENGAGEMENT

The objective of this work is to continue supporting student exposure to the area of soft robotics while emphasizing tinkering in the form of iterative design in the engineering design process. The objectives are met in this work through a detailed layout of the design aspects of a new adjustable gripper platform for K-12 STEM outreach, and pilot feedback on its design and implementation for high school students. The activity is also designed to allow for the introduction of programming to control the gripper, although that was not utilized in the activity reported here.

The gripper activity is introduced to the students in the context of the engineering design process, with the platform designed to emphasize the cyclical nature of design. In our event we began with a presentation and demos of robotic grippers to explore the engineering design space of robotic grippers, soft-robotic solutions, and educational platforms. Then we highlighted the design process for two parts in the kit, with an initial design, fabrication, testing, and redesign cycle. After laying the groundwork, we present them with the last design piece of the gripper, the fingers, for them to design, mold, test, and iterate as needed.

There are several adjustable features throughout the gripper platform to allow the students to make their own design decisions and explore the gripper's capabilities in different configurations. Due to the quick connects of the molds and short cure times of the silicone, students can quickly iterate on their designs during and after testing.

HARDWARE PLATFORM

I. System Overview

FIGURE I
THE GRIPPER KIT (LEFT) CONSISTS OF A PRE-ASSEMBLED BASE AND SUPPLIES TO MOLD AND ATTACH THE SOFT-ROBOTIC FINGERS, RESULTING IN THE FINAL GRIPPER (RIGHT).

The robotic gripper platform provides students with the ability to test and rework many design features. The kit and final gripper are shown in Figure I. Student engagement with the platform consists of two main parts, first, the design and construction of the soft fingers, and second, their installation on the base and testing. These parts will be described in Sections II and III, but here will we describe the functionality and construction of gripper as a whole.

First, the gripper consists of a rigid base and soft, silicone fingers with a tendon-driven transmission. The base is adjustable to allow a two to four fingered gripper at an adjustable distance apart. The fingers length and number of joints are to the discretion of the students.

Second, the base design utilizes LEGO robotic resources and custom parts fabricated on a Fusion3 3D printer and Glowforge laser cutter. The LEGO robotic products consist of the motors, motor axles, connecting wires, and control bricks. Those used in this work are the EV3 models, however we have parts for the NXT models as well. Utilizing the LEGO platform minimizes costs for classrooms that already have access to them, and provides an additional hardware tool to complement previous student experience with the LEGO platform. Laser cut acrylic was used wherever possible in order to increase production speeds for large classrooms. All current CAD files and a bill of materials can be requested by contacting the authors.

II. Soft-Robotic Gripper Finger Construction

The fabrication of the robotic fingers can be broken down into three major steps: molding the finger, cleaning the fingers of excess material, and installing the tendon.

First, the students receive mold pieces to snap together to create their finger designs (Figure II). Mold segments consist of a base pieces, fingertips, joint segments, and solid segments. Students determine how long their finger should be and the number and location of the joints. To allow for the tendon to be inserted, students put a piece of soft Tygon PVC tubing, outer diameter 4mm, to fit from one of the holes in the base mold, through each of the joint pieces, turning around after the furthest joint back the other side to the base. Then the students mix the silicone according to the manufacturer's directions. This project used Mold Star 31T due to its high shore value and short cure time. The molds nest together nicely, but still can leak. This is not a problem in the functionality of the fingers as the excess is easy to remove after it cures. Placing the molds on thick cardstock catches any leaked silicone and also provides as a means of carrying the molds to a place to dry. For faster cure times, the fingers can be placed under a heat lamp or in an empty 3D printer with the bed heated to 50°C.

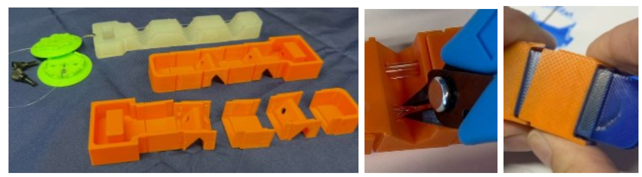

FIGURE II
THE FINGER DESIGNS ARE CREATED WITH MODULAR MOLDS TO ADJUST THE LENGTH OF THE FINGER AND THE NUMBER AND LOCATION OF THE JOINTS. THE TENDON IS CRIMPED AT THE BASE OF THE FINGER AND ON THE END TO ATTACH IT TO THE SPOOL (LEFT). AFTER CURING, THE TUBING SHOULD BE CUT BEHIND THE JOINTS (CENTER) AND THE MOLD REMOVED (RIGHT).

After the fingers are cured, the PVC tubing is cut on the back of the joints and the molds are gently removed (Figure II). Wire cutters or scissors can be used to cut the tubing flush with the surface of the finger and remove excess.

Finally, students cut a piece of fishing line and thread it through the finger. WD-40 or another lubricant can be used to ensure the line is threaded easily. Wire stops are use to crimp the two sides of the fishing line together just past the base piece, where one end is trimmed and the other is terminated with another wire stop about six inches further.

III. Base Installation

The gripper base consists of two laser cut plates attached with 6-inch, metal stand-offs. The base has two adjustable features for students to adapt to their design needs and explorative preferences. First, the bottom plate has tabs to connect to the motor mounts in six possible locations (Figure III), providing the ability to adjust the number of fingers in the gripper and to power and control each finger of the gripper independently. The placements of the motors are at 0° and 180° for a two-fingers gripper, with additional positions at 90° and 270° for a four-fingered gripper, or alternatively using positions at 120° and 240° for a three-fingered configuration.

Second, the motor mount locations correspond with the six slots on the top plates, which span from the center to the edge of the plate. The slots serve as the connection point for the finger mount, allowing the finger spacing to be adjusted radially based on the size of the object grasped, as shown in Figure III. Secondarily, the slots also provide the tendon routing from the fingers to the motor spools below.

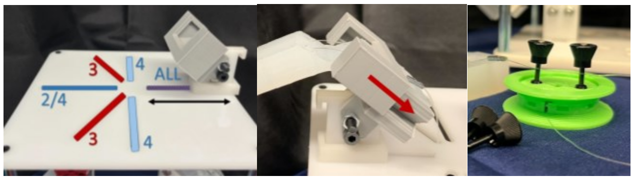

FIGURE III
THE BASE DESIGN IS CONFIGURABLE FOR A TWO, THREE, OR FOUR FINGER GRIPPER, WITH AN ADJUSTABLE DISTANCE BETWEEN THEM (LEFT). THE FINGER (CENTER) AND SPOOL (RIGHT) INSTALLATION USE A QUICK CONNECT.

To install the completed soft fingers, custom 3D printed parts, designed with quick connections in mind, are used as shown in Figure III. The finger adapters slide easily along the top plate slots and are tightened with wing nuts, providing a generic mount for other finger material designs in the future. The finger mount adapters consist of a bottom piece to connect to the finger adapters and provide a seat for the base of the molded fingers. The top piece slides over into slots in the bottom piece for a fastener-free installation to keep the fingers securely in place. The tendon is fed through the slot and connected to the motor spools. The motor spools have two pieces to embed the crimp at the end of the tendon so it does not slip out. Nesting teeth prevent the tendon from slipping between the two sides, and snaps connect the two sides quickly and easily. The gripper is now complete and ready to test.

FEEDBACK SUMMARY

A survey was used to collect student feedback on both the gripper design and the activity as a whole, outlined in Table I. Eleven high school girls and four teachers visited the NERVE Center to learn more about robotics and take part in our activity creating a two-fingered gripper. For the testing phase, the students were split into pairs and given the opportunity to revise their design and mold second set of fingers. Afterward we received fourteen surveys back on their perception of the platform and the activity as a whole for product improvement. They were asked to rate questions 1 to 7 on a ten-point scale, where 1 is low and 10 is high, followed by questions 8 to 11 with short answers.

Survey results are summarized in Table I and Figure IV. The students rated a high level of enjoyment (q1) and the likeliness they would recommend the activity to a friend (q2). The use of the gripper platform as a learning tool was also rated highly (q3), as was the overall activity as a learning experience (q4). Responses on what surprised them (q8) or what we did well (q10) highlighted that the activity was “interesting and fun,” they “like it,” and “learned a lot.” Two respondents said we did everything well. When asked what we could improve (q11), they highlighted using Arduino rather than LEGO, and editing the finger base mold to avoid tears when removing it from the mold.

The difficulty of the overall activity was moderate and more distributed (q5). Separating out the finger construction (q6) and utilization of the base (q7), the finger construction

TABLE I
SURVEY QUESTION AND RATING SUMMARY

No.	Question	Mean Score (Std. Dev.)
1	How would you rate your enjoyment of today’s activity?	8.8 (1.1)
2	How likely are you to recommend this activity to a friend or classmate?	8.5 (1.6)
3	How would you rate the robotic gripper platform as a learning tool?	9.3 (0.8)
4	How would you rate today’s activity as a learning experience?	9.2 (1.2)
5	How would you rate the difficulty of today’s activity?	3.5 (1.4)
6	How would you rate the difficulty of making the fingers?	2.4 (0.9)
7	How would you rate the difficulty of using the base?	4.1 (2.2)
8	What surprised you about today’s activity?	NA
9	What did you think of the second session to iterate your design?	NA
10	What did we do well?	NA
11	What could we improve?	NA

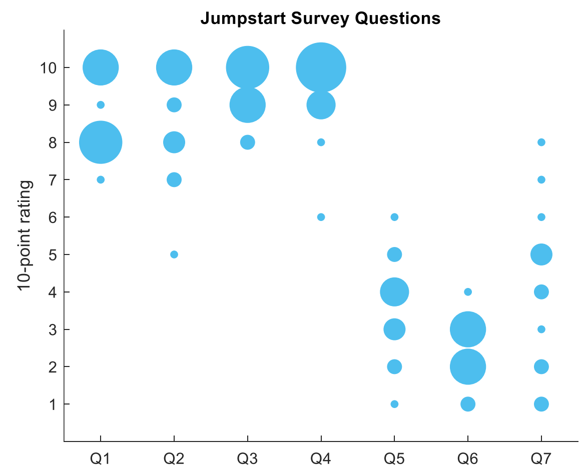

FIGURE IV
SURVEY RESULTS. THE SIZE OF THE DATA MARKERS ARE SCALED TO REPRESENT THE NUMBER OF SURVEYS PROVIDING EACH RATING.

had low difficulty and the use of the base was more moderate and distributed. When asked what surprised them about the activity (q8), many of their comments centered around these two topics. For feedback on the finger construction, several respondents were surprised how easy it was to make the silicone fingers, the molding process surprised them and was “amazing.” Respondents also mentioned the joints, using the tendons, and the surprising strength of the fingers. We initially gave them foam cubes to grasp, however they quickly expanded to picking up metal tools and the cans of WD-40. As for the base design, this activity was limited to two-finger designs due to the number of EV3 kits. One noted aspect was calibrating the spools to be equally as taut, described as not difficult but not as easy as expected. For the challenge point there was conflicting feedback. One respondent said the activity was “a little challenging but still fun.” Another said it was “easier than expected” and they wished “it was more difficult.”

When asked about the second session to iterate (q9), there were fairly positive reviews. An important note, although students were given time to mold a new finger, no one opted to. This could be due to the students molding two different designs in the beginning, and then pairing for the testing phase and having four fingers to test. Instead, as a group we discussed grippers from different groups and talked through design decisions. In the feedback forms, respondents thought it "was a fun way of getting into robotics" and appreciated the opportunity "to keep trying even if it didn't work the first time," and it "was helpful to think about what to change." One respondent wished there was more time to test and iterate.

DISCUSSION AND FUTURE WORK

The goal of this project was to create a robotic gripper platform to highlight exploration and iterative aspects in the engineering design process and expose students to the emerging field of soft robotics. The platform provides flexibility and design choices to allow students to adjust their gripper for their desired task, grasping objects of varying sizes and forms. From initial design feedback the platform was well received as a valuable and fun learning platform. However, the difficulty scores should be taken under consideration. The difficulty scores are distributed, and not very high. We value challenging our students in thinking through problems and understanding new concepts in project-based learning, and expect some distribution. However, that is so long as that difficulty stems from the goals and concepts of the activity and not the assembly and use of the gripper. Further investigation is required to pinpoint necessary design changes, such as the mentioned mold design on the finger base.

Two other specific areas of expansion mentioned were calibrating the spool tightening and replacing the LEGO electronics with an Arduino-based platform. This introduces a specific area of future work, the programming methods. Our goal is to create a block programming and Arduino based activity to utilize this platform in ways accessible to middle school to high school range. An Arduino based system is already underway, in an effort to make a platform adaptable to those schools with electronics components as well as offer a cheaper alternative for those that do not already have LEGO robotics sets available to them.

In addition to additions to the hardware and curriculum, our future work will include educational, self-efficacy, and STEM identification assessments. We hope to end with a platform adjustable to the needs and resources of a variety of classrooms, which can include interesting fun activities for middle to high school students, involving exploration in mechanical design, electrical implementation, programming, and how these areas influence each other. Through the use of an adjustable robotic gripper platform, we hope to create a learning environment for a variety of learners and the needs of educators, to enable them to explore the integrated design space of robotics.

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