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Pre-College Robotics: Best Practices for Adapting Research to Outreach

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Abstract

Adapting research for K-12 outreach is critical for inspiring the next generation of engineers. Community-focused STEM fairs and events attract a wide range of students with varying degrees of knowledge and exposure to engineering. The challenge when creating programming for these events is the ability to adapt research for young students with a wide range of engineering backgrounds. Adding to the complexity, engineers are not trained teachers, therefore outreach events can often contain overly complex activities that do not take a student's dexterity or comprehension skills into consideration. Understanding students' abilities and interests are critical to developing pre-college curricula that are engaging for a variety of students. In this project, we present findings from an observational study conducted at a community-focused outreach event with over 200 participants. This paper is focused on a soft robot gripper activity consisting of two tendon-actuated fingers and its utility as an outreach tool. In the activity, students must navigate various tests of dexterity and comprehension. Observations from these tests were used to record successes and pain points of the activity design. The data collected during the activity was organized into several categories based on age, dexterity, and spatial awareness. After collecting and analyzing data, we identified areas of improvement for wide dissemination of this soft gripper activity. We also categorized prior activities that lead to a successful gripper build. Overall results showed areas where the soft robotics activity could be improved to be more inclusive of a variety of skill and age levels.

Introduction

According to the National Center for Education Statistics, over 400,000 bachelor's degrees are awarded annually [1]. The percentage of STEM bachelor's degrees awarded to female students is 37.4% compared to their male counterparts, who constitute 62.6% of students earning degrees. Furthermore, only 6.5% of these degrees were awarded to Black students, and 12.3% were awarded to Hispanic students. An increase in citations and publications citing the term "STEM Outreach" (Figure 1) is evidence of interest in outreach within academia. As outreach programs are further developed for the purpose of early engagement for students from groups underrepresented in engineering, it is important for researchers to understand how to adapt research to outreach for students to create positive learning experiences.

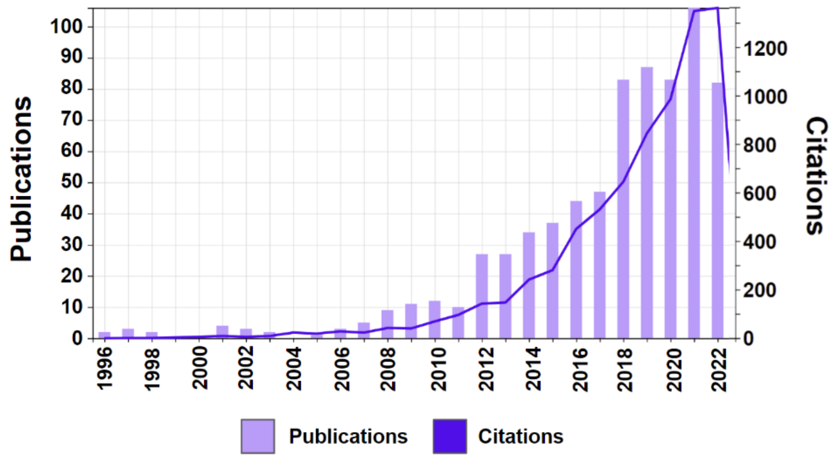

Figure 1. Results from a Web of Science citation report using the search term "STEM outreach" [2].

Despite efforts to recruit more underrepresented students to engineering, overly difficult engineering tasks and courses can serve as a barrier to recruiting students to the engineering workforce. Research shows that negative STEM experiences such as "weed out" courses, or courses that are purposefully difficult, cause low STEM persistence in first-generation college students [3]. A separate study on outreach events geared towards female elementary school students stated that decreases in STEM self-efficacy occur around young elementary age [4]. To mitigate negative experiences, there is a need to focus on creating positive STEM experiences which can increase student engagement and increase the likelihood of persistence in STEM for students starting at a very young age.

Soft robotics has been seen as an emerging field for engaging young students in STEM activities [5 -7] The new, soft materials [8] and open-source designs make it an accessible field to young children [9]. Additionally, recent work has highlighted the opportunities for soft robotics to attract a diversity of students to participate [9,10]. During development of an educational soft robotics toolkit, we sought to understand how young children interact with soft robotics activities. To create a positive STEM experience for pre-college students, this project explores the effect of dexterity and prior student experience on the successful completion of the gripper activity.

Previously, a Nine-hole Peg Test was used to measure children's dexterity [11]. In this evaluation, researchers observed participants as they picked pegs from a container and placed them into holes on the board as quickly as possible. Cognitive abilities can be tested by placing one peg at a time, remembering to use only one hand, and using reasoning to complete the task in the shortest amount of time. In this study, age was inversely correlated with time spent, indicating an increase in dexterity with age [11]. With this in mind, the goal of this work is to understand how a gap in dexterity by age, experience, and focus constitutes success in the context of a soft robotics activity. These observations will be used to mitigate ineffective outreach efforts by answering the following research questions:

1. What are the main bottlenecks to a successful soft robotics outreach activity?
2. How does user age affect the design of a soft robot build?
3. For students who successfully and independently complete the soft robot build, what factors contribute to their success?

To answer these research questions, we piloted an observation protocol to evaluate the success of our outreach program.

Robotics Fair & Project Decision Philosophy

Community-based outreach events serve as an accessible, low-cost opportunity for researchers to promote an interest in STEM. This paper focuses on "Robot Day", a community-based outreach event. The event is composed of engineering societies across the campus as well as local organizations to showcase engineering and robotics to over 200 pre-college students and community members. Over fifteen exhibits related to robotics are hosted by research labs, student organizations, and competition teams. The event is hosted twice per year in Fall and Spring. Toward developing accessible robotics platforms, a soft robot gripper activity was used to demonstrate soft robots to visitors during a 5–10-minute visit. The objective was to monitor how students interacted with the gripper activity to understand how to design a successful STEM outreach program that will create a positive outreach experience for students.

The event was designed with an open table format; therefore, it was necessary for the activity to be robust in large groups but also complex enough to observe design features that lead to a successful STEM experience. As a result, this introductory soft-robotics activity was chosen because of its readily available parts and simple but diverse build process. The Shape Deposition Manufacturing (SDM) finger activity [12] provides the necessary challenges to evaluate student engagement across a wide age range. This activity has previously been demonstrated with students as young as elementary school age [9]. The activity involves the use of tasks that require a student's dexterity and awareness. By building a gripping device, the students' fine motor skills (threading string, zip-tying actuators), cognitive abilities (handling of material and gripper), and reasoning skills (using visual sense to assemble the build) can be engaged.

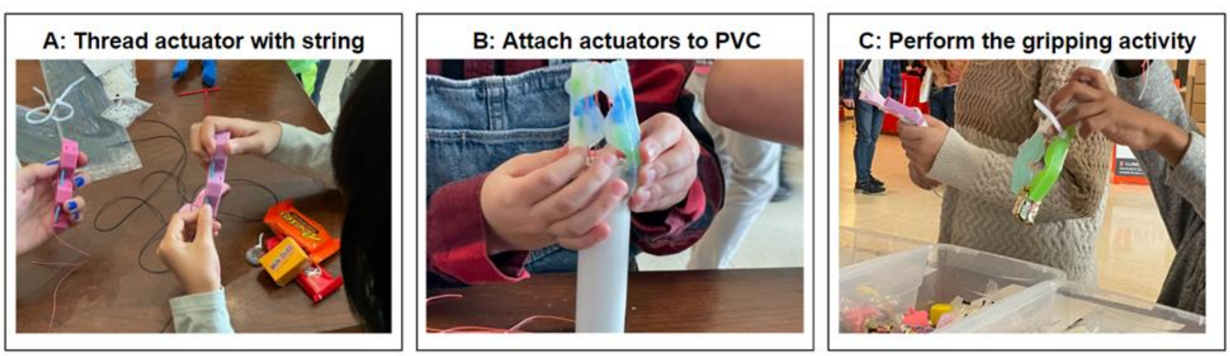

Figure 2. (A) Student sewing string through silicone finger with a plastic needle. (B) Student attaching actuators to PVC pipes with zip ties. (C) Students use a gripper to pick a prize.

The activity starts with students carefully sewing a plastic needle through holes on the SDM finger (Figure 2A). Next students moved on to attaching the fingers to a PVC pipe securing the assembly with a zip tie (Figure 2B). After the students finished assembling the gripper, they were offered a prize in a box of snacks and toys to pick up with their new gripper (Figure 2C). This served as another opportunity to observe the use of the gripper assembly because different gripping styles can be used for object picking.

The activity was observed at two events. The events are described below:

- *Event 1*: The event was held in Fall. It was held on a Saturday in the early evening. It was advertised to schools and families in the surrounding area. The activity was the SDM gripper activity. Volunteers equipped with hand tools to help the students.
- *Event 2*: Held in Winter 2023. The event was once again held on Saturday early evening and advertised to the same audience. The main activity was the SDM gripper activity. At this event we also piloted a second activity, a paper-based scissor lift build, to compare our toolkit observation protocol with a new activity.

Observation Protocol

The research team utilized the AEIOU Observational framework as previously implemented [8] (See Table 1).

Table 1. AEIOU Observational Framework

Activities	Environment	Interactions	Objects	Users
-Threading the needle -Maneuvering strings through PVC -Zip-tying -Gripping prizes with SDM gripper	-Indoors -Varying levels of crowdedness -Standing by tables to work	-Staff welcomes students and explains the activity. Start them off with materials they need -Problem-solve any challenges - Students can communicate with anyone if they need help - Volunteers describing soft robotics and engineering	-String -Plastic needle -Silicone actuators -PVC pipe -Zip-tie -Prizes	- Children in grades K-3 - Children in grades 4-6 - Children in grades 7-8 - College-aged volunteers

During the events, students visited the table in sporadic intervals over a three-hour time period. Data collection was done through observation, not intended for generalizable results, but to evaluate the soft robotic activity. One research team member was tasked with exclusively observing visitors, features of the toolkit, and roadblocks visitors face with the activity. College-age volunteers assisted students by guiding them. Guidance included directions on what materials to pick up, a demonstration of the gripper, and general assistance if students struggled.

Data Collection

At Event 1, the research team member in the observer role took notes on a tablet as community members visited the booth. The grade ranges for data collection were K-3, 4-6, and middle school (7-8). During observations, it was noted if visitors were in a group, if they worked on their own, or if they received caregiver help. There were four tiers of toolkit success which included none, low, medium, and high. Definitions of user interaction were developed around the activity steps, such as the threading of the SDM finger with a string which was the biggest "pain point" of the activity. Table 2 describes the observation categories based on the gripper activity.

Table 2. Pilot Gripper Kit Observation Protocol for Independence, used at Event 1.

Ease of Use rating	Description
None	• Students did not participate in the activity. A parent or guardian completed the gripper activity.
Low	• Threading was overly difficult and not completed. • The student required assistance from members/parents.
Medium	• About half of the actuator could be threaded by the student. • Friction between thread and silicone or size of needle/through hole created difficulties.
High	• Toolkit was easily completed. Threading was completed. • Visitors employed problem solving to complete the activity on their own.

At the second event (Event 2) of the year, we created a numerical scoring system with detailed descriptions of each level. This improvement allowed for collecting data on outlier visitors by allowing the observer to interview caretakers on what they thought contributed to the student's success. The change was motivated by the fact that the medium rating was too broad and needed to be elaborated on further to bring out more distinction between the participants' skills.

Table 3. Refined Observation Protocol, used at Event 2.

Ease of Use rating	Description
1	• Activity not completed
2	• Visitor holds silicone finger while caretaker guides them • Student follows the lead of the adult in completing the activity
3	• Visitor attempts to thread the first through hole but fails • Struggles to place string through PVC pipe
4	• Can thread the first hole, but not the second • Needed help zip tying • Can maneuver through the activity with basic understanding and setup

5	• Can string through most the holes, but gets stuck eventually on the roundabout or the second SDM finger • Usually, student uses brute force
6	• Can attempt thread most an SDM finger with a non-brute force method • Usually gets stuck on towards the end • Active in getting others to help them hold the PVC as they thread
7	• Can thread both SDM fingers with few question or little struggle • Actively rotating parts to make threading or stringing easier • Can place string through the PVC with little to no help
8	• Can thread both SDM fingers and uses different techniques to thread • Usually, quick to finish activity
9	Outliers: Very young visitors who complete the task with ease.

Results

Event 1

Grade K-3 students made up 52.6% of the total participants. Grade 4-6 grade students composed of 35.1% of the total. Middle school students compose around 12.3% of total visitors (Figure 3).

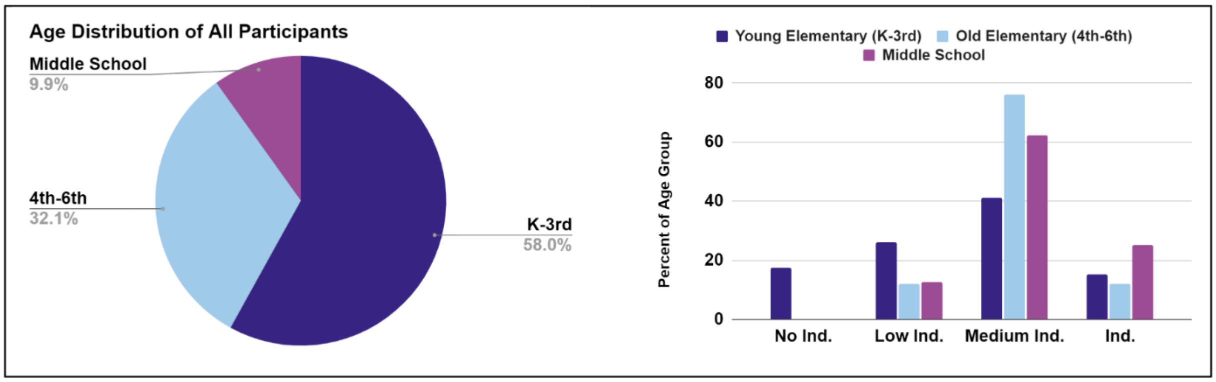

Figure 3. Age Distribution of Participants and Independence Rankings Following Table 2 Protocol.

Compared to their older counterparts, K-3 students received more help from their caregivers to complete the task. About 53% of the students in K-3 group attempted the task until they threaded one finger segment. Students in this group understood the zip-tying process but needed an extra hand to hold the PVC tubes and had average grabbing skills in the prize challenge.

In Grade 4-6 students, almost 85% achieved user level 5 (Table 2). Students in this age range knew to rotate the silicone SDM finger to reach the needle. 71.4% of middle school students were able to achieve user level 5 (Table 2). The notable thing about this group is that they were comfortable with manipulating objects. They were not afraid to rotate and try different angles of approach during the threading exercise.

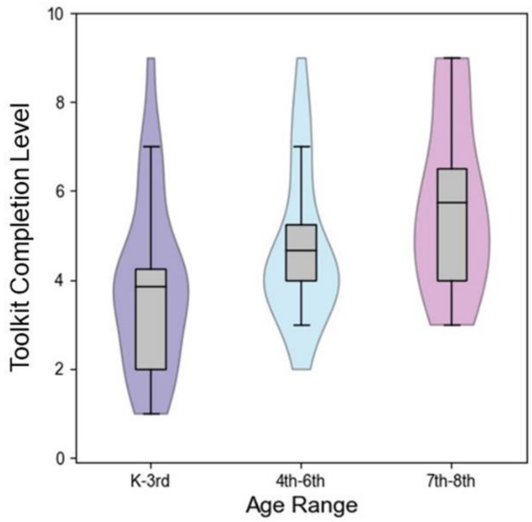

Figure 4: Events 1 & 2 Box Charts of Gripper Toolkit Completion Level Distribution by participant age. As students age, there is an increase in the overall mean dexterity and therefore interaction, with the majority of scores falling within the interquartile range.

Outliers

After analyzing the data, it was concluded that the outliers consisted of a small percentage of their respective age groups. Approximately 3.6% and 3.1% of the Young and Old Elementary groups were placed in this category and about 16.7% of the Middle Schoolers were an outlier, when compared to the whole group. Since these outlier individuals were quite distinctive from their peers in completing the task, caregivers were interviewed to ask what other activities these students engaged in. The parents of the outliers were asked what they thought contributed to the success of the student, and most parents of outliers attributed their success to various activities or hobbies. A summary of their reported activities is reported in Table 4.

Table 4. Outside Experiences of Outliers

Outlier participant age	**Extracurricular experiences**
Young Elementary (K-3rd)	Spends time in dad's shop and enjoys playing with legos, magnetic circuits, etc.
Young Elementary (K-3rd)	Regularly participates in beadwork.
Young Elementary (K-3rd)	Sews with their mother at home.
Old Elementary (4th-6th)	Has done a similar activity and enjoys playing with Legos.
Old Elementary (4th-6th)	Enjoys playing with 3D pens and circuit design toys as well as carving.
Middle School	Helps mechanic Dad at work regularly.

Visitors who regularly participate in beadwork had an easier time tying knots and stringing needles. The student that participated in sewing was able to thread the fingers easily compared to their older counterparts. In general, students who participated in engineering-related activities were familiar with similar activities and therefore had an easier time accomplishing the activity.

Observations of an Alternative Activity

During Event 2, a second, alternative activity was hosted in which the participants gathered to create a scissor lift shown in the figure below (Figure 5). In this activity, participants were instructed to cross-connect a series of arms together with paper fasteners to create this multi-linkage part. Like the other silicone gripper activity, a group of volunteers gathered to lead the activity as well as observe the levels of interaction with the activity. In comparison to the silicone gripper activity, this activity required less dexterity by the students, but required more mental problem solving. Despite this difference, more students were able to complete and produce a functioning scissor lift than in the previous activity. With these results, it was concluded that student dexterity may be a limiting factor in successful robotics outreach activities. When comparing the data, we were able to determine their overall levels of independence and observe how different age groups were able to complete the task they were assigned. Since dexterity did not play a large role in this activity, it was highlighted that complex activities could be accomplished if dexterity is considered. Outlier participants helped illustrate the disparity in dexterity between participants and further investigation of their habits may prove beneficial in understanding how activities should be designed.

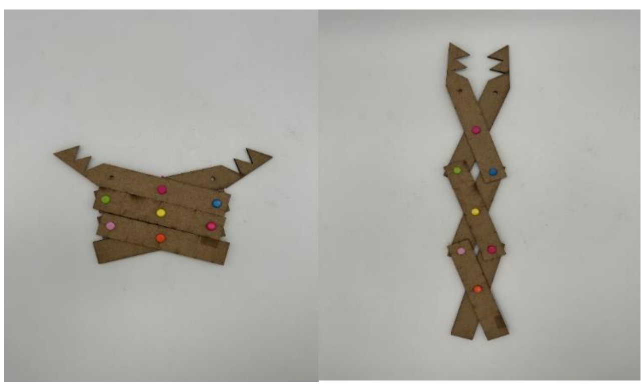

Figure 5. Alternative Scissor Lift Activity.

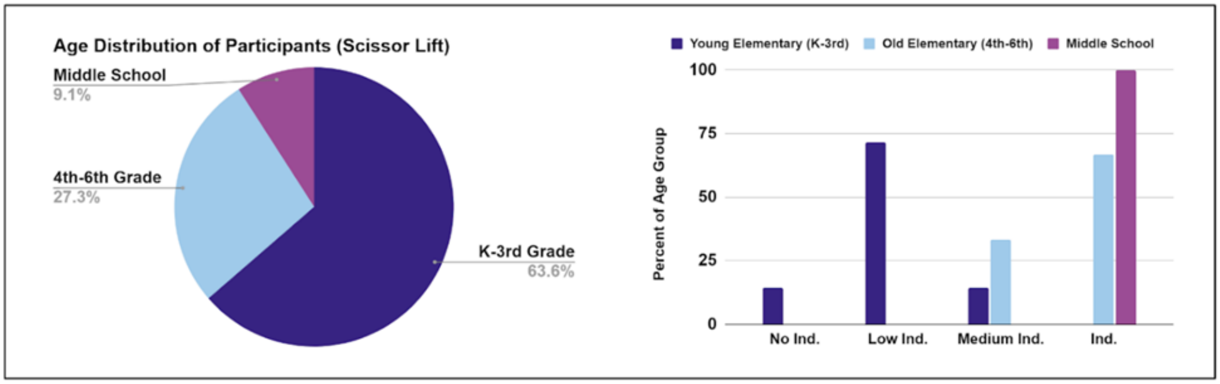

Figure 6. Age distribution and toolkit completion rankings during the Scissor Lift Activity.

Figure 7. Volunteer and Participant Interaction During the Soft Robotics Activity.

Conclusion & Recommendation for Further Study

This type of community based-event draws a very young group of children (58% K-3). For very young students to complete the activity independently, some modifications were necessary. The threading task proved to be the most difficult part of the activity as the small holes required students to use greater force for threading. To eliminate this bottleneck, we plan to create larger threading holes for the students. Additionally, a rig or clip to provide students with an extra "set of hands" may help with the zip-tying step where participants were often seeking a helper. If this activity were to be implemented for educational purposes, mitigating these bottlenecks would allow for more engagement, fewer points of possible frustration, and increased independence. In this setting, college-age students were always available to help, but in an at-home, toy setting or a large classroom, this one-on-one help may not be available.

Based on the data comparing completion levels across age groups, a general trend of increasing dexterity with age was observed as previously and widely reported in literature. Understanding how age range affects dexterity is important for creating activities that become positive experiences for students. Across all age groups, it was observed that most students understood the task conceptually, but for younger age groups, dexterity was the limiting factor in successfully completing the activity. To keep the activity mentally stimulating, it may be futile to simplify the activity itself. Instead, incorporating tools that may supplement a student's low dexterity for younger age groups may provide a more mentally stimulating activity that still involves problem-solving components. Another interesting point was that overall visitors were more successful in completing a scissor lift activity. The key differences between the activities is that the scissor lift activity consisted almost entirely of rigid parts rather than low modulus, soft material parts such as string or silicone. A future study on different ways students interact with rigid vs conforming materials may give insight on successful completion of activities and methods to lower the dexterity level needed for activity levels across ages.

Next, outlier students who showed exceptional skill in dexterity often had a creative or STEM-related hobby. This implicates creative arts and crafts hobbies and activities such as sewing and beading which may be less intimidating for children and can raise dexterity and tinkering self-efficacy in children and should be studied further. In future research, a specific tie between various arts and crafts activities with STEM-related activities can be explored. Additionally, not all participants were surveyed on extracurricular activities. To fully understand the role of these activities, further research and a new study are required. If a relationship with STEM can be introduced through low-skill floor arts and crafts activities, underrepresented students may be more likely to consider STEM a field meaningful enough to enter. Currently, with public schools experiencing budget cuts in art classrooms[13], re-evaluating the impact of such cuts on tinkering self-efficacy and STEM confidence may be important. Since age and experience relate to dexterity, it is important to take age and experience into account when designing soft robotic outreach activities. Satisfied students will ultimately have a better outlook on the activity and STEM.

References

[1] "The NCES Fast Facts Tool provides quick answers to many education questions (National Center for Education Statistics)." https://nces.ed.gov/fastfacts/display.asp?id=899 (accessed Feb. 28, 2023).

[2] "Citation report - 728 - Web of Science Core Collection." https://www.webofscience.com/wos/woscc/citation-report/8c75c603-7be4-4c44-a972-0c3425970bd1-72586299 (accessed Feb. 28, 2023).

[3] M. E. Thompson, "Grade Expectations: The Role of First-Year Grades in Predicting the Pursuit of STEM Majors for First- and Continuing-Generation Students," *J. High. Educ.*, vol. 92, no. 6, pp. 961–985, Sep. 2021, doi: 10.1080/00221546.2021.1907169.

[4] J. Bastiaan and R. Bastiaan, "Increasing the Interest of Elementary School Girls in STEM Fields Through Outreach Activities," in *2019 ASEE Annual Conference & Exposition Proceedings*, Tampa, Florida, Jun. 2019, p. 32961. doi: 10.18260/1-2--32961.

[5] D. P. Holland, S. Berndt, M. Herman, and C. J. Walsh, "Growing the Soft Robotics Community Through Knowledge-Sharing Initiatives," *Soft Robot.*, vol. 5, no. 2, pp. 119–121, Apr. 2018, doi: 10.1089/soro.2018.29013.dph.

[6] S. Shah, A. Beaudette, D. Bergandine, S. Devmal, C. Walsh, and H. Golecki, "Adapting Soft Robotics Outreach to Teacher-Delivered Curriculum in the Virtual Classroom (Work in Progress)," in *2021 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual Conference, Jul. 2021, p. 36651. doi: 10.18260/1-2--36651.

[7] A. H. Greer *et al.*, “Soluble Polymer Pneumatic Networks and a Single-Pour System for Improved Accessibility and Durability of Soft Robotic Actuators,” *Soft Robot.*, vol. 8, no. 2, pp. 144–151, Apr. 2021, doi: 10.1089/soro.2019.0133.
[8] A. H. Greer *et al.*, “Design of a Guided Inquiry Classroom Activity to Investigate Effects of Chemistry on Physical Properties of Elastomers,” *J. Chem. Educ.*, vol. 98, no. 3, pp. 915–923, Mar. 2021, doi: 10.1021/acs.jchemed.0c00528.
[9] S. Lamer, A. Adnan, E. McNeela, T. Tran, and H. Golecki, “Using Drawings to Understand Impacts of Soft Robotics Activity on Elementary Age Students’ Perceptions of Robots,” in *2022 IEEE Frontiers in Education Conference (FIE)*, Uppsala, Sweden, Oct. 2022, pp. 1–5. doi: 10.1109/FIE56618.2022.9962417.
[10] A. Jackson, N. Mentzer, and R. Kramer-Bottiglio, “Increasing gender diversity in engineering using soft robotics,” *J. Eng. Educ.*, vol. 110, no. 1, pp. 143–160, Jan. 2021, doi: 10.1002/jee.20378.
[11] J. L. Poole *et al.*, “Measuring Dexterity in Children Using the Nine-hole Peg Test,” *J. Hand Ther.*, vol. 18, no. 3, pp. 348–351, Jul. 2005, doi: 10.1197/j.jht.2005.04.003.
[12] “SDM Finger Fabrication Guide | Soft Robotics Toolkit.” https://softroboticstoolkit.com/resources-for-educators/sdm-finger (accessed Feb. 28, 2023).
[13] “Public Funding for Arts and Culture in 2019 | Grantmakers in the Arts.” https://www.giarts.org/public-funding-arts-and-culture-2019 (accessed Feb. 28, 2023).