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Board 332: Measuring the Impact of a Soft Robotics Curriculum Embedded in Physics Classes on Students' Engineering Knowledge, Identity, and Career Interest

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Measuring the Impact of a Soft Robotics Curriculum Embedded in Physics Classes on Students' Engineering Knowledge, Identity, and Career Interest

Abstract

Participation in extracurricular educational robotics, tinkering, and building are common precursors to enrollment in engineering majors. Perceptions of pre-college robotics focused on competitions can prevent some students from participating. By broadening the applications of robotics to human-centered designs and bringing soft material robotics into classroom curricula, the field of soft robotics may be a platform to engage a diversity of students in K12 robotics and later, engineering majors. Until recently, most soft robotics work resided in university research labs or as K12 activities presented through practitioner-delivered outreach events. Until soft robot activities are put in the hands of teachers, their reach remains limited. In this project, we leveraged teacher input to develop and deliver an introduction to soft robotics curriculum suitable for high school physics classrooms. This paper gives an overview of a curricular intervention, mixed methods research study, and analysis of a four-day soft robotics curriculum that introduces the field, technical concepts, and allows for student experimentation and design. We employed a mixed methods research design to understand how the curriculum broadened students' understanding of engineering, their STEM identities, and career interest. Data analysis aims to uncover what students learned about the discipline of soft robotics, and how they contextualize the lesson within their understanding of career paths in robotics, and their own interests. Results to date demonstrate that integrating a soft robotics curriculum in high schools may provide a pathway to recruit students to robotics and engineering careers.

Introduction

Pre-college robotics programs are common precursors to majoring in engineering [1]. However, gender disparities persist across engineering disciplines. The fact that girls do not participate in pre-college robotics at the same rate as boys has been proposed as a bottleneck for girls enrolling in engineering majors [2]. When girls are not part of extracurricular robotics programs, they miss vital opportunities to develop tinkering self-efficacy and join engineering majors including mechanical and electrical engineering [3]. Alternatively, bioengineering and biomedical engineering (BME) programs graduate ~40% women students each year [4]. Diversity in BME is well studied, while strategies to attract women to traditional disciplines are less successful in changing national trends. Literature suggests that this disparity in engineering major preference persists from perceptions formed prior to entering college [5]. Because of difficulties in changing majors once in college [5], it is critical to attract students to these majors during high school. The current gendered landscape in engineering led us to ask, what can be done in the pre-college curricula to change students' perceptions of traditional engineering majors?

Soft robotics is a subdiscipline of robotics that uses flexible and low modulus materials to develop bioinspired designs and healthcare applied robotics systems. Soft robots interface safely with humans by replacing hard components with mechanically programmed polymers and flexible electronics [6]. Previous work hypothesized that soft robotics may appeal to women because of its use of chemistry, biology and materials science, disciplines [7]. However, we believe that soft robotics will appeal to students' pre-existing agency beliefs, and through investment in the design objectives, students can gain skills and confidence in robotics, and in turn engineering majors where women are traditionally underrepresented. Using the critical engineering agency theoretical framework as a lens through which we motivated this work [8], we designed a mixed methods study to understand the impacts of a soft robotics curriculum on high school students knowledge, identity, and career interests.

Methods

Intervention

Previously, we implemented soft robotics curricula in a variety of K12 contexts [9], [10], [11], [12], [13], [14]. After a small pilot study, we updated a four-day version of the curriculum and research study [15], [16]. Additionally, to increase utility of the classroom modules for teachers, we aligned the curriculum activities with the Next Generation Science Standards (NGSS) , shown in Table 1. As part of Aim 1 of our NSF RIEF project, we updated our curriculum to represent a broad range of identities of scientists, roboticists, and engineers working in soft robotics with the goal of students being able to see themselves represented in the field. In addition to working with classroom science teachers, we worked with a librarian collaborator to identify age-appropriate books that highlight diverse scientists and engineers that can be promoted in the library and provide information supplemental to the curriculum.

Table 1.

Standards **HS-PS2-6 Motion and Stability; HS-ETS1 Engineering Design; HS-PS3 Energy**		
NGSS Performance Expectations The chart below makes one set of connections between the implementation outlines in this project and the NGSS. Other valid connections are likely. The connections outlined here are just one step toward reaching the performance expectations. **HS-PS2-6.** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. **HS-ETS1-2.** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. **HS-PS3-3.** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.		
Dimension	Name and NGSS code/citation	Specific connection to SR implementation activity
Science and Engineering Practices	Obtaining, Evaluating, and Communicating Information **(HS-PS2-6)** Constructing Explanations and Designing Solutions **(HS-PS3-3, HS-ETS1-2)**	• Students analyze current state of the art in the soft robotics field, through video demonstrations, before building their own devices. • Students brainstorm applications of SR devices based on components built in class.
Disciplinary Core Ideas	Types of Interactions (**HS-PS2-6)** Definitions of Energy **(HS-PS3-3)** Optimizing the Design Solution **(HS-ETS1-2)**	• Students discuss mechanics of materials principles of elastic modulus as a function of polymer chemistry. • Students build polymer pneumatic actuators and discuss energy adsorption and conversion • Students compare materials, geometries, and pressures for different SR applications
Crosscutting Concepts	Structure and Function **(HS-PS2-6)** Energy and Matter **(HS-PS3-3)**	• Students discuss actuator design choices from nanoscale polymer chains to macroscale gripper action and their impact on function. • Students trace robot function from control system to gripping action.

Study Design

Survey A quantitative survey was designed using existing, validated quantitative measures, combined with open-ended response questions. Based on pilot results and in consultation with project advisory board members, we designed a retrospective survey in the next phase of this work. A retrospective test is administered at the end of an implementation and asks participants to reflect on psychological factors and report their current perceptions for each item [17]. In this case, after the soft robotics implementation, students will be asked to report perceptions for the measures reported below “after” the soft robotics module. Then they will be asked to respond to the same items, but report their perception “before” starting the soft robotics curriculum. The difference between present (after) and retrospective (before) responses are used to calculate gain measure scores. Retrospective tests account for response-shift bias [18] and the Dunning-Kruger effect [19] that might when participants overestimate their initial perceptions, which are then adjusted after exposure to the topic. This may be particularly relevant for soft robotics topics in high schools as they are very limited in integration K12 schools. For topics that are new, reports cite the retrospective survey may be a better indicator of change [18]. This retrospective design has been used previously in a similar context, allowing us to compare our work to previously published results [20].

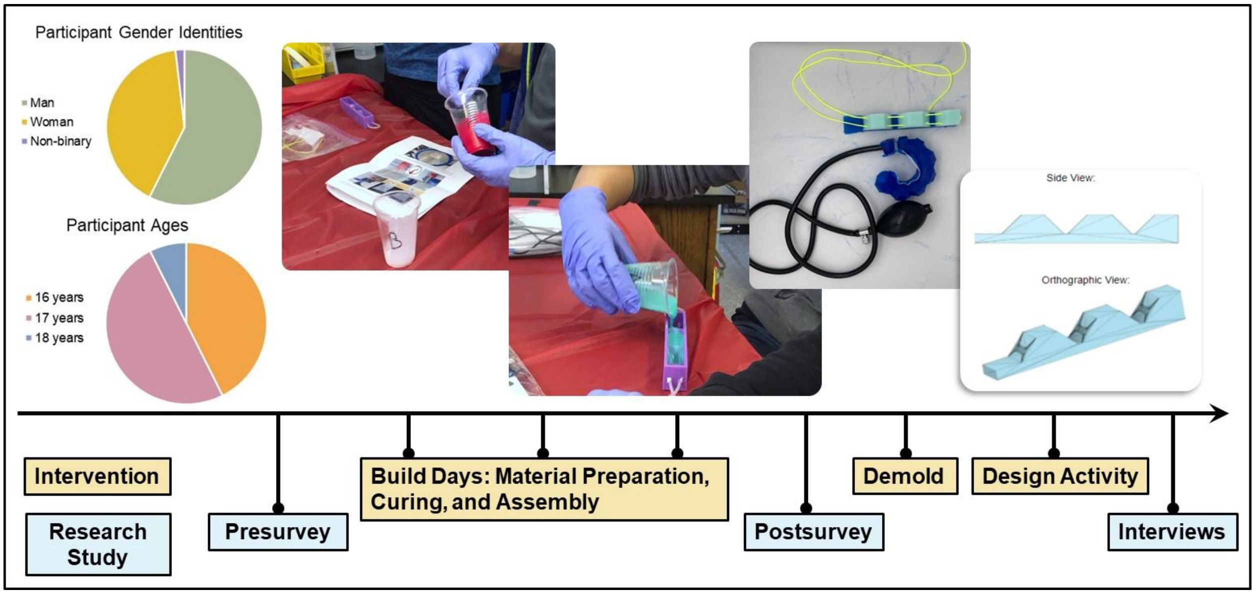
The quantitative measures used in this pilot are as follows:

Identity measures: Survey items include the Persistence Research in Science and Engineering study [21]. These items include math identity, physics identity, and engineering identity. Each identity item includes: (1) two items measuring interest, (2) six items measuring performance/competence beliefs, (3) two items measuring recognition.

Engineering career interest: Engineering career choice is measured with a question that asks students to “Rate the likelihood of choosing a career in the following” including STEM related careers and eight specific engineering disciplines [8].

Agency beliefs: Five items that measure students’ perceptions of their ability to think critically about engineering and use engineering to do good in the world will be included [22].

In the pre-survey, we asked students open-ended questions about soft robotics, engineering majors, and an open-ended prompt asking “Is there anything else you would like us to know?”.



Qualitative Interviews Semi-structured interviews were conducted with a subset of study participants. The objective of the interviews was to understand individual factors that contribute to changes in identities and agency beliefs measured in the quantitative surveys. Further, these interviews aimed to understand how these factors vary across students from different demographics. Example questions include "What applications do you see the soft robotic actuators built in class being used for?", "What is your intended career and why?", "What is appealing/not appealing about engineering majors?"

Data Collection The quantitative survey data were collected with a paper-based survey. Surveys will take an estimated 10 minutes to complete. All interviews were conducted in person. Interviews will last approximately 15 minutes and will be audio recorded. All data collection, analysis and storage was conducted in accordance with IRB requirements.

Data Analysis Descriptive statistics will be calculated for all measures at each time point. Correlations of measures will be assessed at each time point. ANOVA and chi-square tests will determine demographic differences in identification. A regression model will be fit to identify the effect of the intervention with interest in MechE or EE majors as the dependent variable. Qualitative interviews will be analyzed by thematic analysis [23] and provide explanations of responses to quantitative survey findings. The research team will make methodological choices in tool development, data analysis, and interpretation based on The Q3 framework [24]. which draws inspiration from engineering approaches to quality management.

Outcomes and Findings to Date

To date we have delivered the four-day soft robotics module three times. Once as a pilot at a small, public high school [16] and twice at the larger, public high school of study. We have published on the teacher-informed curriculum to the K12 teacher community [15]. The school of study also now has a section of the library dedicated to stories of diverse scientists and engineers to support inquiry and provide resources for students outside of the science classroom in the library which also houses a maker space and supports student research and projects.

In addition to implementing our curriculum at the planned high school of study, we've had the opportunity to use the intervention developed for this project in outreach contexts [9], [10], [14], [25], and as part of an undergraduate soft robotics course [26]. We also delivered a workshop for a broad community of teachers at the ASEE Pre College Engineering Education Pre-Conference [27]. Data analysis is underway. We see soft robotics curricula as a potential to increase diversity in robotics across the educational spectrum.

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References

[1] C. Burack, A. Melchior, and M. Hoover, "Do After-School Robotics Programs Expand the Pipeline into STEM Majors in College?," *Journal of Pre-College Engineering Education Research (J-PEER)*, vol. 9, no. 2, Oct. 2019, doi: 10.7771/2157-9288.1244.

[2] A. Sullivan and M. Umashi Bers, "Girls, Boys, and Bots: Gender Differences in Young Children's Performance on Robotics and Programming Tasks," *JITE:IIP*, vol. 15, pp. 145–165, 2016, doi: 10.28945/3547.

[3] G. Potvin *et al.*, "Disciplinary Differences in Engineering Students' Aspirations and Self-Perceptions," in *2013 ASEE Annual Conference & Exposition Proceedings*, Atlanta, Georgia: ASEE Conferences, Jun. 2013, p. 23.438.1-23.438.11. doi: 10.18260/1-2--19452.

[4] B. L. Yoder, "Engineering by the numbers," 2021. [Online]. Available: http://www.asee.org/papers-and-publications/ publications/14_11-47.pdf

[5] M. W. Ohland, S. D. Sheppard, G. Lichtenstein, O. Eris, D. Chachra, and R. A. Layton, "Persistence, Engagement, and Migration in Engineering Programs," *Journal of Engineering Education*, vol. 97, no. 3, pp. 259–278, Jul. 2008, doi: 10.1002/j.2168-9830.2008.tb00978.x.

[6] F. Iida and C. Laschi, "Soft Robotics: Challenges and Perspectives," *Procedia Computer Science*, vol. 7, pp. 99–102, 2011, doi: 10.1016/j.procs.2011.12.030.

[7] A. Jackson, N. Mentzer, and R. Kramer-Bottiglio, "Pilot analysis of the impacts of soft robotics design on high-school student engineering perceptions," *Int J Technol Des Educ*, vol. 29, no. 5, pp. 1083–1104, Nov. 2019, doi: 10.1007/s10798-018-9478-8.

[8] A. Godwin, G. Potvin, Z. Hazari, and R. Lock, "Identity, Critical Agency, and Engineering: An Affective Model for Predicting Engineering as a Career Choice: Identity, Critical Agency, and Engineering Careers," *J. Eng. Educ.*, vol. 105, no. 2, pp. 312–340, Apr. 2016, doi: 10.1002/jee.20118.

[9] H. M. Golecki and J. Henderson, "Understanding Children's Perceptions of Robotics Through Drawings: Early Development of the Draw a Robot Task (Work in Progress)," in *Proceedings of the American Society of Engineering Education*, 2023. [Online]. Available: https://peer.asee.org/42553

[10] L. Brizzolara, E. McNeela, T. Tran, and H. M. Golecki, "Earning Daisy Girl Scout Robotics Badges with a Hands-on Soft Robot Gripper Design Activity (Resource Exchange)," in *Proceedings of the American Society of Engineering Education*, 2023.

[11] A. H. Greer *et al.*, “Soluble Polymer Pneumatic Networks and a Single-Pour System for Improved Accessibility and Durability of Soft Robotic Actuators,” *Soft Robotics*, p. soro.2019.0133, Jun. 2020, doi: 10.1089/soro.2019.0133.
[12] A. N. Sardesai *et al.*, “Design and Characterization of Edible Soft Robotic Candy Actuators,” *MRS Advances*, vol. 3, no. 50, pp. 3003–3009, Oct. 2018, doi: 10.1557/adv.2018.557.
[13] R. Hennig, A. Beaudette, H. M. Golecki, and C. J. Walsh, “Educational Soft Underwater Robot with an Electromagnetic Actuation,” *Soft Robotics*, p. soro.2021.0181, Jan. 2024, doi: 10.1089/soro.2021.0181.
[14] 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,” presented at the IEEE Frontiers in Education, Upsala, Sweden, Oct. 2022.
[15] T. Tran, E. McNeela, J. Robinson, J. McLean, K. Jensen, and H. Golecki, “Revolutionizing Robotics: Broadening the Definition of Engineering by Engaging Students in Soft Robotics,” *The Science Teacher*, vol. 90, no. 5, May 2023, [Online]. Available: https://www.nsta.org/science-teacher/science-teacher-mayjune-2023/revolutionizing-robotics
[16] H. M. Golecki, T. Tran, E. McNeela, and K. J. Jensen, “Pilot Study of the Impacts of a Robotics Curriculum on Student’s Subject-related Identities and Understanding of Engineering,” in *Proceedings of the American Society of Engineering Education*, Baltimore, MD, Jun. 2023.
[17] S. E. Coulter, “Using the retrospective pretest to get usable, indirect evidence of student learning,” *Assessment & Evaluation in Higher Education*, vol. 37, no. 3, pp. 321–334, May 2012, doi: 10.1080/02602938.2010.534761.
[18] J. Drennan and A. Hyde, “Controlling response shift bias: the use of the retrospective pre-test design in the evaluation of a master’s programme,” *Assessment & Evaluation in Higher Education*, vol. 33, no. 6, pp. 699–709, Dec. 2008, doi: 10.1080/02602930701773026.
[19] D. Dunning, “The Dunning–Kruger Effect,” in *Advances in Experimental Social Psychology*, vol. 44, Elsevier, 2011, pp. 247–296. doi: 10.1016/B978-0-12-385522-0.00005-6.
[20] 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.
[21] Z. Hazari, G. Sonnert, P. M. Sadler, and M.-C. Shanahan, “Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study,” *J. Res. Sci. Teach.*, p. n/a-n/a, 2010, doi: 10.1002/tea.20363.
[22] A. Godwin and P. Geoff, “Fostering female belongingness in engineering through the lens of critical engineering agency,” *The International journal of engineering education*, vol. 31, no. 4, pp. 938–952, 2015.
[23] V. Braun and V. Clarke, “Using thematic analysis in psychology,” *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, Jan. 2006, doi: 10.1191/1478088706qp063oa.
[24] J. Walther, N. W. Sochacka, and N. N. Kellam, “Quality in Interpretive Engineering Education Research: Reflections on an Example Study: Quality in Interpretive Engineering Education Research,” *J. Eng. Educ.*, vol. 102, no. 4, pp. 626–659, Oct. 2013, doi: 10.1002/jee.20029.

[25] E. McNeela, T. Tran, A. Adnan, and H. Golecki, "Understanding Impacts of Soft Robotics Project on Female Students' Perceptions of Engineering (Work in Progress)," in *Proceedings of the American Society of Engineering Education*, Jun. 2022.
[26] H. M. Golecki, J. Robinson, C. Cvetkovic, and C. Walsh, "Empowering Students in Medical Device Design: An Interdisciplinary Soft Robotics Course," *Biomed Eng Education*, Apr. 2024, doi: 10.1007/s43683-024-00143-9.
[27] H. M. Golecki, "Designing Squishy Robots to Teach Engineering, Physics, and Chemistry," presented at the ASEE Pre-College Engineering Educators Conference, Baltimore, MD, Jun. 2023.