WIP: A Model for Building Soft Robotics Knowledge and Interest: Student-Generated Learning Demonstrations

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Abstract. This work-in-progress paper describes our progress on a novel approach to introducing soft robotics content to undergraduate mechanical engineering students. Soft robotics is a new and growing field, emphasizing robotic solutions that prioritize compliant materials. Despite its short history, soft robotics has gained momentum in industry and academia. However, soft robotics education has yet to catch up to the research advancements in this field. Our overarching project explores the potential for student-generated soft robotics modules to impact the learning and interest in soft robotics of both the students designing the modules and the students participating in the modules once they are developed. Our project leverages a course structure called 'engineering clinics', which are modified versions of capstone design experiences. Within clinics, third and fourth-year students engage in team-based projects with faculty or industry mentors. The ten students in our clinic were split into three teams and tasked with 1) surveying existing soft robotics designs and applications, 2) creating a soft robot prototype, and 3) designing a learning activity around their prototype. At the end of the semester, student module designers were asked to self-report their growth in the clinic's learning outcomes (LOs) and the impact of the clinic experience on their career preparation via a post-clinic survey. Students' clinic products and the results of the survey are presented. We anticipate future work to examine the learning of both students designing the modules and students engaging in the modules.

Background

Soft Robotics is a new and growing field that emphasizes developing robotic solutions that prioritize compliant materials, embodied intelligence, and biomechanics in their design [1], [2], [3]. Emerging around 1995, soft robotics designs have been shown to have previously unprecedented capabilities [4], leveraging high degree-of-freedom actuators to adapt to their surrounding environments, change shapes, apply compliant motions, and even manipulate complex objects [5], [6], [7]. Despite its short history, soft robotics has gained significant momentum in industry and academic spaces [8], [9], [10], [11]. Additionally, despite increasing research interest in soft robotics, there are relatively few opportunities for undergraduate engineering students to be introduced to soft robotics during their degree programs. Based on a survey of the top 100 US News institutions offering undergraduate engineering degrees in 2022, only 5 programs offered a soft robotics undergraduate course. The lag between undergraduate engineering education and trends in industry and research requires engineering programs to think critically about how to address educational gaps [12].

To address this tension at our university, we are engaging undergraduate engineering students across multiple phases of soft robotics curriculum development. Students are developing soft robotics learning modules as co-designers, which is what is presented in this paper. In the future, they will get to pilot their activities with other students. Once modules are fully developed and piloted, they will be implemented in courses across our mechanical engineering (ME) curriculum and shared publicly. Overall, our full project will explore the potential for student-generated soft robotics modules to impact the learning and interest in soft robotics of both (a) the students designing the modules and (b) the students participating in the modules once they are developed. This work-in-progress paper describes our progress on the project to date. The project has only engaged student module designers in one semester so far, so we focus the results of this paper on the impact of developing soft robotics learning modules on our first team of students.

Project Context

To implement this project, we leveraged a unique curricular structure of our university, a four-semester, junior and senior-level experience called 'engineering clinics' [13]. Engineering clinics are the capstone experience for our engineering programs. Students are required to participate in four, 2-credit courses resulting in up to four unique projects in their final two undergraduate years. Projects are supervised by engineering faculty and industry sponsors across six engineering disciplines, and students from multiple engineering majors are frequently on a single project. Students can select projects from any discipline and are assigned to projects through a dedicated matching algorithm [14]. Students can elect to stay on a project or select a new project in each of the four semesters of the clinic sequence. Like other engineering courses with teamwork, students' grades are related to their teammates, but final clinic grades are assigned individually, encouraging buy-in for the project each semester. In Fall 2023, we offered a soft robotics clinic project where students would develop soft robotics prototypes and learning activities that can be implemented in ME courses. This paper describes how we have assessed the impact of this project on our clinic students so far, and plans we have to continue this project.

Study Design

The first offering of the soft robotics clinic project was in Fall 2023 and recruited ten students. All students were ME majors and nine were juniors. Students met weekly with the sponsoring faculty to receive feedback on their progress and guidance about the next steps. They also presented their project to an external ME faculty at mid-semester and presented their results verbally at the end of the semester. We started the semester by asking students to survey current soft robotics literature, identifying types of actuation principles used to control soft robots, actions the robots perform, and the targeted audience for the article. Once our students had a grasp on the literature, they split into three subteams of 3-4 students each and selected an actuation principle to design a soft robotic activity around. They were tasked with designing a prototype to demonstrate the actuation principle and then designing a learning activity to demonstrate a fundamental engineering principle with their sample prototype.

Given our desire to introduce soft robotics into undergraduate engineering curricula and the fact that our institution uses clinics as an engineering capstone experience, we wanted to know how their participation impacted their knowledge of soft robotics and their professional preparation. To assess the impact of their participation, we asked students to respond to an anonymous survey, report their growth in the clinic's LOs, and discuss the impact of the experience on their career preparation. Below, we present the outcomes of the Fall 2023 soft robotics clinic in terms of student deliverables, and then provide results of the post-clinic survey.

Results

Project Outcomes. Our clinic team summarized 52 unique soft robot resources, representing nine categories of actuation principles, numerous actions, and both instructional and technical resources in their search. This diverse library of resources was used to identify major focus areas for developing our learning modules. The student subteams were asked to each select an actuation principle based on their interests. Our three subteams selected magnetic, pneumatic, and hydraulic actuation principles for their projects and designed prototypes for each principle. A brief description of outcomes by each subteam is provided below:

1. **Pneumatic Actuation.** The three-student pneumatic team designed a 'creature' that moves based on a soft robot actuator called a McKibben muscle [15]. The McKibben muscle works by creating a contractile force using pressurized air to fill a bladder and extension through passive spring elements. This team's proposed learning module asks students to use McKibben muscles to construct a creature that navigates and collects food in a simulated environment, emphasizing a design based on the environment's constraints. Their module emphasized LOs associated with pneumatic actuation and kinematics of mechanisms. A photo of their prototype is in Figure 1A.
2. **Hydraulic Actuation.** The three-student hydraulic team used 3D printing and silicone rubber molding to design a 'fish toy' that can swim using hydraulic actuation. The toy is meant to be readily used and enjoyed by children, its target audience. Their proposed learning module emphasized LOs associated with soft material fabrication processes and principles of hydraulics. A photo of their prototype is in Figure 1B.
3. **Magnetic Actuation.** The last, four-student team used magnetic actuation and designed a 'flailing tube man' made of silicone rubber embedded with magnets. They then designed a stand to hold electromagnets with controllable magnetic field strength used to create varied motions of their 'tube man'. Their proposed learning module focuses on tube man design and magnet configuration to teach students about soft materials, magnetism, control, and soft actuator design. A photo of their prototype is in Figure 1C.

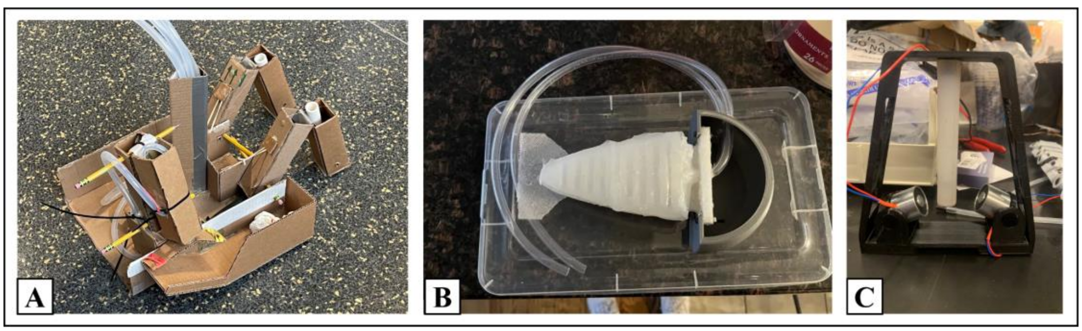

Figure 1. Clinic student-generated soft robot prototypes. A is the pneumatic McKibben muscle creature, B is the hydraulic, silicone fish toy, and C is the magnetic tube man.

Overall, each team demonstrated a working prototype that leveraged the actuation principle they chose. Likely due to the need for students in the first semester of this clinic project to survey the literature before conceptualizing their ideas and starting prototyping, students did not create as robust of learning modules as we had hoped. The students have continued to improve their projects after the semester ended, producing three paper drafts that share their classroom activities and have been submitted to the ASEE conference [16], [17], [18]. Eight students decided to stay on this clinic project for the spring semester, demonstrating high engagement with the project overall. Their documentation efforts also forced our students to think deeply about the LOs and how these activities can be implemented. We are looking forward to seeing the outcomes of their continued engagement and the refinement of their educational activities.

Survey Outcomes. Seven of the ten students in our clinic completed the post-clinic survey, and five consented for us to present their responses in research publications, resulting in a 50% sharable response rate. This section shares findings from those five students. We asked students to rate their familiarity with soft robotics before and after the clinic and saw an increase in their perceived familiarity of approximately 2 points on a five-point scale (average for before = 1.8 and for after = 3.8; n = 5 responses). We also asked students to rate their confidence (1 = Not at all confident to 5 = Very confident; n = 5 responses) in the seven LOs of our clinic project. We asked students to rank these LOs from most (7) to least (1) helpful in achieving their future career goals (n = 4 responses; normalized to a 5-point scale). LOs data are presented in Figure 2. The seven LOs included:

1. Apply 3D modeling principles to design your soft robot prototype (3D Model).
2. Demonstrate one or more actuation principles used in soft robots (Demo Actuate).
3. Integrate your actuation principle in a soft robot prototype (Proto Actuate).
4. Develop learning activities associated with your soft robot design (Learning Activity).
5. Develop learning outcomes associated with your soft robot learning activities (Learning Outcome).
6. Explain the scientific principle(s) behind your design's actuation mechanism (Explain Actuate).
7. Design a soft robot prototype using soft materials (Soft Proto).

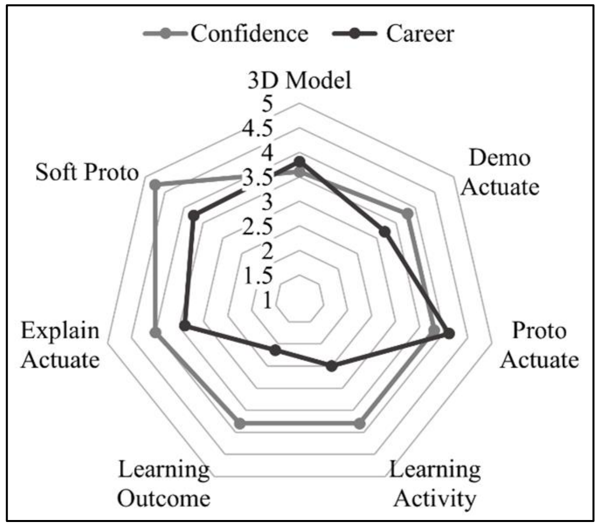

Figure 2. Averaged survey responses to LOs questions about confidence and ranking of career helpfulness.

Overall, students rated themselves above a 3 out of 5 in their ability for all the LOs. Most notably, they reported a high ability to explain their actuation principle (an average of 4) and to create a soft robot prototype with soft materials (an average of 4.75). Students found the requirement to integrate their actuation principles into a prototype, use 3D modeling software for designing their prototypes, and use soft materials in their prototypes to be most helpful in their future careers. We also asked students to tell us about how helpful elements of the clinic structure were to their learning about soft robotics. They ranked the following items from most (7) to least (1) helpful for their learning (refer to Figure 3 for average rank values):

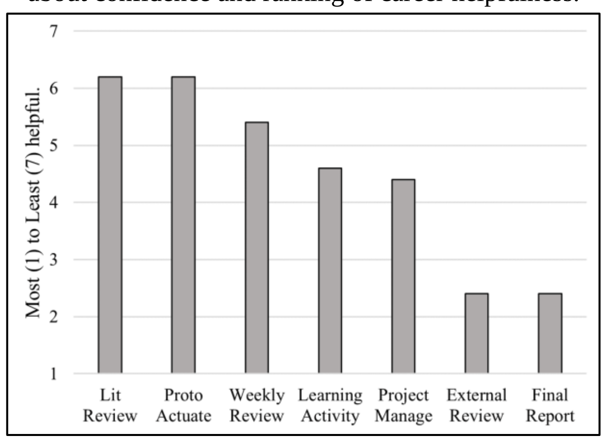

Figure 3. Averaged responses to survey question asking students to rank the usefulness of clinic elements for learning about the soft robotics field.

- Performing a literature review on soft robotics designs (Lit Review).
- Prototyping soft robot designs around a single actuation principle (Proto Actuate).
- Participating in weekly review meetings and interacting with faculty and graduate students on the project (Weekly Review).

- Designing learning activities that use the soft robot prototype we developed (Learning Activity).
- Performing regular project management, organization, and documentation work associated with the clinic project (Project Manage).
- Preparing material for the week 6 design review with an external ME faculty member (External Review).
- Writing a final report and preparing a final presentation to communicate our work (Final Report).

Discussion

Our students prototyped three soft robot designs and established ideas for learning modules that can be implemented using their designs. While we recognize our sample is limited, responding students reported gaining confidence in our clinic's LOs; including those related to soft robotics concepts (e.g., demonstrating actuation principles, designing with soft materials) and those related to engineering but in a soft robotics context (e.g., applying 3D modeling to design, integrating an actuation principle in a prototype, explaining the science behind the actuation principle). Perhaps unsurprisingly, they also ranked these outcomes (1-5) as most helpful for their future careers, as many of our students have plans to enter the industry upon graduation. While students indicated confidence (average of 3.8) in their ability to develop learning activities and outcomes, they ranked these as least likely to support their future career goals and only somewhat beneficial to their understanding of the soft robotics field. In the first iteration of the clinic project, students may not have seen explicit value in developing learning activities and outcomes as part of their project. This could have been partially due to time constraints in the first semester. We prioritized students establishing a database of soft robotics literature to draw inspiration from when developing their prototypes, which limited the time student teams had to generate a prototype and develop a learning activity. As our project progresses, students will have more opportunities to build on existing prototypes, freeing up time to focus on their prototype's module. Eight of our students from Fall 2023 have worked with us to develop the modules further and submit them as ASEE papers, which we believe will contribute to their understanding of the benefits of the learning module design requirements of the clinic. Due to high interest, two students will also continue activity development work with us this summer. We also anticipate that having the opportunity to pilot their learning modules with other students and then iterate on the module will better highlight the potential contributions of these elements to their learning. To capture the impact of those opportunities (i.e., conference publication, piloting modules) in relation to others we included in the Fall survey, we will also ask students to reflect on the impact of those elements in the post-clinic surveys of future semesters.

Future Work

We will continue to offer this clinic for the next two years, generating a database of modules (up to five new per year) that can be implemented as mini-projects to broaden soft-robotics exposure. We plan to continue to iterate on existing projects, gather the perspectives of student module designers, and begin to gather perspectives from students who take part in the modules our clinic students develop through additional surveys. The better-received "mini" course projects will become an integral part of the ME curriculum and can be offered to students on a regular basis. By gathering perspectives from both groups, we aim to explore the differential impacts of designing soft robotics modules versus participating in the modules as a student.

Acknowledgments
This material is based upon work partially supported by the National Science Foundation under Grant No. 2235647. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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