BOARD # 232: Cultivating Student Development Through Student-Designed Soft Robotics Learning Modules

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Abstract
As soft robotics emerges in industry, the need for accessible educational material has also risen. Our project focuses on co-developing easy-to-implement soft robotics learning modules with engineering students through a credit-based design experience at our institution. Modules are designed to be easily integrated into courses across a mechanical engineering curriculum. This paper reports on the lessons learned and progress to date.

Background

Soft robotics is a novel and emerging field of robotics [1]. Unlike traditional robot mechanics, soft robotics uses flexible, compliant materials instead of rigid parts and linkages [2], which has led to their increasing use in organic applications like biomimicry, orthotic devices, and surgical robots [3] [4] [5]. This field has seen rapid growth recently and is projected to continue as the field expands into new engineering settings [6]. However, this rapid growth has led to a lack of accessible state-of-the-art educational material on soft robotics, causing a scarcity of opportunities for learners to be able to experience this field in their education. Our project, funded by the National Science Foundation (NSF) Improving Undergraduate STEM Education (IUSE) program, addresses this gap by engaging undergraduate engineering students across multiple phases of soft robotics curriculum development. Currently, students are identifying and designing new soft robotics modules that support student learning. Students are also responsible for publishing their modules on a public-facing, freely accessible website [7].

Project Context

The project was implemented into a unique aspect of our university's curriculum, an equivalent to a capstone experience called 'engineering clinics' [8]. Clinics encompass four semesters of two-credit courses exclusive to junior and senior-level students. Each clinic is a unique, often multidisciplinary project supervised by engineering faculty that can be either short or long-term. Students indicate the projects they are interested in and are assigned to projects through a project-matching algorithm [9]. Each semester, students can either choose a new project or stay on their previous one, meaning students can have up to four unique clinic experiences. Beginning in the Fall 2023 semester, we offered a clinic project dedicated to student-led soft robotic design for education, where students would develop soft robotics prototypes and learning activities that could be implemented in educational settings. As students designed the prototypes and modules, they were encouraged to work with faculty to identify courses or outreach programs where the modules could be implemented. The long-term goal of the project is to implement the modules in multiple courses at our institution. In this manner, the project has the potential 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. By having projects made by students, for students, our goal is to benefit both groups' learning through soft robotics. This paper focuses on the data collected from the first two semesters of our project in action.

Study Design

Since Fall 2023, our clinic project has been offered every semester for up to 10 students. During the semester, our students were tasked with developing a soft robotic learning module and an associated prototype as appropriate. Weekly meetings were held with the supervising faculty members to update progress and guide students' efforts. At the end of each semester, an anonymous survey was used to assess the impact of student participation in the clinic. Since one of our core goals is to cultivate the future soft robotics workforce, our survey assessed student's growth in respect to the learning objectives (LOs) of the clinic which emphasized soft robotic knowledge and experience. In addition, our survey asked students to report on the clinic's influence on their future goals and career preparation. This paper provides updated survey information, comparing outcomes of Fall 2023 and Spring 2024 survey data, and shares the results of the student-developed modules in the first year of the Cultivate Soft Robotics clinic experience.

Project Outcomes

The Spring 2024 semester recruited 7 junior and 2 senior mechanical engineering (ME) students to the soft robotics clinic project, 8 of which were returning students. An additional sophomore engineering student was brought on the project and was tasked with project management and ensuring tasks were delegated effectively. Similar to the previous semester, the start of the clinic involved an ideation period before the larger group was split into sub-teams, each focusing on their own individual project. The ideation period for the Fall 2023 team involved a literature review of soft robotics; however, with the majority of students returning for Spring 2024, a review of currently existing projects and potential educational niches within our university's curriculum was instead conducted. The intention behind this was to better tailor the students' chosen projects to be more aligned with teaching soft robotics concepts, as well as develop learning modules that could be directly implemented into and support our engineering curriculum. Once this review was conducted and approximately 20 learning module ideas had been generated, students were divided into teams of 2-4 and selected five projects for development. This is in contrast to the previous semester, which had larger team sizes (3-4 per team) and a smaller number of projects developed (3 total). The reason for this is that more focus was placed on smaller, less complex projects that were tailored toward use within our own engineering curriculum. The students' chosen learning module proposals and targeted mechanical engineering courses in italics are listed below.

- **Quality of a McKibben Muscle:** Involved conducting a statistical analysis of a soft robotic actuator that students assembled within a *Quality and Reliability* course.
- **Soft Robotics for Social Good:** Involved researching health-related opportunities for soft robotic devices and presenting for the *Sophomore Engineering Clinic II* course.
- **Pneumatic Claw:** Involved replacing traditional actuators in a mechanical arm project within an *Intro to Mechanical Design* course with soft robotic alternatives.
- **Combustion Soft Robot**: Involved a coding project within an *Intro to Thermal Fluid Sciences* course to simulate the thermal cycle of a combustion soft robot [9].
- **Fish Tail:** Involved designing the oscillating pneumatic driven mechanism for actuating a soft fishtail using a 3D-printed mechanism for a *Machine Design* course.

Overall, the performance of each team was satisfactory. Many proposals developed resulted in a module that could be readily implemented into our engineering curriculum, with the pneumatic claw and fish tail design teams producing successful prototypes to showcase the module outcomes. Documentation of these modules revealed deep connections to both the soft robotic principles chosen and the proper educational material designs. We plan to implement some of these resulting proposals into their intended courses in the future of this project.

Survey Outcomes

Out of 9 students participating in the clinic project, 7 completed the post-clinic survey, and 6 consented for their data to be used for publication. This section outlines the results of that data and how it varies from the first iteration of the survey, which is presented in Figure 1.

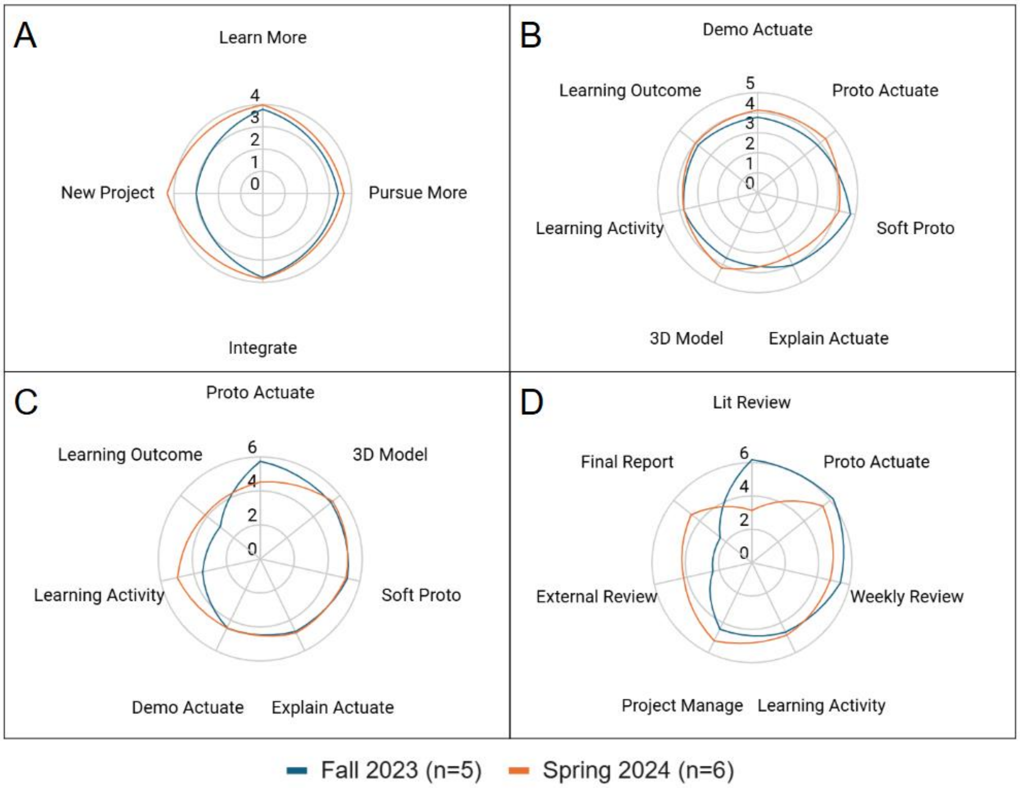

Figure 1: Averaged survey responses for Fall 2023 and Spring 2024 semesters for (A) questions asking students' familiarity with soft robotic concepts, (B) students' confidence levels relating to LOs, (C) students' ranking of how supportive clinic elements were to soft robotic learning, and (D) students' ranking of helpfulness of LOs to achieving career goals.

We asked students to report on their familiarity with soft robotics concepts before and after the semester's clinic work on a five-point scale. Reporting a higher initial average familiarity (3.2 as opposed to 1.8 at the beginning of the semester), students reported a 1.4-point increase in their perceived familiarity with soft robotics. The survey also asked students to rate how strongly they agree with several statements about the impact of the clinic on their soft robotic familiarity (Figure 1A). This included: "The clinic inspired me to learn more about Soft Robotics" (Learn more), "The clinic inspired me to pursue additional Soft Robotics opportunities" (Pursue More), "The clinic taught me how to better integrate knowledge from two or more disciplines (materials, mechanics, physics, biology,...)" (Integrate), and "I would be comfortable working on a new project related to Soft Robotics" (New Project). Data collected from this section did not vary significantly between semesters except for students' comfort levels when working on a new soft robotics project. This is unsurprising, as the majority of respondents were returning from the previous semester.

The survey evaluated the effectiveness of the progress made during the semester in accomplishing the LOs of the clinic (Figure 1B, C). The LOs are as follows: use 3D modeling in soft robot prototype design (3D Model), demonstrate soft robot actuation principles (Demo Actuate), integrate your actuation principle in a soft robot prototype (Proto Actuate), develop learning soft robotic activities (Learning Activity), develop soft robotic learning outcomes (Learning Outcome), explain the scientific principle(s) behind your design's actuation mechanism (Explain Actuate), and design a soft robot prototype (Soft Proto). One section asked the students to rate their confidence in accomplishing the LOs (Figure 1B) based on a five-point scale (1 = Not at all confident to 5 = Very confident, n = 6 responses). Compared to the data from the previous semester, four LOs experienced gains, though changes in this section were minor. The most significant drop in rating was for Soft Proto LO, decreasing from 4.75 to 4.2, which may be explained by the design on paper approach for this semester. Another section asked students to rank each learning objective from most (7) to least (1) helpful in achieving their future career goals (Figure 1C). Significant gains were observed in this section for the “Learning Outcome” and “Learning Activity” LOs, while losses were observed for the “Proto Actuate” LO. The shift away from this LO might be correlated with some projects not having physical prototypes. However, the shift towards relevance of learning-related LOs is promising.

The survey also asked students to rank how supportive elements of the clinic were to their learning about soft robotics. The following items were ranked from most (7) to least (1) helpful to their learning: performing a soft robotics literature review (Lit Review), prototyping soft robot designs around a single actuation principle (Proto Actuate), participating in weekly review meetings with faculty and graduate students (Weekly Review), designing learning activities that use the developed soft robot prototype (Learning Activity), performing regular project management (Project Manage), preparing material for the mid-semester design review with an external ME faculty member (External Review), and writing a final report and preparing a final presentation to communicate our work (Final Report). Significant changes were noted in the responses, such as a shift towards the usefulness of the final report, external review, and project management (Figure 1D). The increase in the usefulness of the final report is likely due to the report writing format being well-established in the previous semester. The source of the change in ranking of the external review process is uncertain but may be related to the review process for the student-drafted ASEE papers started in the previous semester [11-13]. The increase in project management directly correlates to a higher emphasis on this during the semester, while the decrease in the usefulness of the literature review correlates to a lower emphasis.

Discussion

Overall, data from the Spring 2024 semester suggests the continued effectiveness of the clinic in fostering soft robotics learning. Most areas of the survey saw either growth or remained unchanged, while those areas that saw decline could be readily explained through changes in the structure of the clinic between semesters. The most significant improvement was a shift towards modules that are aligned with the LOs of existing courses. We observed during the first semester of clinics that the students preferred developing soft robotic prototypes instead of identifying the relevant LOs. In Spring 2024, students were asked to focus on the LOs synchronously or prior to developing a prototype. The latest work suggests that management changes improved student outcomes by better aligning with the project goals.

Future Work

Continuing until the Spring 2026 semester, the project will generate more modules and train incoming students in soft robotics. Already developed modules have been placed in an online database tailored for educators [7] for implementation beyond our university and new ones will be added as the project progresses. As our students continue to report on their growth, we will refine the clinic's management and operation to ensure a learning environment conducive to learning and successful outcomes. Furthermore, as the modules developed in the clinic begin to be implemented in courses, further study will be completed on the impacts on students involved in the learning targeted by the modules developed by our clinic teams. Two courses at our institution have been selected for student module implementation in the Spring 2025 semester, starting the integration of the first soft robotic education modules into the curriculum.

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