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Work-in-Progress: Multidisciplinary Soft Robotics Workshops to Foster Collaborative and Experiential Learning

Dr. Chuhao Wu, Clemson University

Chuhao Wu is a Strategic Assessment Librarian at Clemson University. He holds a Ph.D. degree in Informatics from the Pennsylvania State University and a master's degree in Industrial Engineering from Purdue University. His research focuses on the human-centered design of educational technology and the application of artificial intelligence in higher education.

Minghao Zha, Clemson University
Yinhong Qin, Clemson University

Yinhong Qin is currently a first-year Ph.D. student at the Holcombe Department of Electrical and Computer Engineering, Clemson University. He received M.S in Computer Engineering degree from New York University in 2023 and B.Eng degree from Central South University, China, in 2020. His research mainly focuses on robotics, reinforcement learning and computer vision.

Luyang Zhao, Clemson University

Luyang Zhao is an Assistant Professor in the Department of Electrical and Computer Engineering at Clemson University, where she directs the SMILE Robotics Lab. Her research focuses on soft and modular robotic systems, using AI to co-design robot morphology and control policies and to enable adaptive decision-making in real-world environments. Her work has been published in venues including Nature Communications, npj Robotics, and IEEE Robotics and Automation Letters.

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Abstract

Soft robotics is an emerging area with growing applications in automation, healthcare, and environmental systems, and it offers rich opportunities for experiential and multidisciplinary learning. However, access to soft robotics education remains limited and is often confined to specialized majors, creating barriers for undergraduates with diverse academic backgrounds. This work-in-progress paper reports on the early design and pilot implementation of a low-barrier, hands-on soft robotics curriculum intended to reduce barriers to entry and support introductory engagement with soft robotics concepts and practices. The project involved modular, project-based learning activities implemented through a non-credit workshop and an experiential learning course to provide an inclusive learning space for students. Students worked in small, multidisciplinary teams to assemble and test modular soft robotic systems through guided build-and-test activities emphasizing iteration, collaboration, and learning through failure. An exploratory, formative assessment approach was used, drawing on student self-report surveys, classroom observations, instructor and teaching assistant reflections, and analysis of student-created artifacts to examine how targeted student learning outcomes manifested during initial implementation. Preliminary findings suggest that students were able to assemble functional soft robotic prototypes, identify common failure modes, and report increased perceived confidence and interest in soft robotics following participation. The pilot implementation also surfaced instructional challenges related to procedural complexity, the need for just-in-time scaffolding, and the importance of teaching assistant preparation in supporting novice learners. As a work-in-progress, this study contributes early design-informed insights to guide future curriculum iterations and the development of more robust assessment strategies for soft robotics education.

Introduction

Soft robotics is a rapidly evolving field that holds significant importance due to its unique capabilities and potential applications across various domains [1, 2, 3, 4]. Compared to traditional rigid robots, soft robots are characterized by the use of compliant materials [5], embodied intelligence [6], and bio-inspired design principles [7, 8] that enable safe and effective interaction with humans and the environment [9, 10]. This adaptability makes them particularly suitable for applications requiring delicate handling, such as in medical devices and human-machine interactions [11, 12, 13]. Therefore, the technology has the potential to influence fields such as healthcare, manufacturing, and agriculture by providing solutions that are not feasible with conventional robotics.

Despite potential advantages, the field is still maturing, and issues such as accurate modeling, control strategies, and the integration of complex materials need to be addressed [14, 15]. Hence, there is a growing need to prepare engineers and researchers with the interdisciplinary knowledge required to design, model, fabricate, and control these systems. However, soft robotics education currently faces several challenges. As the field spans compliant mechanics, material behavior, fabrication, sensing, and nonlinear control, students must integrate concepts across domains that are often taught separately, creating significant demands on instructional scaffolding and sequencing [9]. Hands-on activities, while central to soft robotics, can also be resource-intensive. For one thing, the specialized fabrication methods and materials needed for soft robotics hardware may not be readily available in many educational institutions [16]. For another, engaging students in hands-on activities and competitions may require pedagogical training for instructors and teaching assistants [17]. These factors have limited the availability of soft robotics curricula and constrained broader participation among undergraduate students.

This work represents a preliminary phase of a larger research project aimed at broadening student participation in soft robotics education and research by lowering barriers to entry for learners from diverse disciplinary backgrounds. Through collaboration with the Department of Electrical Engineering and the University Libraries, the research team designed and piloted a multidisciplinary soft robotics training curriculum that enables students with little to no prior experience to develop foundational knowledge through structured, hands-on activities. The curriculum draws on project-based learning approaches that emphasize iterative design, teamwork, and learning through the construction and evaluation of physical artifacts [18, 19].

As a work-in-progress, this paper reports findings from the pilot implementation and is guided by the following exploratory research questions:

- RQ1: What preliminary changes in undergraduate students' perceived interest in and self-efficacy related to soft robotics are observed following participation in low-barrier, hands-on soft robotics workshops?
- RQ2: What instructional challenges and support needs are identified during the early implementation of modular, hands-on soft robotics learning activities for novice learners?

This work makes two primary contributions as a work-in-progress study. First, it describes the design and early implementation of an accessible, low-barrier soft robotics training curriculum, providing a replicable framework for institutions seeking to introduce soft robotics learning experiences to students from diverse academic backgrounds. Second, it documents instructional affordances and challenges observed during the pilot phase, offering formative, design-informed insights that inform future curriculum refinement and subsequent assessment-focused iterations.

As an exploratory pilot, the study is intentionally limited in scope and does not seek to evaluate comparative effectiveness, measure long-term learning gains, or establish causal relationships between participation and student outcomes. Instead, the focus is on examining how targeted student learning outcomes manifest during initial implementation and on identifying instructional supports, barriers, and design considerations that are critical for scaling soft robotics education in inclusive and pedagogically sound ways.

Curriculum Design

Soft Robots Prototyping Platform

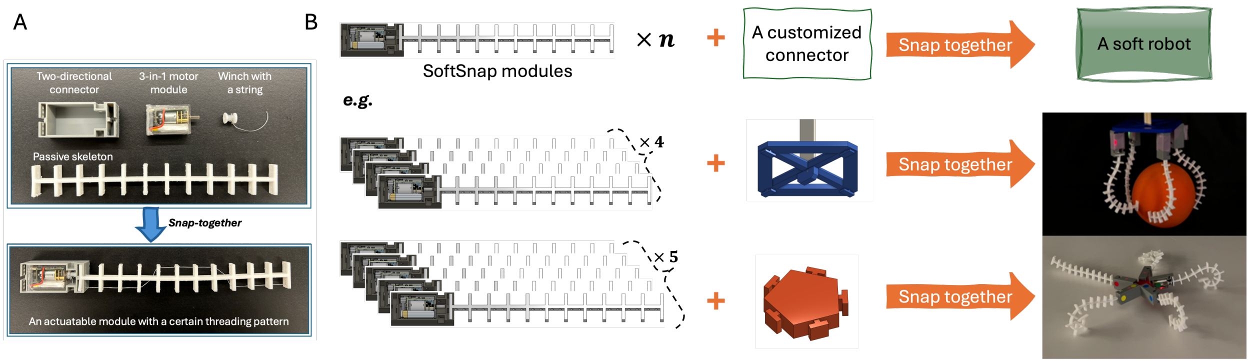

Figure 1: Overview of the modular soft robotic platform [20]. (**A**) Assembly of an actuatable module consisting of a passive skeleton, a 3-in-1 motor module, and a two-directional connector. (**B**) Multiple modules can be connected through customized connectors to form diverse soft robots, such as grippers and starfish-shaped configurations.

The curriculum is developed based on the SoftSnap modular soft robotic platform [20], which enables rapid prototyping of untethered soft robots using snap-together components, as illustrated in Figure 1. Each module integrates a flexible thermoplastic polyurethane (TPU) skeleton, a motor-driven cable actuation system, an onboard microcontroller (ESP32-C3), and a rechargeable battery, allowing fully wireless control and operation. The modules are joined through two-directional connectors that mechanically and electrically snap together, enabling reconfiguration without tools. Each module can be fabricated using off-the-shelf components and low-cost 3D printing, making the platform accessible, reproducible, and suitable for classroom or outreach deployment.

By rethreading a single actuation cable through different holes in the skeleton, students can rapidly explore diverse deformation modes—such as bending, curling, or twisting—without redesigning molds or hardware. Multiple modules can be assembled via 3D-printed connectors into various morphologies, including starfish-like, snake-like, gripper, and ring-shaped robots, demonstrating locomotion, grasping, and caging behaviors. A quasi-static simulation framework accompanies the hardware, predicting deformation based on threading geometry and cable tension to bridge physical design with modeling intuition.

The modularity and ease of reconfiguration make the platform uniquely suited for educational contexts, where students from diverse disciplines can engage with robotics design through low-cost, safe, and intuitive hardware. Its integrated sensing, wireless communication, and simulation support provide a tangible foundation for adaptive, data-driven scaffolding in soft robotics education.

Project-based Learning Experience

The primary instructional goal is to broaden participation in robotics by reducing reliance on advanced prerequisites and emphasizing learning-through-making. The curriculum is structured around a unifying design philosophy—Build, Benchmark, Evolve—which frames hardware development as an iterative scientific process rather than a one-shot construction task. This framing encourages students to view failure as productive data, aligning with research-oriented mindsets while reducing performance anxiety often associated with traditional laboratory courses.

Phase I: System Integration (Build). Students begin by assembling a baseline cable-driven soft robotic hand using a lab-provided kit. Activities include silicone casting, tendon routing, mechanical assembly, and basic actuator control. By providing standardized materials and a reference design, this phase minimizes financial and technical barriers while allowing students to gain confidence with unfamiliar tools and fabrication processes. Assessment is pass/fail and demonstration-based, emphasizing functional understanding over optimization.

Phase II: Benchmarking and Failure Analysis (Benchmark). Once a functional system is achieved, students systematically evaluate the manipulator against a standardized set of everyday objects (e.g., rigid, compliant, and elongated items). Rather than grading on success rates, students are assessed on their ability to document and analyze failure modes such as slippage, insufficient torque, or geometric mismatch. This phase explicitly reframes failure as a learning outcome and introduces students to experimental methodology, qualitative data analysis, and evidence-based reasoning.

Phase III: Reporting and Design Evolution (Evolve). In the final phase, students synthesize their findings into a comprehensive report and public poster presentation. Optional extension tracks allow motivated students to pursue deeper research contributions, such as modular redesigns, in-hand manipulation, or sensor integration. These extensions are framed as additive rather than required, preserving accessibility while creating pathways for advanced engagement and potential research authorship.

Several design decisions explicitly support inclusivity and low barriers to entry. First, the course relies on team-based work, allowing students to contribute according to their strengths while learning from peers. Second, material kits are fully provided, reducing cost barriers and ensuring equitable access to hardware resources. Third, grading emphasizes completion, documentation, and reflection rather than competitive performance metrics, which has been shown to disproportionately disadvantage students with less prior exposure to robotics.

Implementation

The study took place at a large public research university in the southeastern United States. The curriculum was partially implemented in Fall 2025 and Spring 2026 through two formats as described below.

Non-credit workshop. One workshop session was offered to students at the end of Fall 2025. The purpose of the workshop was to lower the entry barrier and provide an inclusive participation option for students from diverse backgrounds. It also helped us gather potential interest in soft robotics and develop better outreach strategies for the formal implementation. The workshop was advertised to undergraduate students two weeks in advance through the University Libraries' website and social media, and through emails to student organizations and clubs.

Experiential learning course. The formal implementation takes advantage of the university's creative learning program. This university-wide, faculty-mentored undergraduate research and creative practice program engages students from all majors in extended, project-based inquiry. Students participate in small teams led by a faculty mentor and earn academic credit for their involvement. Participation may span multiple semesters, allowing students to develop increasing levels of technical expertise, ownership, and professional identity. The program is open to undergraduates at all academic levels and is intentionally structured to support interdisciplinary collaboration and experiential learning. By offering the course through this program, we are able to offer student credits while emphasizing open-ended problem formulation, iterative design, and dissemination of results. The course was advertised to students through the program's website.

Targeted Student Learning Outcomes. As a work-in-progress study focused on early implementation, this project articulates a set of targeted student learning outcomes (SLOs) and a broader participation objective intended to guide curriculum design and formative assessment rather than summative evaluation. By the end of the workshop or course session, participating students were expected to demonstrate the following outcomes:

Conceptual Understanding. Students can describe, at a basic level, defining characteristics of soft robotic systems (e.g., compliant materials, cable-driven actuation) and explain how design choices influence deformation and motion.

System Assembly. Students can assemble a modular soft robotic system using provided components and produce a functional prototype capable of basic actuation and object interaction.

Teamwork and Collaboration. Students can work collaboratively in small, multidisciplinary teams to complete hands-on prototyping tasks, distribute roles, and communicate design decisions during iterative build-and-test cycles.

Participation Pathway Development. As a higher-level program objective, the curriculum seeks to support students' confidence and interest in pursuing further learning or participation in soft robotics-related activities; in this pilot, these dimensions were examined through self-reported perceptions rather than treated as direct measures of learning.

Data Collection

Multiple data sources were collected to support a formative, mixed-methods examination of student experiences and instructional practices during the pilot implementation. Consistent with the work-in-progress nature of the study, data collection emphasized indirect and qualitative indicators commonly used in early-stage engineering education research to surface instructional affordances, learner challenges, and promising directions for future, more objective assessment.

Student demographic information was collected prior to participation using a self-report questionnaire, including academic major, year of study, and prior exposure to robotics or related coursework. At the conclusion of the workshop or course session, students completed a post-session survey designed to capture perceptions of learning, engagement, teamwork, and self-efficacy related to the targeted outcomes and participation objective. Survey items were primarily descriptive and exploratory in nature and were not intended to support causal or comparative claims.

Instructor and graduate teaching assistant (TA) perspectives were gathered through semi-structured interviews conducted following the conclusion of the pilot activities. Interview protocols focused on instructional goals, mentoring practices, observed student challenges, perceived student development, and implementation considerations. All interviews were audio-recorded and transcribed to support systematic qualitative analysis.

Classroom observations were also conducted to document instructional activities, student interactions, and team dynamics during hands-on prototyping. Observation field notes focused on patterns of collaboration, help-seeking behavior, points of difficulty, and instructional scaffolding. These observational data were used to triangulate student self-reports and interview findings, strengthening interpretive validity across data sources.

All data collection procedures were reviewed and approved by the institution's Institutional Review Board (IRB).

Preliminary Findings

This section reports formative assessment findings from the pilot implementation, organized around the targeted student learning outcomes (SLOs) described earlier. Consistent with the work-in-progress nature of the study, the findings draw on multiple indirect and qualitative evidence sources—including student self-reports, observations, instructor and teaching assistant (TA) reflections, and student-created artifacts—to examine how the intended outcomes manifested during initial implementation. Table 1 summarizes the alignment between each outcome or objective and the corresponding evidence sources.

Student Demographics

For the workshop, 10 students signed up for registration, and 5 of them eventually participated in the workshop. For the course, 14 students enrolled, and 10 of them attended the first class session (those who did not attend due to time conflicts arranged individual meetings with the instructor). Table 2 summarizes the distribution of year of study, major, and gender identity of students who participated.

Table 1: Alignment of targeted student learning outcomes (SLOs) and the participation objective to evidence sources collected during the pilot implementation.

Targeted outcome or objective	**Primary Evidence Sources**
Conceptual understanding of soft robotics	Post-session survey items on learning new concepts and ability to explain how components are created/controlled (Fig. 4); brief in-session Q&A prompts during the introductory mini-lecture (observation field notes).
System assembly and functional prototyping	Student-created artifacts (completed gripper prototypes; Fig. 3); in-class build activity completion during the guided session (observation field notes); instructor/TA interview reflections on successful actuation and grasp demonstrations.
Teamwork and collaboration	Post-session survey items on confidence working on a team and contributing to a robotics application (Fig. 4); observation field notes documenting collaboration, help-seeking, and peer-to-peer explanation during build-and-test.
Participation pathway development	Post-session survey items on confidence/interest and intention to participate in future activities (workshop survey; Fig. 4); topical interest ratings (Fig. 5); instructor/TA interview reflections noting student excitement and follow-up inquiries about additional courses/workshops.

Table 2: Distribution of Student Demographics

Category	**Group**	**Workshop (n=5)**	**Course (n=10)**
Year of Study	Freshman	60%	–
	Sophomore	–	20%
	Junior	–	60%
	Senior	40%	20%
Major	General Engineering	20%	30%
	Computer Engineering	20%	10%
	Electrical Engineering	20%	20%
	Mechanical Engineering	20%	40%
	Biomedical Engineering	20%	–
Gender	Man	60%	80%
	Woman	40%	20%

Hands-on Activities and Outcomes

Both the workshop and class session had the same procedure. The session began with a 20-minute interactive lecture introducing the fundamentals of soft robotics, including defining characteristics, representative applications, core components, and common fabrication and actuation processes. Following the lecture, students participated in a 30-minute guided build activity in which they assembled a soft robotic gripper using the modular soft robotics system. Working in small groups (2-4) and supported by the instructor and teaching assistants, students explored modular assembly, deformation behavior, and basic design tradeoffs while constructing and testing their own gripper prototypes. Figure 2 illustrates students working collaboratively to prototype a soft robotic gripper and Figure 3 shows the completed artifacts.

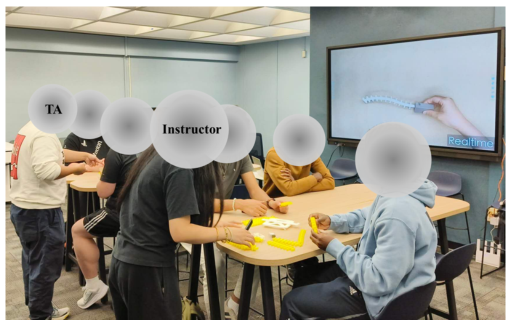

Figure 2: Student using modular robotic kits to assemble a soft robotic gripper.

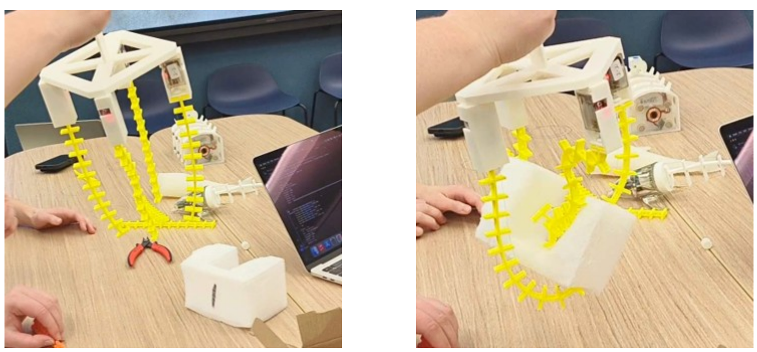

Figure 3: Student-built soft robotic gripper prototypes.

Post-session survey results suggest that students' feedback was overall positive. On a scale from "Strongly disagree" (1) to "Strongly agree" (5), workshop participants, on average, agreed that the workshop improved their knowledge of soft robotics (4.2) and ability to work with soft robotics (3.8). They also expressed strong interest in future participation in soft robotics workshops or coursework (4.6).

Similarly, Figure 4 illustrates student feedback for the class session. Students agreed that they learned new concepts about soft robotics, felt more confident working on a team and contributing to a robotics application, and became more interested in soft robotics. Figure 5 shows students' interest in learning more about soft robotics topics. Except for materials, students expressed high interest in all topics, especially simulation, modeling, sensing, and electronics.

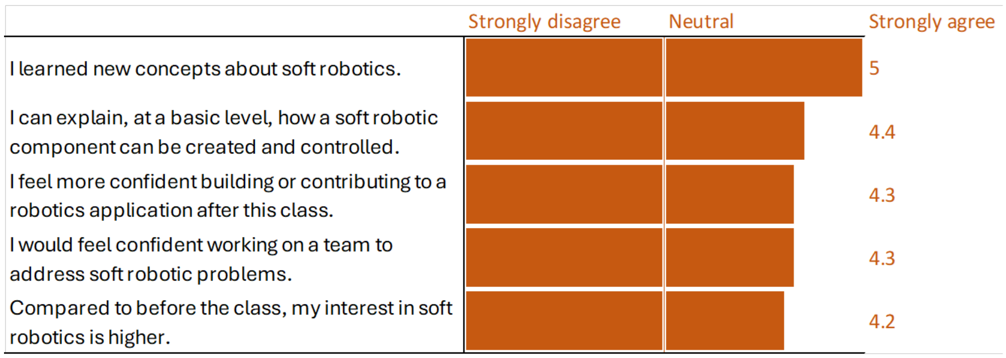

Figure 4: Average student ratings on session outcomes.

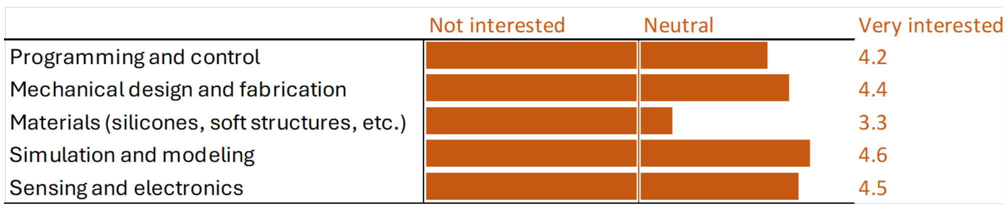

Figure 5: Average levels of interest in soft robotics topics.

Across the workshop and class session, students consistently reported that building their own robotic gripper prototypes was both the most engaging and the most challenging part of the session. Classroom observations indicated a clear increase in interactions between students and the instructor or TAs during the build process. In addition to signaling engagement, these interactions highlighted the difficulties students experienced during their first hands-on soft robotics activity. Specifically, students relied heavily on TA guidance while learning how to assemble the modules, and groups mentored by a more experienced TA progressed faster than other groups.

Instructor and Teaching Assistant Reflections

Semi-structured interviews with instructors and TAs also described overwhelmingly positive student responses, particularly during moments when students successfully assembled and actuated their own soft robotic grippers. One TA noted that students were "*happy when their robot gripper worked*" and became "*very passionate about our daily research and the project*" once they observed successful grasping behavior. Similarly, the instructor observed that when students saw the gripper grasp objects, "*every student is so excited,*" and that students in the workshop reached out to ask whether additional courses related to soft robotics might be offered.

At the same time, instructors and TAs consistently reflected on the challenges students encountered during the assembly process. Threading patterns, knot tying, and motor–winch integration were frequently cited as the most difficult tasks. One TA explained that threading was challenging because "*this is the first time they have practical experience on soft robots, especially these cable-driven modules.*" The instructor similarly acknowledged underestimating the difficulty of these steps, noting that tasks expected to take 10 minutes instead required "*like 30 minutes*" for students to complete. They also noted that students struggled to anticipate how different threading patterns would influence the robot's final motion.

Reflections further highlighted the need for additional instructional scaffolding. Both instructors and TAs suggested that short demonstration videos, example threading patterns, or concise assembly guides could improve efficiency and reduce repeated explanations. One TA commented that "*if we have a video to show them, it will be much simpler,*" particularly for difficult steps such as knotting and cable routing. The instructor echoed this concern, explaining that it was difficult to incorporate detailed assembly procedures into a lecture format without significantly slowing down the presentation.

Another prominent theme in the reflections was the importance of TA preparation. The instructor observed clear differences in student outcomes based on TA experience, stating that groups supported by well-trained TAs produced higher-quality grippers, whereas insufficient TA guidance led to partially functional artifacts. TAs themselves emphasized that repeated hands-on practice assembling the robot was essential for effective mentoring.

Finally, instructors and TAs reflected on the accessibility of the workshop to students with diverse backgrounds. Although most participants had limited prior exposure to robotics, interviewees reported that students were generally able to complete the workshop successfully with guidance. One TA noted that initial differences in experience required more explanation early on, but that students eventually "*get used to the whole process*" and performed well by the end of the session. These reflections suggest that the session was approachable for novice learners while still presenting meaningful technical challenges.

Discussion

This work-in-progress study explores the design and pilot implementation of a multidisciplinary soft robotics curriculum intended to lower barriers to participation while maintaining authentic engagement with complex engineering practices. Results from both the non-credit workshop and the experiential learning course suggest that a modular, hands-on structure can support meaningful entry for learners with heterogeneous prior preparation. This pattern is consistent with prior soft robotics education efforts that leverage low-cost materials, scaffolded build pathways, and openly available resources to broaden access without reducing the disciplinary authenticity of the work [21]. Our observed increases in interest and confidence also align with mechanisms emphasized in experiential learning and self-efficacy theory: repeated cycles of building, testing, and refining can convert early success into stronger beliefs in one's capability to "do" robotics, while compelling, tangible artifacts can trigger and sustain situational interest—especially for novices encountering an emerging technology for the first time [22, 23].

Although our curriculum intentionally reduced reliance on advanced prerequisites, students still encountered authentic technical challenges related to actuation, deformation behavior, and system integration—challenges that required iteration, physical reasoning, and empirical troubleshooting. This supports prior arguments in soft robotics education that accessibility does not equate to reduced rigor, but instead can re-center rigor around materiality, iterative design cycles, and "tinkering" competence that are characteristic of soft-robot development in practice [24]. The strong student interest in advanced topics such as simulation, sensing, and electronics suggests that early, artifact-centered experiences may function as a motivational "hook" that sustains engagement and prompts learners to seek deeper theoretical tools in later coursework.

The data also highlight the pedagogical value of productive struggle and failure within the Build–Benchmark–Evolve framework. Students consistently reported that assembling and testing their own robotic grippers was both the most engaging and the most challenging component of the session, which was echoed by instructor reflections. Our findings align with "productive failure" learning designs, where failed attempts are treated as informative data that fuel explanation-building and improved solutions rather than as endpoints [25]. Rather than viewing these difficulties as instructional shortcomings, the results suggest that soft robotics may be particularly well suited for pedagogies that normalize failure and reinforce research-oriented mindsets central to engineering design practice. Crucially, the non-destructive, snap-together nature of our TPU-based modular platform uniquely enabled this rapid iteration, allowing students to experience "productive failure" without the prohibitive time costs associated with traditional silicone casting.

At the same time, the findings underscore the importance of just-in-time scaffolding in hands-on soft robotics activities. Instructors and TAs noted that students needed more time and support than anticipated for procedural tasks, and that small differences in guidance led to substantial variation in group progress. This aligns with prior research suggesting that brief worked examples, demonstrations, and concise job aids can reduce extraneous load for novices [26, 27]. Groups with more experienced or better-prepared TAs progressed more consistently and produced more functional artifacts, while inconsistent support sometimes yielded partially operational systems. This finding suggests that in hands-on, embodied domains such as soft robotics, TA preparation is not merely a logistical concern but a key factor influencing consistency and scalability. Intentional TA training that emphasizes repeated hands-on practice and anticipates common student difficulties may therefore be essential for broader adoption of similar curricula.

Conclusion and Future Directions

This work-in-progress paper reports on the design and pilot implementation of a multidisciplinary soft robotics curriculum intended to lower barriers to participation while preserving authentic engagement with complex engineering practices. The preliminary findings suggest that the curriculum is approachable for students with limited prior exposure to robotics, while still offering meaningful opportunities to engage with technical concepts such as actuation, deformation behavior, and system integration.

As a work-in-progress, this study is necessarily limited by its small sample size, short duration, and reliance on self-reported measures of student experience. Consequently, the findings should be interpreted as illustrative rather than evaluative, and do not support claims about long-term learning gains, persistence, or transfer of skills. Nevertheless, the pilot implementation surfaced valuable design insights related to instructional scaffolding, the role of productive struggle, and the importance of teaching assistant preparation in hands-on, embodied learning environments.

These insights will guide future iterations of the curriculum, including the development of expanded scaffolding materials (e.g., short demonstration videos and assembly guides), more structured TA training that emphasizes repeated hands-on practice, and the collection of longitudinal data to examine how early exposure to soft robotics influences students' confidence, learning trajectories, and continued engagement over time. Through this iterative process, the project aims to contribute design-informed knowledge to the engineering education community and to support broader efforts to create inclusive, accessible pathways into emerging engineering fields such as soft robotics.

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