WIP: Soft Robotics as a Learning Platform: A Case Study on Using a McKibben-Muscle-B Module for Teaching Fluid Mechanics Concepts

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WIP: Soft Robotics as a Learning Platform: A Case Study on Using a McKibben-Muscle-Powered Module for Teaching Fluid Mechanics Concepts

Abstract

Soft robotics offers a hands-on way to contextualize fluid mechanics, though its use in thermo-fluid education is limited. This study implemented a seven-week soft robotics module in an undergraduate fluid mechanics course, where 22 students built a McKibben muscle-actuated fluid pump inspired by the human heart. Learning was assessed via demonstrations, analysis, and a post-module survey. Results show increased familiarity with soft robotics, positive engagement, and support for understanding fluid concepts, though some noted limited alignment with course content. Findings suggest soft robotics can enhance engagement and conceptual learning when clearly integrated into instruction.

Background

Soft robotics is a novel field that is undergoing rapid development and steady integration into industrial applications.[1] Characterized by their emphasis on compliance and deformability within both materials and actuation, soft robots can be advantageous over their more rigid counterparts in various settings, especially where high degrees of versatility or environmental adaptability are needed.[2] This has led soft robotics to be implemented into a wide range of applications, including biomedical uses, bionic technology, exploratory robotics, and many others.[3] In response to this uprise in technological and industrial developments within this field, engineering education has responded with a steady increase in pedagogical applications of soft robotics.[4] While educational robotics based on more traditional, rigid materials and actuators has been enormously successful in STEM education, soft robotics can be more effective in teaching concepts such as material science, bioinspired design, and actuation principles.[5] Because of this, educational soft robotics have been employed in a wide range of settings and topics, spanning K-12 through collegiate education, varying fields of application, and differing student backgrounds.[6, 7] Fluid mechanics is a core subject in mechanical engineering education[8] and can be used as an excellent platform for soft robotics education. Soft robotics has previously been used to teach various fluid mechanics principles, with applications generally falling into two categories: soft robots that use fluids for internal actuation, and soft robots that interact with fluids as an external medium.[9, 10] Educational modules leveraging both approaches have successfully conveyed fluid mechanics concepts like hydrodynamics, lift, drag, etc.[4, 11] Although both approaches cover fluid concepts, the use of soft robotic actuators allows analytical exploration of fluid concepts such as hydrostatics and pneumatics, which remain underrepresented in undergraduate fluid mechanics education.

This paper presents a novel soft robotic project for the introduction of fluid mechanics principles within a core Fluid Mechanics course at our institution. There are significant overlaps between soft robotics and fluid mechanics concepts (e.g., pneumatics, fluid-structure interactions), making Fluid Mechanics an ideal course to integrate soft robotics into a mechanical engineering curriculum. Furthermore, the current iteration of the Fluid Mechanics course at our institution has few project-based learning methodologies. As such, this research seeks to investigate the effect of introducing a hands-on, experiential learning module that blends soft robotics and fluidic principles within this course. Therefore, the project has two aims: 1) investigate the usage of a hands-on project to teach fluid mechanics concepts through soft robotics, and 2) explore whether that project can lead to increased awareness of soft robotics and its interdisciplinary applications.

Study Design and Implementation

The project was implemented in the Fluid Mechanics course as a group-based hands-on activity. The course follows a traditional lecture format without mandatory labs, and this project served as its hands-on component. The course was exclusive to mechanical engineering students. This module was implemented as a 7-week midterm project of a 14-week course with final demos delivered in class in Week 9. One lecture period equivalent was spent introducing students to the project with 1 lecture hour per week of available teaching assistant time to help with fabrication. It was introduced to 22 students, divided into groups of three or four to foster collaboration. Project objectives were to: 1) construct a McKibben muscle activated with a syringe, 2) create a compressive pump system using the muscle and a water filled IV bag to mimic a cardiologic device, 3) demonstrate measurable water movement, and 4) perform an engineering analysis. The muscles, shown in Figure 1a, are made from five items: nylon expandable cable mesh, 12" party balloons, 5/16" stop nuts, zip ties, and 1/8" flexible tubing. Students received a step-by-step guide and lab support for construction, inspection, and testing. They then calculated the final syringe pressure, plotted the pressure vs. volume curve, and listed analysis limitations and alternative applications. Assessment involved practical demonstrations using a manometer test (Figure 2b, d) and a pumping test (Figure 2a, c), along with a design report. Each team demonstrated their muscle could raise water in the manometer and move the predicted amount of water into a measuring cup within three pumps. A post-module survey was conducted to evaluate students' perceptions of the project and its effects. It included both quantitative and qualitative responses to capture overall progress and self-assessment. The quantitative section used Likert-style questions on topics such as general learning experience, soft robotics knowledge, and satisfaction. The qualitative section included three questions to explore deeper perceptions, including relevancy and difficulty. Together, the sections aimed to provide a comprehensive view of students' perceptions and expectations, complementing insights from project outcomes to assess the module's effectiveness. The full set of survey questions (Appendix A) and assignment prompt (Appendix B) are provided as a part of the Appendix.

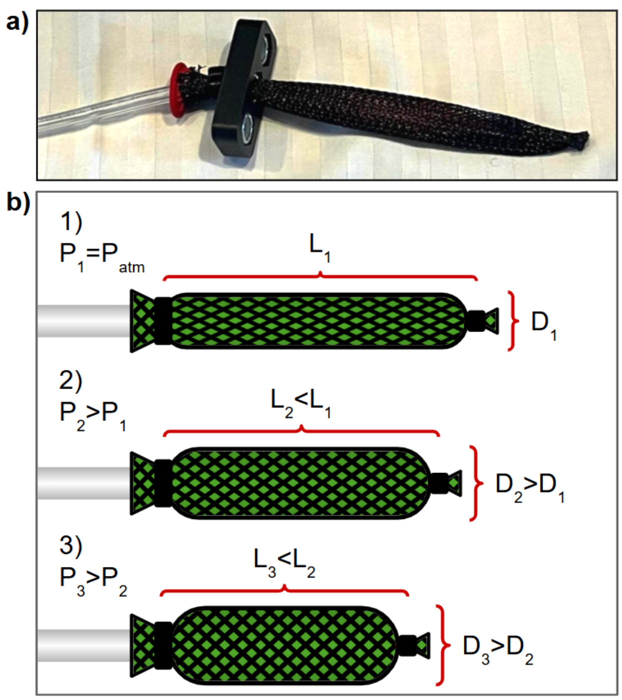

Figure 1: a) actual McKibben muscle and b) McKibben muscle operating principle, where P is pressure, L is length, and D is diameter.

Project Outcomes

All groups and participants successfully built McKibben muscles. Most initial designs performed well, with minor issues such as slight air leaks or muscles being too short, which were easily fixed. Performance was evaluated in two tests: a vertical "manometer" measuring water displacement (≥10 inches for success) and an IV flow test measuring 50 ml fluid displacement over three pumps, with a curved tube adding difficulty. All teams successfully completed both demonstrations in class and submitted design reports analyzing their systems. They also identified most calculation limitations and proposed novel applications for the McKibben muscles. Student success in achieving the project objectives, their ability to accurately explain the calculations that informed the project, and their ability to identify other uses of McKibben muscles demonstrated satisfactory learning related to both soft robotics and fluid mechanics.

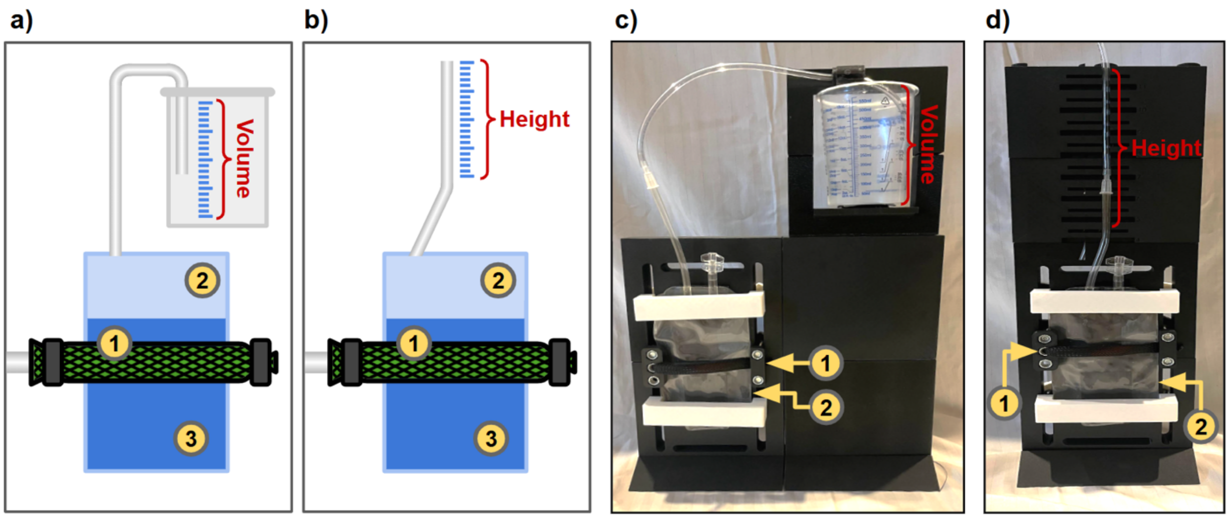

Figure 2: a) diagram of volume testing setup, b) diagram of pressure testing setup, c) actual volume testing setup, and d) actual pressure testing setup. Key: 1) McKibben muscle, 2) IV bag, and 3) working fluid (water).

Survey Outcomes

The survey, as previously mentioned, was conducted immediately after the completion of the module within the Fluid Mechanics course. The number of respondents of the survey was 9 out of 22 enrolled students, a 40% response rate. This lower percentage may have been caused by a lack of motivation or indifference towards taking the survey. Although this response rate is sufficient for analysis purposes, nonresponse bias may play an effect, especially with the possibility that respondents were only from select groups. Survey questions were intended to capture students' perceptions and experiences in soft robotics in respect to the project. A total of 7 Likert-style questions were asked on this topic, with responses ranging from "Strongly agree" to "Strongly disagree" on a 5-point scale. Figure 3 shows the responses to soft-robotic-related questions. Overall, the responses captured in this section indicate the project's influence on students' knowledge and perception of soft robotics was significant. As indicated by the first two questions in Figure 3, students self-reported a significant increase in familiarity with soft robotics over the course of the module, shifting from an even split of agree, neutral, and disagree prior to the project to a 100% agreement rate following its completion. Furthermore, a majority (78%) of students reported that the hands-on experience increased their understanding of soft robotics, as shown under the question "Hands-On Increases SR (Soft Robotics) Understanding." The last three questions in Figure 3 related to student comfort in working with soft robotics. A 2/3 majority reported that they were comfortable working with a new project related to soft robotics (from "SR Comfort"). The questions "SR Comfort, Soft" and "SR Comfort, Robotics" asked students on their comfort level in working with the "Soft" or the "Robotics" aspects of soft robotics. The "agree" response rate was 89% and 67%, respectively. The lean towards the "Soft" aspect of soft robotics is likely due to the nature of the project, as actuation of soft materials and their interaction with fluids was highlighted rather than other aspects of soft robotics that better align with "Robotics." This shows that students' comfort level in respect to this field was influenced by the project's implementation.

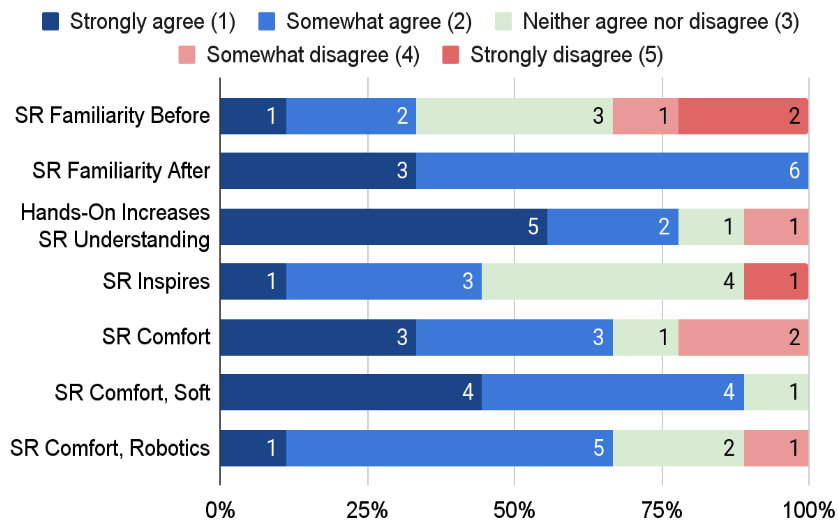

Figure 3: Response data for 7 Likert scale questions on the topic of soft robotics.

The question "SR Inspires" asked students whether the module inspired them to read more about the field of soft robotics. Overall, responses to this question are mixed, with 4 out of 9 respondents (44%) agreeing to the question prompt, while another 4 were neutral and one person highly disagreed with the prompt. This can be explained by the sample of students possessing a variety of interests within engineering, some of which align with soft robotic concepts and others do not. This is backed by qualitative data, as a question that asked "which topics did you find most relevant for your future goals?" yielded responses indicative of this. Some of the responses show that the module inspired interest within the topic of soft robotics, as two students reported that "seeing the application and potential uses of soft robotics was interesting to me as an aspiring engineer", and "how soft robotics can have different applications I wouldn't have thought about before" was relevant. However, other responses indicated that some students did not resonate with the soft robotics concepts due to interests in separate fields, one of which was "Aerodynamics in the course as a whole is probably more in line with my future plans as a Mechanical Engineer in automotive fields, more than Soft Robotics", and another respondent's perceived relevancy was "None. I plan on doing nuclear related work independent of soft robotics." This indicates that the project's inclusion of soft robotic principles led to an increase in interest in some students who were more receptive to the topic. On the other hand, the field's inclusion was perceived as to be not as relevant to students who had pre-existing career goals they felt were disconnected from soft robotic applications.

This perceived relevance to their future careers could have affected a quantitative metric in the survey that measured students' likelihood to recommend the project to a fellow peer, the results of which are shown in Figure 4. Students responded to this question on a level from extremely likely to extremely unlikely on a 10-point scale, shown below. As one can see in Figure 4, some of the students (33%) gave a higher recommendation rating between 1-2 for this module, while a majority (67%) gave a lower rating between 5-8, with responses divided into two district groups. Additionally, some of the qualitative responses describe negative feedback that may have contributed to this effect. A few students who rated this question lower cited aspects needing to be improved on due to the developmental nature of the module. This includes responses such as "make the fabrication instructions clearer" and "the instruction for building were a little [complicated]" that indicate the instructions may have been hard to follow for these students. Another student who gave a lower rating for this question stated "I feel you should make design aspect little more advance[d]." These responses show that the likely cause of lower recommendation ratings was perceived relevance to their future careers as well as the fact that the module was untested previously and needs slight improvements to better cater to students' needs. Student-identified factors for potential improvement that will be considered and refined in the future iterations of the learning module, hopefully leading to higher scores in this metric in future implementations.

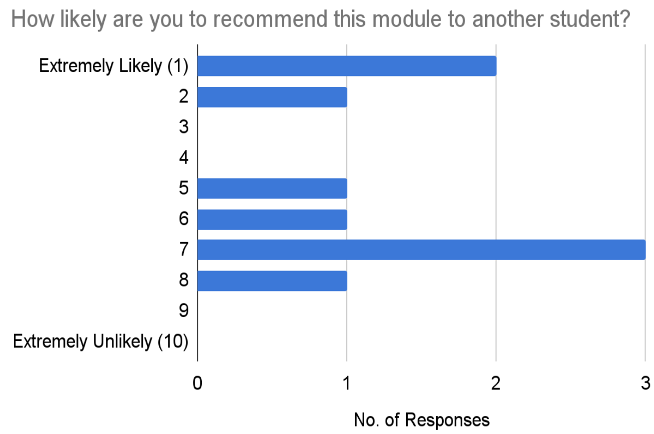

Figure 4: Ratings for likelihood of students recommending this project to a peer.

Another aspect of the project investigated in the survey was students' overall learning experience. These included questions related to the practice of integrating two disciplines in the project, whether learning was effective within the module in general, and student satisfaction. The results from these other Likert-style questions are shown in Figure 5. Overall, the results from these questions show the learning experience was perceived by a majority of students to be effective. A majority of respondents (78%) agreed to the prompt "The module taught me how to better integrate knowledge from two or more disciplines". This is a positive outcome for the project as a whole, as a key goal behind it was the emphasis on integrating disciplines. Furthermore, this soft robotic application of fluid mechanics principles was perceived by the students to have utility, as reflected in their qualitative prompt responses. Students were asked about what made the module useful, with three responses to this being "the concepts of fluid movement has been very useful in conjunction with soft robotics principles," "the application factor helps visualize real world applications it can be used for," and "the fact that we directly applied the fluid mechanics concepts that we learned in class to the project made it useful." These three responses all highlight a perceived benefit from observing, interacting, and learning from a real-life application of fluid mechanics into the soft robotics platform, a significant positive takeaway for the project as a whole despite the mixed feedback on career relevance and recommendation of the module to peers.

However, although there were several positive aspects of responses about perceived utility, a few negative responses were recorded as well. These responses highlight that the project felt pushed onto the students or randomly placed in the curriculum, specifically with the soft robotic aspect of it. One student commented that the module "felt railroaded," while another stated, "we did not talk at all about soft robotics in class, which made the project feel somewhat random." These comments indicate that while the project was generally received well as a cross-disciplinary platform for increased fluid mechanics knowledge, the connections to soft robotics in the broader course could have been clarified. Despite some negative reception of the project, a majority of respondents strongly agreed (56%) and none disagreed with the prompt "The learning tools and course activities (notes, slides, videos, demonstrations, projects, hands-on experiences, etc.) are effective in promoting my learning experience," as shown by the responses for "Learning Tools Effective" in Figure 5. This result shows that students generally agreed that the project assisted their learning experience. Students also responded with a high agree rate (78%) on a prompt on outcome satisfaction, as shown by the data for "Satisfied With Outcome" in Figure 5. Overall, these data suggest that students' overall learning experience was positive.

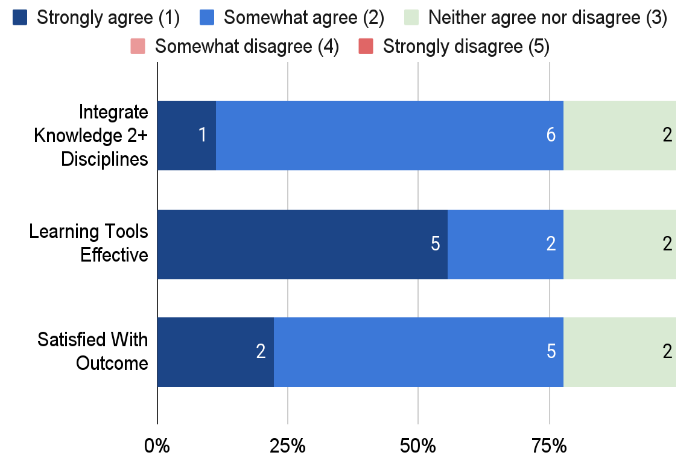

Figure 5: Likert scale ratings from three questions related to students' learning experiences.

Discussion and Future Work

Analysis of project outcomes and student survey responses indicates that the module increased student familiarity with soft robotics and was generally perceived as an effective learning experience. Students with prior interest in soft robotics reported higher engagement, while those focused on other areas noted weaker alignment with the project. Because soft robotics functioned primarily as a contextual tool rather than a central course topic, some students perceived a disconnect between the project and core fluid mechanics content. Nevertheless, the module was well received as a cross-disciplinary approach to supporting fluid mechanics learning. Based on student feedback and the outcomes of this first implementation, future iterations of the module will focus on improved implementation and framing. To improve implementation, planned revisions include refining fabrication instructions and dedicating additional in-class time to introduce the project. To improve framing, more emphasis on the project being an interdisciplinary activity will be made along with clearer connections to soft robotics and course content. Furthermore, the possibility of creating different disciplinary scenarios within the project for students to choose from will be explored, with the intent to better tailor the project to individual student interests. Future studies will improve survey questions as well as include a comparison class that does not use the module to assess differences in learning experiences and soft robotics awareness. Additionally, future surveys will implement literature-reported methods of increasing student response rates to decrease the potential for nonresponse bias.

Acknowledgement

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References

[1] O. Yasa *et al.*, "An overview of soft robotics," *Annual Review of Control, Robotics, and Autonomous Systems,* vol. 6, no. 1, pp. 1-29, 2023.

[2] C. Majidi, "Soft-matter engineering for soft robotics," *Advanced Materials Technologies,* vol. 4, no. 2, p. 1800477, 2019.

[3] Y. Wang, Y. Wang, R. T. Mushtaq, and Q. Wei, "Advancements in soft robotics: A comprehensive review on actuation methods, materials, and applications," *Polymers,* vol. 16, no. 8, p. 1087, 2024.

[4] I. U. Cayetano-Jiménez, E. A. Martinez-Rios, R. Bustamante-Bello, R. A. Ramirez-Mendoza, and M. S. Ramirez-Montoya, "Experimenting with soft robotics in education: A systematic literature review from 2006 to 2022," *IEEE Transactions on Learning Technologies,* vol. 17, pp. 1249-1266, 2024.

[5] X. Yu, S. G. Nurzaman, U. Culha, and F. Iida, "Soft robotics education," *Soft Robotics,* vol. 1, no. 3, pp. 202-212, 2014.

[6] X. Yu, D. Assaf, L. Wang, and F. Iida, "Robotics education: A case study in soft-bodied locomotion," in *2013 IEEE Workshop on Advanced Robotics and its Social Impacts*, 2013: IEEE, pp. 194-199.

[7] B. Finio, R. Shepherd, and H. Lipson, "Air-powered soft robots for K-12 classrooms," in *2013 IEEE Integrated STEM Education Conference (ISEC)*, 2013: IEEE, pp. 1-6.

[8] M. Zhao, X. Lan, Z. Jia, and H. Sun, "Research on Teaching Mode Reform of Fluid Mechanics Under the Consideration of Engineering Education Certification," in *2023 9th International Conference on Humanities and Social Science Research (ICHSSR 2023)*, 2023: Atlantis Press, pp. 1362-1369.

[9] P. Polygerinos *et al.*, "Soft robotics: Review of fluid-driven intrinsically soft devices; manufacturing, sensing, control, and applications in human-robot interaction," *Advanced engineering materials,* vol. 19, no. 12, p. 1700016, 2017.

[10] F. Giorgio-Serchi and G. D. Weymouth, "Underwater soft robotics, the benefit of body-shape variations in aquatic propulsion," in *Soft Robotics: Trends, Applications and Challenges: Proceedings of the Soft Robotics Week, April 25-30, 2016, Livorno, Italy*: Springer, 2016, pp. 37-46.

[11] T. R. Consi, D. Fan, and G. Jodin, "Fishbots: Bio-inspired marine robots give students a hands-on introduction to fluid mechanics," *Marine Technology Society Journal,* vol. 54, no. 4, pp. 6-15, 2020.

Appendix A: Soft Robotics Modules Survey

Start of Block: Consent

Q1 **Cultivating the Future Soft Robotics Workforce through Integrated Undergraduate Research and Education** You are invited to participate in this online research survey entitled Soft Robotics Module Learning Experience Survey. You have been invited to participate in this survey because you are a Rowan undergraduate student in a course with implemented soft robotics learning modules and above the age of 18. We would like to hear about your learning experience. The number of participants to be enrolled in the study will be up to 230. The survey may take approximately 15 minutes to complete. You will be asked to complete the survey in class, but your participation in the research element of the survey is voluntary. If you would like to allow your data to be used for research, check the second box below. Checking both boxes below and completing this survey indicates that you are voluntarily giving consent to use your responses in research. You can complete the survey without consenting to your data being used for research purposes by leaving the second checkbox blank. The purpose of this research study is to understand how well students learn the soft robotics related concepts and skills after taking relevant courses and their overall abilities in applying engineering methods in solving problems in soft robotics projects. We will use this information to improve our course design, which in turn will promote students' learning experience. There are no foreseeable risks or discomforts associated with this survey. There may be no direct benefit to you, however, by participating in this study, you may help us understand the weaknesses in our current course design, so we can make necessary changes to improve the learning experience for future students. Your response will be kept confidential. We will store the data in a secure, password protected folder and the data will be destroyed once it has been published. Your participation in the study will not impact or affect your student status. It is not required as part of an engineering course. It is not associated with your student records. Any part of the research that is published as part of this study will not include your individual information. If you have any questions about the survey, you can contact Dr. Wei Xue at the address provided below, but you do not have to give your personal identification. Wei Xue, Associate Professor, Mechanical Engineering, Rowan Hall 227, xuew@rowan.edu, (856) 256-5358. If you have any questions about your rights as a research subject, please contact the Office of Research Compliance at (856) 256-4078– Glassboro/CMSRU. This study has been approved by the Rowan IRB, PRO-2022-412.

*

Q2 Please complete the checkbox below.

▢ To participate in this survey, you must be 18 years or older. To indicate you are 18 years of age or older, place a checkbox here. (1)

▢ If you consent to have your data used in published research, place a checkbox here. (2)

End of Block: Consent

Start of Block: General Module Information

Q3 Which of the following modules did you most recently complete?

○ Intro to Mechanical Design (ME 10101) (1)

○ Manuf. & Meas. Tech (ME 10210) (2)

○ Dynamics (ENGR 01291) (3)

○ Materials Science & Mfg. (ENGR 01283) (4)

○ Intro Thermal-Fluid Sciences (ME 10310) (5)

○ Dynamic Systems & Control (ME 10345) (6)

○ Mechatronics (ME 10442) (7)

○ Introduction to Soft Robotics (ME 10466) (8)

○ Machine Design (ME 10301) (9)

○ Sophomore Clinic (ENGR 01202) (10)

○ Fluid Mechanics for Mechanical Engineers (ME 10330) (11)

Q4 What format of delivery was your module?

- ○ Virtual (1)
- ○ In-Person (2)
- ○ Hybrid (3)

End of Block: General Module Information

Start of Block: Concepts and Skills

Q6 Which of the following concepts did you address in the module? Select all that apply.

- ☐ Soft Materials (1)
- ☐ Smart Structures (2)
- ☐ Sensing Mechanisms (3)
- ☐ Actuation Principles (4)
- ☐ Fabrication Methods (5)
- ☐ Modeling (6)
- ☐ Robotics (7)
- ☐ Control (8)
- ☐ Machine Learning (9)
- ☐ Design (10)

Carry Forward Selected Choices from "Which of the following concepts did you address in the module? Select all that apply."

X→

Q7 Please drag and drop the options to rank the concepts you applied from most relevant (1) to least relevant to how you understand the field of soft robotics.

______ Soft Materials (1)
______ Smart Structures (2)
______ Sensing Mechanisms (3)
______ Actuation Principles (4)
______ Fabrication Methods (5)
______ Modeling (6)
______ Robotics (7)
______ Control (8)
______ Machine Learning (9)
______ Design (10)

End of Block: Concepts and Skills

Start of Block: Module Perspectives

Q8 Please tell us about your module experience.

	Strongly Agree (1)	Somewhat Agree (2)	Neither agree nor disagree (3)	Somewhat Disagree (4)	Strongly Disagree (5)
I was familiar with Soft Robotics concepts BEFORE taking the module. (1)	o	o	o	o	o
I am familiar with Soft Robotics concepts AFTER taking the module. (2)	o	o	o	o	o
The module taught me how to better integrate knowledge from two or more disciplines (materials, mechanics, physics, biology,...). (17)	o	o	o	o	o
The lecture materials are relevant to the scope of the module. (3)	o	o	o	o	o
The lectures are well presented. (4)	o	o	o	o	o
The concepts are explained clearly in lectures. (5)	o	o	o	o	o
The hands-on components (demonstrations, experiments, and projects) are interesting. (6)	o	o	o	o	o
The hands-on components improved my understanding of soft robotics concepts. (7)	o	o	o	o	o
The instructions for the hands-on components are easy	o	o	o	o	o

to follow. (8)					
The hands-on components align well with the lectures. (9)	○	○	○	○	○
There should be more hands-on components in this course. (10)	○	○	○	○	○
The module inspires me to read more about Soft Robotics. (11)	○	○	○	○	○
The learning tools and course activities (notes, slides, videos, demonstrations, projects, hands-on experiences, etc.) are effective in promoting my learning experience. (12)	○	○	○	○	○
I am comfortable working on a new project related to Soft Robotics. (13)	○	○	○	○	○
I am comfortable with the "Soft" (or materials) aspect of Soft Robotics. (14)	○	○	○	○	○
I am comfortable with the "Robotics" aspect of Soft Robotics. (15)	○	○	○	○	○
Overall I am satisfied with the learning outcomes from this module. (16)	○	○	○	○	○

Q9 How likely are you to recommend this module to another student?

- ○ Extremely Likely (1)
- ○ 2 (2)
- ○ 3 (3)
- ○ 4 (4)
- ○ 5 (5)
- ○ 6 (6)
- ○ 7 (7)
- ○ 8 (8)
- ○ 9 (9)
- ○ Extremely Unlikely (10)

Q10 What about the module has been useful and what has made it feel useful? How could non-useful things be made to feel more useful?

____

____

____

____

____

Q11 What about the module has been difficult and what has made it feel difficult? How could the instructor(s) make it better?

____

____

Q12 Which topics did you find most relevant for your future goals? Why?

End of Block: Module Perspectives

Appendix B: Assignment Prompt and Project Guidelines

Midterm Project

Bio-Inspired Fluid Mechanics: Designing an Artificial Heart Sleeve

Final content due and demo: Nov 3rd

This document defines your assignment. Please refer to project guidelines for help with fabrication information.

Narrative: In the not-so-distant future, cardiac failure remains one of the leading causes of death worldwide. While mechanical hearts and artificial pumps have advanced, they are still plagued by issues: rigid components wear out, cause blood clotting, and fail to replicate the dynamic, organic nature of a real heartbeat. A biomedical startup named SomaPulse has launched a bold initiative: to build a fully soft, bio-inspired cardiac assist device. No pistons. No rotating parts. Just air, elastic membranes, and geometry - like the body itself. The concept borrows from nature's own design - a muscular sleeve that contracts in synchrony with the heart to augment its pumping power.

You are part of a design team contracted by SomaPulse to create a proof-of-concept artificial heart sleeve using McKibben muscles, a type of pneumatic actuator modeled on human muscle. These muscles can contract and squeeze in response to air pressure, an ideal stand-in for biological motion. The goal? Use your McKibben muscle to rhythmically squeeze a water-filled chamber (simulating a heart ventricle) and demonstrate measurable flow, the first heartbeat of a soft robotic system. But there's a catch: SomaPulse is on a tight deadline to impress investors. Your prototype must be complete by mid-semester, and each engineer must be able to fabricate their own actuators to prove the design's robustness and reproducibility. Your team's success could mark a new era in biomechanical design - or just another heartbeat missed.

Project Brief: You have been tasked with designing a wearable system of soft artificial muscles that can compress a flexible fluid chamber (saline/IV bag) to displace water, mimicking the action of a ventricle. The muscles will be manually actuated using syringes and tubing, allowing you to analyze unsteady flow, force generation, and fluid displacement without electronic components. Your team of three engineers will collaboratively wrap your artificial muscles around a shared fluid chamber. However, each team member must individually fabricate and test their own muscle unit, contributing to the overall sleeve.

Project Goals

- Design and fabricate a set of McKibben muscles using instructions given in project guidelines.
- Integrate muscles with a fluid filled IV/saline bag to create a functioning peristaltic or compressive pump system as shown in project guidelines.
- Demonstrate that your design can move a quantifiable amount of water using pneumatic actuation using compression cycles.
- Analyze your design.

Learning Objectives

By completing this project, students will:

- Understand the working principle of McKibben artificial muscles.
- Apply core fluid mechanics concepts, including:
  - Unsteady flow and pressure transients
  - Force-balance and pressure-volume work
  - Conservation of mass in deformable systems
  - Translate biological inspiration into mechanical design.
- Collaborate effectively in a team while documenting individual contributions.

Deliverables

Each student must individually fabricate and test their own muscle set. As a team, you will submit the following. The demonstration will be performed with only one muscle per team.

Component	Format	Due Date
Muscle Fabrication	Demonstration in class	3^{rd} Nov
Design Documentation	PDF	3^{rd} Nov
Engineering Analysis Report	Embedded in Documentation	3^{rd} Nov

Your report should contain the following information:

1. A section describing the design of the muscle.
2. An engineering analysis specifically addressing the following questions:
    a. Assume you are analyzing the saline/IV bag as a manometer. As you actuate the muscle, the fluid level in the IV bag/tubing rises. Assuming the pressure rise in the tubing is *h* meters, how much does the pressure increase at the actuation point? First present your answer in the form of variables. Then answer: How much would the pressure change if the fluid in the bag is blood instead of water? What would be the pressure change required if you need to pump the blood to a height equivalent to 150 mm Hg. Explain the limitation of your analysis, if any. Make appropriate assumptions.
    b. Calculate the pressure change inside the syringe assuming the volume of the McKibben muscle does not change. Plot the pressure change as a function of syringe volume using at least 3 points. Make appropriate assumptions. Explain the limitation of your analysis, if any.
3. The artificial muscle sleeve project is not working out so well at SomaPulse. Your team has been tasked with coming up with an alternative commercial application for your muscle system. Each team member should propose one application and you justification for using McKibben muscle. Make sure that you list the name of the team member in the report.

Grading Rubric

Category	Points	Excellent	Average	Poor
Functionality	40	Muscles actuate reliably and pump measurable water. Tight integration with IV bag. System is sealed and repeatable.	Muscles inflate but water movement is limited or inconsistent. Leaks or poor attachment reduce performance.	Muscle does not actuate or fails to move water. Leaks, poor construction, or incomplete integration.
Engineering Analysis	30	Clear explanation with correct physics. Uses pressure-volume concepts, force estimates, and flow calculations.	Basic or partially correct explanation. Some relevant ideas but lacks detail or contains errors.	Little or no application of fluid mechanics. Vague, incorrect, or missing analysis.

Category	Points	Excellent	Average	Poor
Design Documentation	20	Detailed steps with labeled diagrams or photos. Design reasoning is explained clearly.	Some documentation present but lacks visuals or detail. Unclear fabrication process.	Incomplete or missing write-up. No visuals or explanation of design steps.
Presentation & Clarity	10	Clear, confident, and engaging. Ideas are well-organized and easy to follow.	Adequate but unpolished. Some unclear sections or weak visual aids.	Confusing or disorganized. Lacks clarity or preparation.

Project Guidelines

McKibben Muscle Fabrication & Guidelines

Materials List (per person or group)

- Latex balloons (5–9 inch party balloons recommended) **Given or Student Choice**
- ½" Braided nylon sleeve (e.g., expandable cable sleeve) **Given**
- Zip ties or thread (to anchor sleeve ends) **Given or Student Choice**
- Hex nuts (for weight / muscle preload) **Given**
- 1/8" plastic tubing (at least 2-4 inches for muscle construction) **Given**
- 3/16" tubing connectors (for multiple muscles to be powered at once) **Given or Student Choice**
- 250mL Syringe **Given**
  - Possibly treat foot pump
- Some heating source must be obtained (lighter, hair dryer, heat gun) **Students Choice**
- 350 mL IV Bag **Given**

Purchase List: Assuming for 10 teams each making 3 muscles

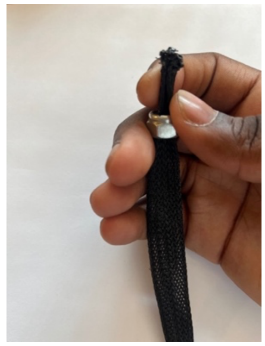
- Braided Sleeve **Quantity: 2**
- Zip Ties **Quantity: 2**
- Balloons **Quantity: 2**
- Plastic Tubing **Quantity: 2**
- Tubing Connectors **Quantity: 3**
- 250mL Syringes **Quantity: 6**
- Measuring Cups **Quantity: 1**
- Lock Nut **Quantity: 1**

Muscle Fabrication Steps: Video Example From Online

- **Step 1:** Cut the desired length of the nylon sleeve. (¼" inch longer than balloon)

- **Step 2:** Carefully use heating source to lightly singe the ends of the nylon sleeve to avoid further unraveling. (Be careful not to completely melt the sleeve ends and seal it)

- **Step 3:** On one end of the sleeve, screw on a stop nut (hex nut). This can be done by pinching the end of the sleeve closed and fitting it into the nut and twisting with pressure to have the end go through the nut. After the end is completely through the nut, this end can be sealed shut using a heating source. Use the image below as a reference.



- **Step 4:** Carefully insert the balloon into the sleeve. This can be done by putting the tip of the balloon in the sleeve. After getting the balloon tip into the sleeve, pinch the sleeve and slide your fingers down to the inserted tip of the balloon. This will cause the tip to widen. When this happens, using the same hand, pinch onto the tip of the balloon and pull it towards the end of the sleeve. Repeat this process until the end of the balloon reaches the end of the sleeve
- **Step 5:** Slide stop nut down to the open end of the sleeve. (Be careful not to slide all the way down to balloon end)
- **Step 6:** With the nut at the end of the sleeve, insert the plastic tubing into the balloon until you feel contact is made with the nut. Once contact is made, tighten the nut onto the tubing to secure it in place inside the balloon.
- **Step 7:** Once screwed onto the tubing, use a zip tie to add additional support and avoid air leakages.
- **Step 8:** Connect plastic tubing to a syringe and inflate. The balloon should inflate, and the sleeve should decrease in length.

Integrating With IV Bag:

- Instead of making a new silicone model, IV bag will make calculations and tests more standard.
- IV bag will be 350mL and will be squeezed by muscles. Simulate the heart experiment.
- The length of the tubing connected to the IV bag can be set and changed for different scenarios.

Testing and Measurement:

- For the project, groups of 2-3 can construct up to 3 muscles to be used on the IV Bag.
- These groups are tasked with constructing air muscles that will compress an IV Bag and cause enough pressure and force to have the fluid travel to a measuring container. Achieve a certain flow rate based on calculations.
- Before testing students will do sample calculations to determine the length, design, and orientation of their muscles.
    - Equations:
    - $P_1V_1 = P_2V_2$, final pressure from syringe to muscle
    - $P_{IV} = \frac{(8\mu LQ)}{\pi r^4}$, pressure of IV bag to achieve length and volumetric rate
    - $F = P_{IV} \cdot A_{IV}$, force on the IV bag
    - $C = \frac{(L_o - L_f)}{L_o}$, contraction ratio of the McKibben muscle
        - Based on the ratio, the value of θ can be approximated.
    - $F = P_2 \cdot A_{muscle} \cdot (3\cos^2 \theta - 1)$, Pressure of the muscles to achieve force
- After calculations and testing, the actual flow rate will be compared to theoretical values previously calculated.

Useful Tips:

- Be extremely careful when using heating sources
- Practice and familiarize yourselves with the muscles to get a feel for how strong they really are.
- Experiment several times, will need several trials and revising