Introducing Bioengineering to Non-Majors: An Active Learning Model for Interdisciplinary STEM Engagement

Prof. Caroline Cvetkovic, University of Illinois Urbana-Champaign

Caroline Cvetkovic is a Teaching Assistant Professor of Bioengineering at the University of Illinois Urbana-Champaign, where she instructs courses in quantitative physiology, biofabrication, and heat transfer. She earned her B.S., M.S., and Ph.D. in Bioengineering at the University of Illinois Urbana-Champaign. She then completed a postdoctoral fellowship in the Center for Neuroregeneration and Department of Neurosurgery at the Houston Methodist Research Institute.

Prof. Enrique Valera, University of Illinois at Urbana - Champaign

Enrique Valera is a Research Assistant Professor in the Department of Bioengineering at the University of Illinois Urbana-Champaign. Over the past 20 years, his research has focused on biosensor technologies and their applications in clinical diagnostics and food safety. His work includes the development of electrochemical and optical sensing platforms, with particular expertise in multiplexed quantification of human biomarkers, detection of nucleic acid targets and pathogens, and analysis of low molecular weight analytes. Prof. Valera has extensive experience in designing point-of-care diagnostic devices and microfluidic cartridges for clinical applications, including molecular diagnostics and pathogen detection encompassing nucleic acid targets, bacteria, and respiratory and bloodborne viruses. Enrique received his PhD in Electronic Engineering from Universitat Politècnica de Catalunya.

Mr. Andy Granados, University of Illinois at Urbana - Champaign

Andy Granados (he/him) is a second-year undergraduate student studying bioengineering in the Grainger College of Engineering at the University of Illinois Urbana-Champaign. He studies applications of soft robotics in medical device design and is interested in increasing accessibility in engineering education. Andy plans to pursue graduate school and a career in biomedical research.

Prof. Holly M Golecki, University of Illinois at Urbana - Champaign

Dr. Holly Golecki (she/her) is a Teaching Associate Professor in Bioengineering at the University of Illinois Urbana-Champaign and Department of Biomedical and Translational Sciences at the Carle-Illinois College of Medicine. Holly studies biomaterials and soft robotics and their applications in the university classroom, in research and in engaging future engineers in human-centered design. Holly received her BS/MS in Materials Science and Engineering from Drexel University and her PhD in Engineering Sciences (Bioengineering) from Harvard University.

Introducing Bioengineering to Non-Majors: An Active Learning Model for Interdisciplinary STEM Engagement

Abstract

Bioengineering is a multidisciplinary field that applies engineering principles to address challenges in medicine and human health. Bioengineering is relevant to multiple majors, specialties, and student interests. An introductory course for honors students outside the bioengineering major at a large, public institution provides an appreciation of the field's interdisciplinary nature. The course exposes students to topics such as medical imaging, biomaterials, nanotechnology, medical device design, and neural engineering, and insights into campus research facilities and potential career paths. Unlike traditional lecture-based introductory courses, this course experimented with a mix of lecture and active learning classes intentionally designed to promote active engagement, connect students with campus resources, and foster collaboration reflective of bioengineering's integrative character on our campus and beyond. This paper sets out to understand the value of the active learning components of the course. We used the soft robotics module within the course as a case study to understand the value of active learning in this course. Students provided qualitative and quantitative feedback throughout the course regarding their familiarity with the fields and their perceived applicability to their majors and intention to stay engaged with the field. This paper describes the perceptions of students across our campus who enrolled in this introductory bioengineering course. We examined students' understanding of (and confidence in) topics and concepts, feedback on the course's active learning modules, their interest in STEM careers, and their discernment of its relationship to their majors and academic experiences. This course and its outcomes may inform future iterations of this introduction to bioengineering course, outreach events, and multidisciplinary collaborations across campus.

Introduction

Bioengineering is a discipline that brings together many engineering and science specialties to address challenges in nature and human health [1]. Many disciplines, and therefore undergraduate majors, also apply their technical skills to healthcare without direct training in bioengineering. Because of this, there is strong student interest in bioengineering on our campus, which has even led to the creation of new undergraduate programs that combine Bioengineering with other disciplines such as Computer Science + Bioengineering (CS + BIOE program at University of Illinois Urbana-Champaign). The Campus Honors Program (CHP) at the University of Illinois Urbana-Champaign provides a select group of students with the opportunity to take small, collaborative courses in a range of departments outside of their majors. In these courses, students are exposed to and engage with "compelling social, environmental, economic, philosophical, scientific, historical, and/or cultural questions" in a variety of fields to provide educational breadth and perspective (https://honors.illinois.edu/). In the semester in which this course was offered, for example, fields represented included anthropology, architecture, gender studies, classics, creative writing, molecular biology, food science and nutrition, horticulture, linguistics, psychology, systems engineering, and theater. Moreover, a variety of co-curricular activities, including campus facility tours, meetings with government and local representatives and administrators, travel courses, and exploration across the campus and local community are available to students in this program. This particular course, called Introduction to Bioengineering (BIOE 199), provided honors students with the opportunity to experience application of bioengineering in lectures, hands-on activities, and laboratory tours (**Figure 1**). The course objectives stated that students should gain an (a) overview of various sub-fields of Bioengineering; (b) appreciation for its interdisciplinary nature; (c) introduction to relevant research facilities; and (d) basic understanding of the wide range of career opportunities.

Figure 1. BIOE 199 active learning course activities.

The challenges in offering these types of survey courses is in rotating instructors, maintaining consistency in content, and sourcing experts to cover each topic. We hypothesize that the active learning aspects of this course (tours, hands-on activities, projects) enhance the students' experiences. However, given the resource intensity of active learning, we sought to gather evidence of the benefit of active learning in this course. In this paper, we will detail a case study of a soft robotics module in BIOE 199 to understand how active learning may enhance student motivation toward bioengineering.

Soft Robotics is a subfield of robotics that prioritizes use of low modulus materials to increase safety and comfort for human-robot interactions [2]. With applications in physical therapy [3], agriculture [4], and manufacturing [5], this bioinspired field is attractive to students in majors across campus. With this in mind, we adapted a soft robotics module to meet BIOE 199's course objectives as stated above. We delivered the module and collected feedback from students to understand the perceived relevance of soft robotics to their learning, majors, and future careers.

Theoretical Framework

In developing this course, we aimed to understand non-major motivations to explore bioengineering as well as the importance of active learning to support that motivation. To frame our understanding of this implementation, we used Self-Determination Theory (SDT), a theory of motivation. SDT is a framework proposing that human motivation is grounded in three inherent psychological needs: autonomy, competence, and relatedness. When met, these factors result in innate motivation and related behaviors [6]. Autonomy is the feeling of control over your own choices. Competence is the belief in your ability to succeed with knowledge. Relatedness is a sense of connection with a topic through others [7]. In engineering

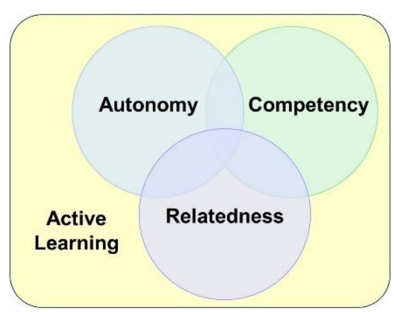

Figure 2. Self Determination Theory Factors within the context of active learning.

education, the SDT framework has been used to explore how course organization and learning activities motivate students. In large courses, relatedness was most significant for students. In this context, researchers highlight the desire for social connection among engineering students [8]. In project-based engineering learning environments, biomedical engineering students showed increases in autonomous motivations and changes in situational motivation as a result of a social impact project [9]. Building on this, we aimed to understand how a survey course like BIOE 199, can influence non-major student motivations toward bioengineering themes.

Our goal of providing a meaningful educational introduction of bioengineering to non-major students, and the application of the SDT framework to the BIOE 199 course, led us to develop our research question (RQ): *How and in what ways does an active learning soft robotics module in a survey course influence non-major students' autonomy, relatedness, and competence toward bioengineering themes?* We hypothesize that an active learning module can support student motivation for learning, course engagement, and intention to incorporate bioengineering thinking in home majors and careers. We aim to use evidence collected to plan future iterations of this course and justify resources necessary to facilitate active learning. To answer this research question, we analyze quantitative and qualitative feedback from students through the lens of SDT (autonomy, relatedness, and competence). Later in the paper, we contrast results from the soft robotics module with a lecture-only module and propose future efforts that may enhance motivations for study in this course context.

Methods

Participants and Context

In the Spring 2025 semester, 15 students from the Campus Honors Program enrolled in BIOE 199. The makeup of the students in the course was 33% freshmen, 40% sophomores, and 27% juniors, with a range of majors and minors (**Table 1**).

Table 1: Demographics of Students in the Course, with (number of students).

College	Majors and *Minors	
Liberal Arts & Sciences	▪ Biology (1) ▪ Mathematics (1) ▪ Statistics (1) ▪ Computer Science & Economics (1)	▪ Computer Science & Statistics (2) ▪ Neuroscience (1) ▪ *Data Science (1)
Engineering	▪ Computer Science ▪ Computer Engineering (2)	▪ *Physics (1)
Agricultural, Consumer & Environmental Sciences	▪ Agricultural Leadership, Education, and Communication (1)	▪ Undeclared (1)
Applied Health Sciences	▪ Kinesiology (1)	
Information Sciences	▪ Information Sciences (1)	
Business	▪ Finance (1) ▪ *Business (1)	▪ *Technology & Management (1)
Fine & Applied Arts	▪ Studio Art (1)	

Throughout the semester-long course, students were introduced to a variety of sub-disciplines in the field with the goal of adapting the course in real time to address student motivations for joining. A representative list of topics and modes of teaching and learning are included in **Table 2**. Each theme was 1 to 2 weeks long. Lectures were provided by the instructor, while guest speakers ranged from on-campus faculty, industry professionals, and collaborators from other institutions. Group-based hands-on learning activities helped students experiment with the topics [10], [11]. Students also had opportunities to ideate on how they might apply their expertise (competence) and major course work (relatedness) to this field. For example, students drew concept maps (**Figure 1**) that not only connected sub-fields of bioengineering but also related the field to their own majors (autonomy).

Table 2: A subset of representative course topics with modes of teaching and learning. Bolded topics are described in this paper.

Theme	Representative Topics	Type
Cellular Genetics	Introduction to cells	Lecture
	DNA model & extraction	Hands-On
	Gene editing	Lecture
Medical Devices	Medical equipment evaluation	Guest Speaker/Activity
	Regulatory & safety	Guest Speaker/Activity
	Bioinstrumentation	Guest Speaker
	Designing MedTech solutions in industry	Guest Speaker
	Developing clinical devices in academia	Guest Speaker
	Visit to Medical Simulation Center	Tour
Bio-nanotechnology	**Point-of care (PoC) diagnostics**	**Guest Speaker**
	Microfluidic systems	Guest Speaker/Activity
Research & Data	Library resources	Guest Speaker
	Visit to on-campus Research Institute	Tour
Neural Engineering	Introduction to 3D neural cultures	Guest Speaker
	Engineering 'mini brains'	Lecture
Biomechanics & Robotics	**Introduction to soft robotics**	**Guest Speaker**
	Soft robotics activity	**Hands-On**
	Biological machines and ethics	Lecture/Activity
	Biomechanics of the body	Lecture/Activity
	Mechanical building challenge	Hands-On
	Prosthetics & bionics	Guest Speaker
Cancer	Advancing personalized medicine	Guest Speaker
Tissue Engineering	Major milestones in tissue engineering	Lecture/Activity
Experiment	Mass transport & fluid flow	Lecture
	Soil porosity and flow	Hands-On
Bioengineering Design	Brainstorming & ideation	Activity
	3D Prototyping	Guest Speaker/Activity
	Design and prototyping	Guest Speaker
	Research showcase	Activity

Data Collection and Analysis
Students were surveyed to provide their feedback on the modules and its perceived applicability to their majors and future careers (autonomy, relatedness, and competence). To analyze the data (n = 15 students), we conducted simple statistical analysis on quantitative data and deductive thematic analysis on qualitative data using theory-driven coding. A pre-survey open response question ("*What is a soft robot?*") was analyzed for word frequency. We first tokenized responses to single words, normalized the data set, removed stop words (e.g., *a, of, that*), and created a word frequency list. Likert scale questions were analyzed by descriptive statistics (means ± standard deviations). Post-survey open response questions were analyzed by deductive thematic analysis using theory-driven coding for the SDT factors (autonomy, competence, and relatedness) to understand if qualitative data shows evidence of supporting factors that lead to motivation in this course. This project was reviewed and approved by the University of Illinois IRB (26-0178).

Soft Robotics Module
The Soft Robotics module was presented in Week 7 of the course. Students completed pre-reading and a pre-survey before class. On the first day of the module, students heard a guest lecture from a faculty member in Bioengineering who teaches and conducts research in this area. On the second day, students visited the teaching lab for the department's soft robotics course. During this visit, they built and tested a soft actuator (**Figure 3**). Finally, students reflected on the activities in post-module assignments.

Soft Robotics Assigned Pre-Reading
In preparation for the Soft Robotics lecture, students were asked to read "Biomedical Applications of Soft Robotics" [12], specifically sections on:

- Medical Devices (*Soft robotic devices for surgery, Soft materials for drug delivery*)
- Rehabilitation and Assistance (*Wearable soft robotics, Other soft assistive robotics*)
- Soft Robotics Mimicking the Human Body (*Prostheses, Artificial organs, Soft robots as body-part simulators*)

In preparation for the hands-on activity, students were asked to review the following sections linked from the Soft Robotics Toolkit [13]: Pneumatic Artificial Muscles: Design, Fabrication, Modeling, Testing, and Case Studies.

Lecture Introducing Soft Robotics
The module started with a guest lecture that presents students with an overview of the field of soft robotics. Knowing that students came from majors in colleges across campus, the lecture was designed to be broad and show applications of soft robotics in many fields, with a focus on technologies developed on our campus. The following topics were discussed:

- Nature's actuators (example: bilayer structure of pinecones) [14]
- A historical overview of soft actuator development: the 1950s McKibbens muscle, 1990s flexible microactuators, and 2010s pneumatic network actuators (pneunets) [15]
- Development of pneumatic actuators from 2010s to current day [16]
- Research development of pneumatic actuators for task trainers [17]
- Research development of fiber reinforced actuators for agricultural applications [18]
- Research development of hydrogel actuators in surgical tools [19]

- Commercial development of soft actuators for manufacturing [20] and of wearable soft robots [21]

Hands-on Build: McKibbens muscle

Next, we brought students to a teaching laboratory to build a soft actuator (**Figure 3**). The McKibbens muscle activity was chosen for two reasons: first, the materials are simple and cost effective; second, the activity typically takes ~25-30 minutes, allowing time for introduction, building, imaging, and cleaning up without rush in a 50-minute class period. Most silicone-based projects would be too involved for this brief interaction. The McKibbens muscle build is ideal because it was also highlighted in the Introductory lecture (first example in 1950s with and exosuit integration in 2017 [22], and more recent agricultural applications [23], and whole body canine models [24].

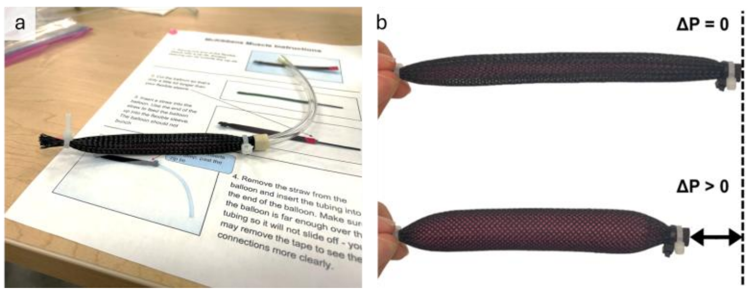

Figure 3. (a) Photo of McKibbens muscle actuator made by a student. (b) Photo created by a student showing pneumatic actuation and demonstrating best practices of data visualization.

Survey Design

To understand the value of this activity for students in the course, we designed a survey to gather information about their perceptions of the field and its applicability to their majors. The related SDT factor is labeled on applicable questions.

Pre-module survey questions [with related SDT dimension]:

1. Based on what you know now, what is a soft robot? Please define <u>without</u> using the terms "soft" or "robot." [competence]
2. How applicable are soft robots to your major/intended career? *(Likert scale)* [relatedness]
3. Based on your answer to Q2, how (or why not) do you think they are applicable or not? [relatedness]

Post-module survey questions [related SDT dimension]:

4. We talked a lot about soft robots and their many forms and functions this week. Has your viewpoint of the field of soft robotics changed at all since last week? *(yes, somewhat, no)* [competence]
5. Based on our discussion this week, how applicable are soft robots to your major/intended career? *(very applicable, somewhat applicable, not applicable, not sure)* [relatedness]
6. How likely are you to keep up with new advances in soft robotics if you see them in the news since learning about them this week? *(I would never, not likely, somewhat likely, very likely)* [autonomy]
7. Can you describe an application of soft robotics relevant to your field that is inspired by our discussion this week? [relatedness]

8. Is there anything else you want us to know?

Results

Incoming Motivations for BIOE 199

Students had various motivations for enrolling in the Bioengineering Experience CHP course. Many expressed interest in engaging in the field when given the chance, despite having no prior experience (**Table 3**).

Table 3: Students' Motivations for Enrolling in BIOE 199.

SDT Dimension	Why Did You Decide to Take this Class?
Autonomy	▪ "I find BIOE fascinating. I don't know much about it, but I'm excited to learn more!" ▪ "I'm excited to try hands-on activities." ▪ "I love how CHP allows you to take classes that are very different from your field of study!"
Competence	▪ "I have learned quite a bit about biology, but I have no idea what goes on in BIOE." ▪ "I'm interested in a [BIOE] minor or major." ▪ "This sounded like an interesting introduction to a topic that I was in [not] familiar with."
Relatedness	▪ "I'm considering a career in bioinformatics." ▪ "I'm curious how BIOE can intersect with Computer Science."

Understanding of Soft Robotics (Pre-Survey)

Results show that the soft robotics module changed student perceptions about its applicability to their careers. Students (mainly first and second year university undergraduates) came into the module with a reasonable understanding of what soft robotics is, by definition (pre-survey Q1) (**Figure 4**).

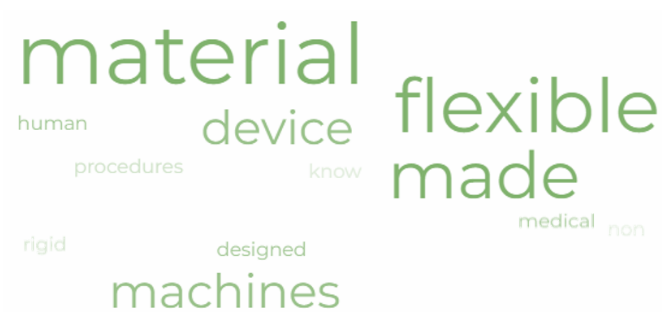

Figure 4. Word cloud of student definitions of soft robotics (pre-survey Q1) [competence].

Students were asked, "*Based on what you know now, what is a soft robot? Please define without using the terms "soft" or "robot.""* 7 of 12 students confidently and correctly identified a core principle of soft robotics. With the most common words being "flexible" along with "malleable" and "non-rigid," students accurately identified the importance of low modulus materials in soft robotics. Of the remaining students, three were openly unsure on the topic, with one noting "I do not know much about soft robots" and "I'm guessing they are technology/machines made out of materials that are not as hard as typical machines." This shows a basic intuitive understanding of soft robotics that could be ascertained by those with no familiarity in the subject. Another student offered, "I have no idea; a machine made of organic materials," which reinforces the idea that the field was generally understood as organic materials are an important concept in soft robotics.

Soft Robotics Relatedness to Major and Intended Career
Despite this general understanding, in pre-survey responses, students did not perceive high value or relation to their own careers (**Figure 5**).

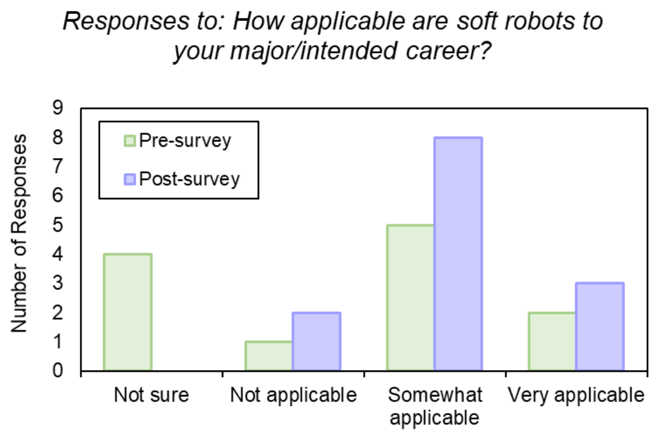

Figure 5. Student responses to the pre-survey question, "*How applicable are soft robots to your major/intended career?*". Student responses to the post-survey question, "*Based on our discussion this week, how applicable are soft robots to your major/intended career?*"

Quantitative results show interest varies by major. 41.7 % (5 students) said "Somewhat applicable." Of these, two were Computer Engineering majors, and the other three represented Information Sciences, Mathematics, and Animal Science. 33.3 % (4 students) answered "Not sure." This group included one Computer Science major, one Statistics major, one Agricultural Leadership, Education & Communications major, and one Kinesiology major. 16.7 % (2 students) felt it was "Very applicable." Those two were majors in Molecular & Cellular Biology and Neuroscience, respectively. 8.3 % (1 student majoring in CS + Statistics) indicated "Not applicable."

Students of varying majors demonstrated novel familiarity with soft robotics by applying the field to their future careers. A notable response by a student interested in law stated, "There are ethical concerns about the implementation of soft robotics, particularly in the workplace," which draws attention to the use of soft robotic assistive technologies in physically demanding workplaces. The student followed with an excellent application of soft robotics to their future career: "It's not hard to imagine labor disputes over requiring soft robotic technology to be worn." This shows that beyond engineering and technical work, soft robotics is subject to a multidisciplinary approach that expands to ethics and law.

Another student majoring in Molecular and Cellular Biology applied a more technical approach to soft robotics and their future career: "I plan on pursuing orthopedics, so I could see lots of rehab uses for soft robotics." This student draws upon the great potential of soft robotics in rehabilitation technology and treatment, as compliant and gentle robots are perfect candidates for delicate injuries and bodily fragility. Both students, among others, show evidence of a more abstract understanding of soft robotics due to this lesson module. Students were able to accurately apply soft robotics to their possible future careers.

Only 1 of the 14 students remained unsure of their future career's ties to soft robotics. The Statistics major stated, "I'm not totally sure about what the main connections would be between soft robotics and statistics." Nevertheless, the student was still able to generalize a possible connection and stated, "but there is likely data analysis involved in analyzing any results collected by the soft robotics." Even in the most uncertain students, the intuitive nature of soft robotics still allows relatively strong connections to applications in future careers.

Feedback on Active Learning

At the end of the semester, students provided open response feedback in response to questions including, "*What are the major strengths of the course?*" and "*What do you suggest to improve the course?*" In their responses, students highlighted their appreciation for active learning and also provided feedback that aligns with SDT factors (**Table 4**).

Table 4. Open-ended feedback on the BIOE 199 course.

Quote	**Active Learning or SDT Factor**
Strength: "It was more project-oriented to teach materials rather than lectures."	Active Learning
Strength: "I liked touring all of the different labs and buildings."	Active Learning
Strength: "Very open to discussion"	Autonomy
Strength: "Its open-endedness. None of us are bioengineering majors and this aspect of the class allowed us to explore our own interests in the field, as well as how it connects back to our own interests outside of bioengineering"	Autonomy
Improvement: "More hands-on activities"	Active Learning
Improvement: "More hands-on experiments like the strawberry DNA extraction"	Active Learning
Improvement: "I would start the design project earlier. I think starting the project earlier is better, as it would allow for teams to iterate on their designs multiple times."	Active Learning and Autonomy

Overall Course Feedback

The first offering of BIOE 199 allowed non-majors to access the breadth of the field without overwhelming depth, instead focusing on real-world applications and familiar biomedical technologies through a variety of modalities. General feedback on the course is shown in **Table 5** below. Overall, students agreed with the statement "*This course increased my interest in the subject matter*" with a 4.38 score (on a 1-5 scale) at the end of the semester. When asked to rank themselves (on a 1-7 scale) if they "*fit right into BIOE 199*" (1) or "*felt pretty out of place in BIOE 199*" (7), students responded with an average score of 2.5.

Table 5: End-of-semester student feedback on scales of 1 to 5.

	Mean	Std. Dev.
General		
Rate the overall quality of this course. *[Exceptionally Low ... Exceptionally High]*	**4**	0.5
How much have you learned in this course? *[Very Little ... A Great Deal]* (competence)	**3.56**	1.3
The scope of this course was: *[Too Broad ... Too Narrow]*	**3.0**	1.1
This course increased my interest in the subject matter. *[Strongly Disagree ... Strongly Agree]*	**4.4**	0.7
The amount of technical information was appropriate. *[Strongly Disagree ... Strongly Agree]*	**4.1**	0.9
The level of difficulty of the course material was appropriate for me. *[Strongly Disagree ... Strongly Agree]*	**4.0**	0.8
Did this course improve your understanding of concepts and principles in this field? *[No, Not Much ... Yes, Significantly]* (competence)	**4.25**	0.7
Course content was explained clearly. *[Almost Never ... Almost Always]*	**4.1**	0.6
Teaching and Learning Modalities		
The instructor provided a diversity of material, techniques, and content. *[Strongly Disagree ... Strongly Agree]* (active learning)	**4.6**	0.7
In-class learning activities stimulated critical thinking about course material. *[Strongly Disagree ... Strongly Agree]* (active learning)	**4.22**	0.7
How useful were out-of-class assignments for learning course content? *[Not Useful At All ... Extremely Useful]*	**3.9**	0.8
Field trips and tours were valuable learning experiences. *[Strongly Disagree ... Strongly Agree]* (active learning)	**4.5**	0.9

Discussion

During the BIOE 199 course and after analysis of student feedback, we observed evidence of increasing student motivation for studying bioengineering (**Figure 6**). This was observed through feedback relating the SDT factors to [25] increasing perceptions of major/career relevance (relatedness, **Figure 5**), active learning and open-ended nature of the course (autonomy, **Table 4**), and increased understanding of bioengineering concepts (competence, **Table 5**). We also observed high student interest in active learning. Not surprisingly, incorporation of active learning supports factors associated with student motivation (autonomy, competence, relatedness), as this has been previously reported in literature [26]. This earlier work promotes "student-centered" design of courses in higher education as a theory-informed practice for supporting student motivation. When students were asked if they planned to keep up with soft robotics news after the class, 100% indicated they were "somewhat likely" to (3 out of 4 on Likert scale) (autonomy). The autonomy dimension of the SDT framework was most pronounced in the qualitative feedback received. Students were enthusiastic about the open-ended assignment, possibly due to the course structure being pre-planned and not providing many opportunities for choice within the course, aside from the final project (not discussed in this paper). Relations to major and career were the strongest dimensions displayed by students, as expected based on the structure of the course and the pre-course survey (**Table 2**).

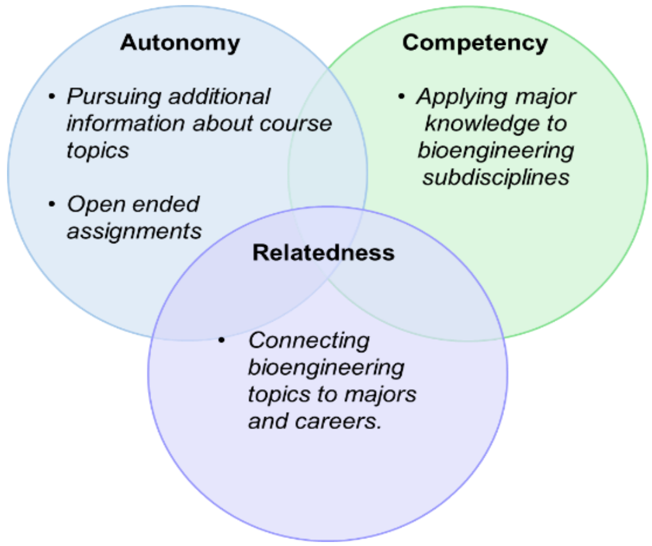

Figure 6. SDT framework applied to BIOE 199 course structure and feedback.

Altogether, our findings provide evidence that students not only enjoyed active learning in the BIOE 199 Introduction to Bioengineering course, but also that this course increased motivations for further bioengineering exploration. The field of bioengineering benefits from multidisciplinary perspectives [27]. Additionally, students benefit from training in diverse teams for future leadership in multidisciplinary projects [28]. Therefore, if students gain motivation to stay up to date with a field tangental to their own, as non-majors in BIOE 199, they may identify oppportunities for multidisciplinary projects and to apply their skills in more areas in the future.

The goal of this study was to collect evidence to support the implementation of active learning in this course, given the time, resource, and instructor constraints present in typical first-year or survey courses. Literature supports the continuous engagement in active learning as a way to develop competence in engineering skills [29]. Studied in the context of self-efficacy, the development of compentence is a critical factor for motivation also. The two constructs have been used together previously [30]. Therefore, addition of active learning modules throughout the BIOE 199 course may support student competence development in bioengineering. This can reinforce the benefits desribed above in helping non-major students to apply their interdisciplinary skills to bioengineering applications later in their careers.

Limitations
Framing study results within the SDT framework does highlight for us some limitations of this study. First, this course is an honors-level elective. The CHP offers multiple courses each semester in various topics, and the students enrolled in BIOE 199 were already motivated to study the topic (**Table 3**). Similar studies in a majors course, standard-level elective, or general engineering course (all offered in this department) may be good sites for a comparison study. The class size is also a limitation of this study. While it provides a rich environment for exploring nuances in motivation, the small sample size limits the ability for course instructors to make sweeping changes in future offerings based on this quality improvement study. However,

the nuances are interesting and may support future ideation for "BIOE +" majors in the department, minor offerings, and electives for non-majors. However, what this study does is to create a template for building in more active learning modules, where lecture-only modules were previously offered in BIOE 199.

Future Work

Based on the findings in this study, we propose that future work explores other "bioengineering" contexts on our campus (described above in Limitations). Additionally, we can begin to build activities for lecture-only modules present in the course. One module, Point-of-Care (PoC) diagnostics, is particularly well suited for the addition of a hands-on activity to complement the existing lecture. PoC devices are portable medical instruments used to perform diagnostic tests at or near the patient's point of care [31]. Previously, this module was presented in Week 5 of the course. Students heard a guest lecture from a faculty member in Bioengineering who conducts research in this area. The speaker combined the explanation of general concepts such as the definition of point-of-care devices and biosensors, with more specific concepts such as sensitivity and specificity in diagnosis. A connection was made to the COVID-19 pandemic, and examples of point-of-care detection carried out on our campus during the pandemic were given [32], [33]. In the course feedback, some students mentioned that some topics were highly complex and more abstract in lecture format. One student stated that "some material covered in class was significantly over our heads." Building in a hands-on activity may provide concrete, tangible supplement to context covered in lecture, making the material easier to conceptualize.

Proposal for a Hands-On Activity

PoC is a strength of the Bioengineering department at the University of Illinois Urbana-Champaign [33], [34], [35], [36], [37]. Therefore, there are many experts who can deliver this content and developing a module for this course can be used in other courses, and will not suffer from turnover. We envision designing an activity where students can build their own PDMS-based microfluidic device. A tour of a cleanroom (in a building where a "research institute" tour is already hosted as part of the course schedule) would demonstrate the instrumentation required to create the SU-8-based negative molds, which are fabricated on silicon wafers. In two sessions, students can mix polydimethyl siloxane (PDMS), pour it over prefabricated SU-8 negative molds, cure it, peel it off, seal it to a microscope slide using an O_2 plasma chamber, perform an optical characterization (using a microscope), and flow food coloring through the device to confirm its functionality. Experimenting with fast-cure silicones may enable instructors to constrain the time even further, but use of PDMS elastomers may facilitate silicone based soft robotics activities if students build competence in fabrication techniques.

The mixed methods exploration of BIOE 199 presented here and student motivations for studying bioengineering as non-majors provided evidence that inspires us to critically evaluate content in the course and may lead to favoring hands-on activities over breadth of topics covered.

Conclusion

Because this was the first delivery of the content in this context, we considered this a pilot evaluation and that the data are not generalizable. However, we are encouraged by findings from this course and module. Students increased their understanding of how different bioengineering technologies (such as soft robotics or point-of-care diagnostics) apply to their majors, and were able to articulate ways in which their skills could be applied to these fields. In future iterations of this curriculum, we may probe for more information about intended roles post-graduation. Overall, we can see ways in which we can better connect robotics and diagnostics to specialties across our campus.

Acknowledgement
This material is based in part on work supported by the National Science Foundation under Grant Number NSF CAREER 2541364.

References

[1] M. Pool and M. Marjanovic, "Board 9: Introducing Bioengineering Approaches through Healthcare Grand Challenges," in *2019 ASEE Annual Conference & Exposition Proceedings*, Tampa, Florida: ASEE Conferences, Jun. 2019, p. 32455. doi: 10.18260/1-2--32455.

[2] S. Kim, C. Laschi, and B. Trimmer, "Soft robotics: a bioinspired evolution in robotics," *Trends in Biotechnology*, vol. 31, no. 5, pp. 287–294, May 2013, doi: 10.1016/j.tibtech.2013.03.002.

[3] L. N. Awad *et al.*, "A soft robotic exosuit improves walking in patients after stroke," *Sci. Transl. Med.*, vol. 9, no. 400, p. eaai9084, Jul. 2017, doi: 10.1126/scitranslmed.aai9084.

[4] J. F. Elfferich, D. Dodou, and C. D. Santina, "Soft Robotic Grippers for Crop Handling or Harvesting: A Review," *IEEE Access*, vol. 10, pp. 75428–75443, 2022, doi: 10.1109/ACCESS.2022.3190863.

[5] N. Elango and A. A. M. Faudzi, "A review article: investigations on soft materials for soft robot manipulations," *The International Journal of Advanced Manufacturing Technology*, vol. 80, no. 5–8, pp. 1027–1037, Sep. 2015, doi: 10.1007/s00170-015-7085-3.

[6] E. L. Deci and R. M. Ryan, *Intrinsic motivation and self-determination in human behavior*, [5]th print. in Perspectives in social psychology. New York: Plenum Press, 1996.

[7] R. M. Ryan and E. L. Deci, "Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being.," *American Psychologist*, vol. 55, no. 1, pp. 68–78, 2000, doi: 10.1037/0003-066X.55.1.68.

[8] K. F. Trenshaw, R. A. Revelo, K. A. Earl, and G. L. Herman, "Using self determination theory principles to promote engineering students' intrinsic motivation to learn," vol. 32, no. 3, pp. 1194–1207, 2016.

[9] Y. Zhu, L. Abidi, H. Savelberg, S. E. Köhler, R. A. Kusurkar, and D. Dolmans, "Fostering university students' autonomous motivation through a societal impact project: a qualitative study of students' and teachers' perspectives," *BMC Med Educ*, vol. 24, no. 1, p. 1503, Dec. 2024, doi: 10.1186/s12909-024-06494-9.

[10] H. M. Golecki, "Engaging students with soft robotics," *Nat Rev Bioeng*, vol. 3, no. 11, pp. 912–913, Sep. 2025, doi: 10.1038/s44222-025-00372-9.

[11] H. M. Golecki, J. Robinson, C. Cvetkovic, and C. Walsh, "Empowering Students in Medical Device Design: An Interdisciplinary Soft Robotics Course," *Biomed Eng Education*, vol. 4, no. 2, pp. 399–408, Jul. 2024, doi: 10.1007/s43683-024-00143-9.

[12] M. Cianchetti, C. Laschi, A. Menciassi, and P. Dario, "Biomedical applications of soft robotics," *Nature Reviews Materials*, vol. 3, no. 6, pp. 143–153, May 2018, doi: 10.1038/s41578-018-0022-y.

[13] D. P. Holland, E. J. Park, P. Polygerinos, G. J. Bennett, and C. J. Walsh, "The Soft Robotics Toolkit: Shared Resources for Research and Design," *Soft Robotics*, vol. 1, no. 3, pp. 224–230, Sep. 2014, doi: 10.1089/soro.2014.0010.
[14] K. Oliver, A. Seddon, and R. S. Trask, "Morphing in nature and beyond: a review of natural and synthetic shape-changing materials and mechanisms," *J Mater Sci*, vol. 51, no. 24, pp. 10663–10689, Dec. 2016, doi: 10.1007/s10853-016-0295-8.
[15] M. De Volder, A. J. M. Moers, and D. Reynaerts, "Fabrication and control of miniature McKibben actuators," *Sensors and Actuators A: Physical*, vol. 166, no. 1, pp. 111–116, Mar. 2011, doi: 10.1016/j.sna.2011.01.002.
[16] F. Chen and M. Y. Wang, "Design Optimization of Soft Robots: A Review of the State of the Art," *IEEE Robotics & Automation Magazine*, vol. 27, no. 4, pp. 27–43, Dec. 2020, doi: 10.1109/MRA.2020.3024280.
[17] D. Wilcoski, R. Sridharan, S. Edward, I. Ryals, S. Jamison, and H. Golecki, "Gelatin Material Properties and their Role in Increasing Medical Task Trainer Fidelity," in *2025 Design of Medical Devices Conference*, Minneapolis, MN, USA: American Society of Mechanical Engineers, Apr. 2025, p. V001T06A010. doi: 10.1115/DMD2025-1104.
[18] S. M. G. Vidwath, P. Rohith, R. Dikshithaa, N. Nrusimha Suraj, R. G. Chittawadigi, and M. Sambandham, "Soft Robotic Gripper for Agricultural Harvesting," in *Machines, Mechanism and Robotics*, R. Kumar, V. S. Chauhan, M. Talha, and H. Pathak, Eds., Singapore: Springer Singapore, 2022, pp. 1347–1353. doi: 10.1007/978-981-16-0550-5_128.
[19] M. W. Gifari, H. Naghibi, S. Stramigioli, and M. Abayazid, "A review on recent advances in soft surgical robots for endoscopic applications," *Robotics Computer Surgery*, vol. 15, no. 5, p. e2010, Oct. 2019, doi: 10.1002/rcs.2010.
[20] J. Amend, N. Cheng, S. Fakhouri, and B. Culley, "Soft Robotics Commercialization: Jamming Grippers from Research to Product," *Soft Robotics*, vol. 3, no. 4, pp. 213–222, Dec. 2016, doi: 10.1089/soro.2016.0021.
[21] L. N. Awad, A. Esquenazi, G. E. Francisco, K. J. Nolan, and A. Jayaraman, "The ReWalk ReStore™ soft robotic exosuit: a multi-site clinical trial of the safety, reliability, and feasibility of exosuit-augmented post-stroke gait rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, vol. 17, no. 1, p. 80, Dec. 2020, doi: 10.1186/s12984-020-00702-5.
[22] L. N. Awad *et al.*, "A soft robotic exosuit improves walking in patients after stroke," *Sci. Transl. Med.*, vol. 9, no. 400, p. eaai9084, Jul. 2017, doi: 10.1126/scitranslmed.aai9084.
[23] S. Edward *et al.*, "Engineering protein-based fiber-reinforced pneumatic actuators," *RSC Appl. Polym.*, p. 10.1039.D5LP00370A, 2026, doi: 10.1039/D5LP00370A.
[24] H. Ito *et al.*, "A Canine Musculoskeletal Robot for Investigating Biomechanical Functions During Locomotion," *adv. robot. res.*, vol. 2, no. 1, p. e70086, Feb. 2026, doi: 10.1002/adrr.70086.
[25] N. D. Fila and S. Purzer, "Using self-determination theory to understand engineering student motivation during innovation projects," in *2017 IEEE Frontiers in Education Conference (FIE)*, Indianapolis, IN: IEEE, Oct. 2017, pp. 1–8. doi: 10.1109/FIE.2017.8190579.
[26] L. Jeno, "Encouraging active learning in higher education: A self-determination theory perspective," *International Journal of Technology and Inclusive Education*, vol. 5, no. 1, pp. 716–721, 2015.

[27] L. Montesinos, D. E. Salinas-Navarro, and A. Santos-Diaz, “Transdisciplinary experiential learning in biomedical engineering education for healthcare systems improvement,” *BMC Med Educ*, vol. 23, no. 1, p. 207, Apr. 2023, doi: 10.1186/s12909-023-04171-x.
[28] Emmanuella Onyinye Nwulu, Tari Yvonne Elete, Ovie Vincent Erhueh, Oluwaseyi Ayotunde Akano, and Kingsley Onyedikachi Omomo, “Leadership in multidisciplinary engineering projects: A review of effective management practices and outcomes,” *Int. J. Sci. Res. Updates*, vol. 4, no. 2, pp. 267–283, Dec. 2022, doi: 10.53430/ijsru.2022.4.2.0188.
[29] S. Higbee, D. Harrell, A. Chase, and S. Miller, “A Study of Biomedical Engineering Student Self-efficacy toward Design throughout an Undergraduate BME Curriculum,” *Biomed Eng Education*, vol. 5, no. 1, pp. 15–36, Jan. 2025, doi: 10.1007/s43683-024-00163-5.
[30] K. Iwanaga, F. Chan, T. N. Tansey, W. T. Hoyt, and N. L. Berven, “Evaluation of Constructs Based on Self-Determination Theory and Self-Efficacy Theory as Predictors of Vocational Rehabilitation Engagement for People With Physical and Sensory Disabilities,” *Rehabilitation Counseling Bulletin*, vol. 64, no. 3, pp. 131–144, Apr. 2021, doi: 10.1177/0034355220942301.
[31] S. Rasheed, T. Kanwal, N. Ahmad, B. Fatima, M. Najam-ul-Haq, and D. Hussain, “Advances and challenges in portable optical biosensors for onsite detection and point-of-care diagnostics,” *TrAC Trends in Analytical Chemistry*, vol. 173, p. 117640, Apr. 2024, doi: 10.1016/j.trac.2024.117640.
[32] D. R. E. Ranoa *et al.*, “Mitigation of SARS-CoV-2 transmission at a large public university,” *Nat Commun*, vol. 13, no. 1, p. 3207, Jun. 2022, doi: 10.1038/s41467-022-30833-3.
[33] E. Valera *et al.*, “COVID-19 Point-of-Care Diagnostics: Present and Future,” *ACS Nano*, vol. 15, no. 5, pp. 7899–7906, May 2021, doi: 10.1021/acsnano.1c02981.
[34] E. Valera *et al.*, “Electrochemical point-of-care devices for the diagnosis of sepsis,” *Current Opinion in Electrochemistry*, vol. 39, p. 101300, Jun. 2023, doi: 10.1016/j.coelec.2023.101300.
[35] H. Lim, H. S. Kim, R. Qazi, Y. Kwon, J. Jeong, and W. Yeo, “Advanced Soft Materials, Sensor Integrations, and Applications of Wearable Flexible Hybrid Electronics in Healthcare, Energy, and Environment,” *Advanced Materials*, vol. 32, no. 15, p. 1901924, Apr. 2020, doi: 10.1002/adma.201901924.
[36] A. M. Jankelow *et al.*, “Smartphone clip-on instrument and microfluidic processor for rapid sample-to-answer detection of Zika virus in whole blood using spatial RT-LAMP,” *Analyst*, vol. 147, no. 17, pp. 3838–3853, 2022, doi: 10.1039/D2AN00438K.
[37] L. T. P. Le *et al.*, “Current smartphone-assisted point-of-care cancer detection: Towards supporting personalized cancer monitoring,” *TrAC Trends in Analytical Chemistry*, vol. 174, p. 117681, May 2024, doi: 10.1016/j.trac.2024.117681.