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Embedding the Entrepreneurial Mindset into Undergraduate Bioengineering Courses: Two Instructional Laboratory Case Studies

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Abstract

Experimental laboratory courses are foundational to undergraduate instruction in various engineering disciplines. Traditionally, students demonstrate competence in laboratory curricula through protocol-based experimentation as well as assignments such as lab reports, but generally do not gain experience in open-ended design or entrepreneurial innovation – skills which may be highly valued by future employers or graduate schools, and even in upper-level project-based courses such as capstone design.

Biofabrication Lab is an upper-level elective laboratory course offering students hands-on experience in advanced cell culture, computer aided design, additive manufacturing, and prototyping related to translational bioengineering. Quantitative Physiology Lab is a required laboratory course in which third-year bioengineering students conduct experiments to measure and model human physiological systems, while gaining experience in data analysis and presentation. To expand the breadth of knowledge and experience gained by students, a project with new learning objectives was incorporated into both courses. Through expert lectures and a robust project, students were introduced to technology commercialization and the entrepreneurial mindset, skills that aid in the development of career-ready and innovative engineers. Students applied these concepts through a laboratory-based design project by participating in a product pitch competition to justify the value of their design to a panel of experts in the field who exemplified potential investors. To measure outcomes, we assessed students' self-reported expertise in various components of these disciplines through surveys administered at multiple points throughout the modules and gathered anonymous feedback through end-of-semester course evaluations.

In this paper, we detail the design projects of both courses, demonstrate a new resource to introduce the basics of the entrepreneurial mindset and technology commercialization in technical settings, and highlight the observed outcomes. Finally, by providing evidence of this module's implementation in two distinct engineering laboratory courses that vary in class size, topic, scope, and organization, we aim to provide suggestions and encouragement for translation of this module to laboratory and design courses in a variety of STEM disciplines.

Introduction

Experimental laboratory courses are foundational to undergraduate instruction and experiential learning in various engineering disciplines [1], [2]. The Accreditation Board for Engineering and Technology (ABET) standards for engineering education list student outcomes (Criterion 3) that include the ability to identify complex problems, apply engineering design to formulate solutions, function within a team framework, conduct experimentation appropriately, and apply new knowledge. Traditionally, students demonstrate competence in laboratory curricula through performing protocol-based experimentation and completing assignments such as lab reports, but generally do not gain experience in open-ended design or entrepreneurial innovation – skills which may be highly valued by future employers or graduate schools, and even in upper-level project-based courses such as capstone design. Here, we discuss the implementation and assessment of a new, repeatable module incorporating the entrepreneurial mindset and technology commercialization into two distinct undergraduate bioengineering laboratory experiences.

Entrepreneurial Mindset

Many institutions have successful records of technology commercialization from research labs and endeavors [3]. Training undergraduate students and providing opportunities in which they can practice components of the commercialization process is valuable both to students' engineering education and to the university as a whole. This is also one way in which students can formally enhance their entrepreneurial mindset within the classroom setting. Per KEEN, the entrepreneurial mindset is defined as "a set of attitudes, dispositions, habits, and behaviors that shape a unique approach to problem-solving, innovation, and value creation" [4]. The KEEN framework emphasizes three primary components of the entrepreneurial mindset: curiosity, connections, and creating value. Project-based learning in which students are given a specific audience to understand and design for is one way in which students learn to create value with their technical skills. Projects with simulated or real-world applications also provide students the opportunity to practice situational curiosity [5].

Effective science communication is particularly necessary in the process of commercializing technology. When engineers create goods and services that are to have a societal impact or address a need, it is crucial for their success that the value of these innovations are clear to their intended audience [6]. In other words, the technical specifications and capabilities of an innovation must be communicated in a way that explains and justifies its use. One method of communication is through a pitch, a brief speech that encapsulates the value of an innovation. In practice, pitches take on many forms and are dependent on the allotted timeframe, audience, and overall purpose (i.e., what is being asked of the audience).

Though there are examples of embedding entrepreneurial mindset into undergraduate engineering education, both in Bioengineering (from introductory courses [7] to capstone design [8]) as well as other technical fields such as computing [9], it is not well integrated into many experiential learning courses within engineering. Because of their hands-on and project-based nature, instructional laboratories are well-positioned to be a key part of the engineering curriculum to actively enhance students' entrepreneurial mindset.

Instructional Laboratories

To expand the breadth of knowledge and experience gained by students, a project with new learning objectives was incorporated into two bioengineering laboratory courses (Table 1). Through expert lectures and a robust project, students were introduced to technology commercialization and the entrepreneurial mindset, skills that may aid in the development of career-ready and innovative engineers. Students applied these concepts through a laboratory-based design project by participating in a product pitch competition to justify the value of their design to a panel of experts in the field who exemplified potential investors. To measure outcomes, we assessed students' self-reported expertise in various components of these disciplines through surveys administered at multiple points throughout the modules and gathered anonymous feedback through end-of-semester course evaluations.

This project was first piloted in an upper-level elective Biofabrication Lab course and, following its success, was repeated the following semester in a required Quantitative Physiology Lab course in the same Bioengineering department at the University of Illinois Urbana-Champaign, to validate its ability to be translated. In this paper, we detail the design projects of both laboratory courses, demonstrate a new resource to introduce the basics of the entrepreneurial mindset and technology commercialization in technical settings, and highlight the observed outcomes. Finally, by providing evidence of this module's implementation in two distinct engineering laboratory courses that vary in class size, topic, scope, and organization, we aim to provide suggestions and encouragement for translation of this module to laboratory and design courses in a variety of STEM disciplines.

Methods

Course Backgrounds

Biofabrication Lab (course number BIOE 306) is an upper-level elective laboratory course offering students hands-on experience in advanced cell culture, computer-aided design, additive manufacturing, and prototyping related to translational bioengineering. The assignments are completed in pairs, which allows each student to gain firsthand experience in experimental design, wet lab and computational skills, data analysis, and methods for reporting and formatting scientific findings. All participants have passed an introductory laboratory course in cell and tissue engineering [10], [11], and many students in this course have some experience with independent research or capstone design [12], [13]; this course allows them to further hone their experimental skills, while providing an approachable facsimile of graduate-level research experiences and expectations [14]. This course was offered in Spring 2023.

Quantitative Physiology Lab (course number BIOE 303) is a required instructional bioengineering laboratory course in which third-year students conduct experiments to measure and model human physiological systems, while gaining experience in data analysis and presentation. The laboratory work is completed in groups of three, which allows the students to gain hands-on experience and data from multiple subjects while also benefiting from the synergy that comes from varied perspectives. The course experiments cover neural, cardiovascular, respiratory, muscular, endocrine, and renal systems. These systems are studied using both simulations along with BIOPAC software [15] that translates physiological measurement data into quantitative models. This course was offered in Fall 2023.

	Biofabrication Lab (BIOE 306)	*Quantitative Physiology Lab (BIOE 303)*
Term	Spring 2023	Fall 2023
Course size	Up to 20 students/semester ("small")	50-60 students/semester ("large")
Level	Third- and fourth-year students	Third-year students
Type	Elective, in major	Required, in major

Table 1. Course comparisons for BIOE 306 and BIOE 303

Introductory Lectures

Students received introductory lectures throughout the semester to prepare them for the project requirements. Beyond the instructor-led introduction to the project itself, these guest-delivered introductory lectures included an introduction to pitching, and, for BIOE 306, neural organoid research. For consistency between sections and semesters, the lecture content was not modified after the first iteration.

A faculty member from the university's Technology Entrepreneur Center provided a lecture on the fundamentals of communicating to non-technical audiences through pitching. This lecture was developed to aid students in understanding the purpose of a pitch, the differences between various pitch formats, and the primary components of a pitch. Students were introduced to a pitch as a verbal speech that conveys the value of an idea to an audience, and then were given further details on how to effectively communicate the value of technology to a diverse audience (i.e., not only composed of field-specific experts). This lecture also highlighted the importance of getting an audience to care about what is being pitched through various methods including describing a pain point, telling a story, justifying the scope of the problem or need, and discussing the urgency of implementation and plan in which to address the need. In addition to a lecture that engaged students through active listening and participation (e.g., raising hands to agree with certain statements, answering brief questions, etc.), students also completed an activity in which they practiced writing a value statement that could be used within an effective pitch. Finally, after learning a few tips to communicate their pitch both verbally and visually, students were given time to begin formulating their own pitch for the assignment with their project team.

In the BIOE 306 elective, students received additional instructional content wherein they were introduced to the field of neural organoid research [16] through an introductory lecture by the course instructor on the history, techniques, and use of organoids as a research model [17], [18]. This was followed by additional guest lectures from two experts in neuroscience and neural engineering, who discussed recent findings in organoid-based neural network generation, organoid transplantation, and difficulties faced in translating organoid research to clinical applications. These diverse applications helped to illustrate the possibilities as well as challenges within the field of organoid research, while the overview helped stimulate the students' creativity as they devised organoid-based solutions in their subsequent projects.

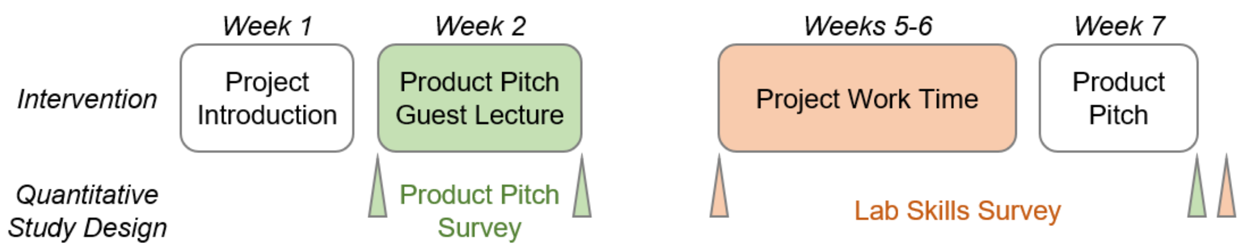

Figure 1. Project timeline, include interventions and study designs (i.e., quantitative student evaluation surveys) for BIOE 303

Multifaceted Design Projects

To encourage students to gain practical entrepreneurial skills outside of a traditional technical lab-based assignment, a multifaceted design project was developed which was worth 10% of the final course grade (Figure 1). Students selected a project from a provided list of eligible topics (Table 2) and determined a relevant problem in their selected topic for which they could develop a feasible solution. They built on prior class experience to devise an experimental component of their project to test a potential solution. In BIOE 306, student teams followed a protocol to produce neural organoids and then fabricated a 3D printed device as a "solution" to an issue facing translational neural engineering research. In BIOE 303, groups performed a physiological experiment and used their results as inspiration to design a hypothetical bioengineering device that addressed a need. Finally, students presented their results in an entrepreneurial product pitch that highlighted their designs.

	Biofabrication Lab (BIOE 306)	*Quantitative Physiology Lab (BIOE 303)*
Projects	Problem Statements 1. Engineer customized organoid dimensions and geometries for instructional or research lab budgets. 2. Design a low-adherence setup for organoids to enhance diffusion of oxygen and nutrients during *in vitro* studies. 3. Provide an environment for spherical organoids to be connected in a tubular shape within a syringe for spinal cord transplantation. 4. Mimic the formation of neuronal networks to permit the study of cell-cell interactions and synapse formation.	Topics 1. Electroencephalography (EEG) 2. Biomechanics 3. Electrooculography 4. Spinal Cord Reflexes 5. Electromyography (EMG) 6. Muscular Biofeedback 7. Electrogastrogram (EGG) 8. Reaction Time 9. Aerobic Exercise 10. Electrodermal Response
Group size	2 students/group	5-6 students/group
Product pitch	30% of project grade	50% of project grade (see Appendix)

Table 2. Project component comparison between BIOE 303 and BIOE 306

The students were subsequently challenged to format their chosen project idea into an entrepreneurial-style product pitch. The pitches were presented in the style of the entrepreneurial reality television series *Shark Tank*, with the students providing a persuasive presentation of their proposed idea to a panel of volunteer experts. Students focused on highlighting the existing need for their idea and the value behind their product's ability to fill that need in a novel way. The panel queried the students on both technical and nontechnical aspects of their products, in addition to the feasibility of their proposed downstream applications.

Project Assessment

Projects were assessed using criteria presented to students at the project onset. Students in BIOE 306 also earned a small number of points for various other components of the experimental module, including participation in guest lectures and submission of digital design files. The product pitch (30 or 50% of the project grade) was evaluated on the presentation style as well as the content. Students were given the following criteria:

1. *Background*: The information provided is sufficient to help the audience understand the need or problem. The presentation includes an overview of experimental objectives and any pertinent background, a brief introduction to methods, and analyzed experimental results.
2. *Value*: The value of the idea or product is conveyed, and the information provided is sufficient to help the audience understand the existing need or problem.
3. *Solution*: The solution to the problem is clearly demonstrated and explained in a convincing pitch of the new product or device.
4. *Presentation*: The pitch is clear, persuasive, and professional, with equal contribution from all students. Visually, the presentation exhibits overall neatness, organization, aesthetic appeal, and use of images to support the pitch in the slides.
5. *Communication to a broad audience*: The presentation is effective in conveying a technical idea through a non-technical context.

During the pitch competition, a diverse team of "investors" that included the instructor, course staff, and guest lecturers evaluated the pitches using provided rubrics (Appendix). Teams that scored highest in the pitch competition also earned extra credit (5% of the project score).

Data Collection and Analysis

Student feedback was solicited in three different formats:

1. Anonymous university-wide course and instructor evaluations, including quantitative items, at the completion of the semester.
2. Quantitative surveys that asked students to self-evaluate their knowledge and familiarity (on a scale of 1 to 5) of various laboratory- and entrepreneurial-based topics before and after the introductory lecture about effective pitching, and at the completion of the experiment and product pitch, in BIOE 303. See Appendix and Figure 1.
3. Qualitative project-specific questions (regarding the experimental protocols, lectures, project timeline, etc.) at the completion of the experiment and product pitch.

For the first format, the university provided the de-identified data to the instructor. For the course surveys, the instructor downloaded evaluation data from the learning management system or online form from the first two formats above; responses were then de-identified for the course staff to analyze blindly using Microsoft Excel. Responses which did not include all quantitative surveys as outlined in Figure 1 were excluded. A student's two-tailed paired t-test was used to determine significance between two groups at a time (e.g., lab skills at two time points). This study was deemed exempt by the Institutional Review Board of the University of Illinois Urbana-Champaign Office for the Protection of Research Subjects (NHSR Determination #24477).

Results

Project Outcomes

Students devised solutions in response to the problems and topics described above, with project results detailed below. Here, we demonstrate representative assignments from each course.

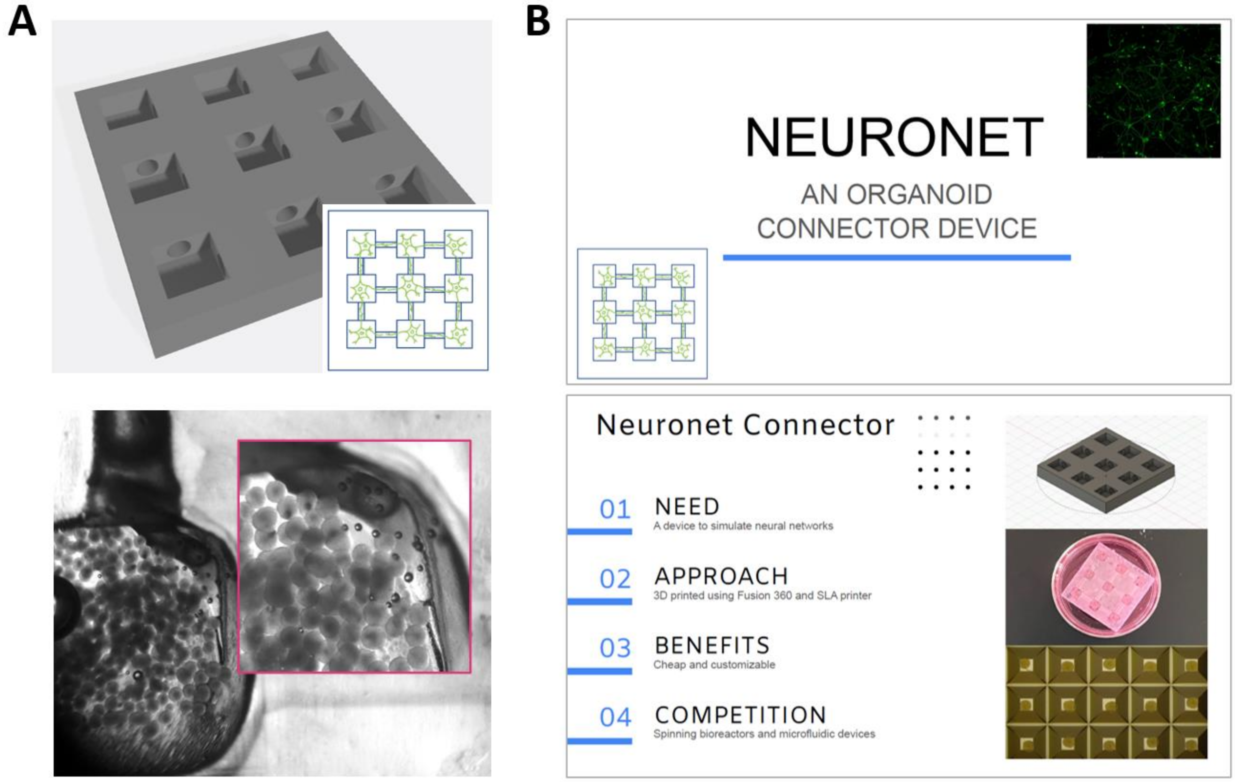

Figure 2. BIOE 306 students designed Neuronet, an "organoid connector device to mimic the formation of neuronal networks." (A) CAD renderings (*top*) and microscope images of organoids in 3D printed devices (*bottom*). (B) Slides from the product pitch.

In BIOE 306, a group of two students chose to complete project 4 (Table 2) to address a roadblock in neural organoid engineering. In neuroscience research, there is a critical need to study cell-cell interactions-for neurite extension, synapse formation, and interconnectivity between organoids [19], [20] while also keeping them from merging. As a solution, this project group developed "Neuronet," a 3D printed device with multiple wells for organoid culture. In addition, they designed internal channels that could allow for the formation of neural networks that promote synapse formation and communication (Figure 2).

In BIOE 303, the two winning groups used BIOPAC software and hardware to study reaction time (project 8, Table 2) and electrogastrography (EGG; project 7, Table 2). Project group 8 studied human reaction time in various stimulus-response situations, observing that consumption of caffeine significantly increased how quickly a subject could react (using a press-and-release device) to a sound stimulus through headphones by 57%. They used their data to inspire "Mocha

Mist," which they marketed as a safe, effective way to consume caffeine while driving. Their bioengineering design relied on aerosolized caffeine particles diffusing through the lid of a piezoelectric coffee cup-like device; it also uniquely considered the device's financial and environmental impacts.

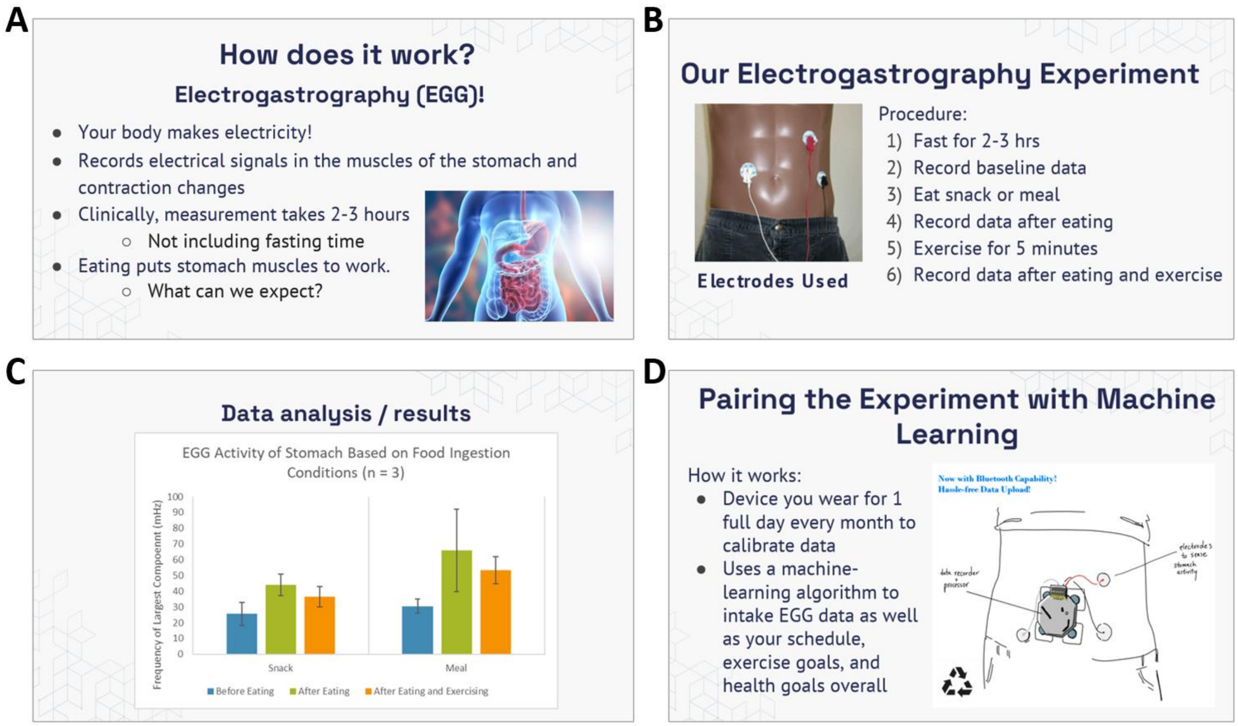

Figure 3. (A-B) BIOE 303 students developed ElectroByte after studying the effects of eating and exercise on digestion using electrogastrograms. (C) Analyzed EGG data from various experimental conditions. (D) The group's proposed device and app design.

Another group from BIOE 303, project group 7, analyzed electrical signals from the stomach (electrogastrograms) to observe the effects of eating and exercise on digestion (Figure 3). Their human subjects studied both the type of food consumed and whether a post-meal workout would impact the detected signals. The group observed more digestion without rigorous exercise, and more digestion overall after eating (as measured by percentage difference in EGG activity from baseline); they also calculated more digestive signals when eating a meal, as opposed to eating a snack (as measured by percentage increase in EGG activity afterwards). These results inspired students to propose a device and app called ElectroByte to pair with machine learning to customize the user's diet and exercise plan around their schedule.

Student Evaluations and Survey Data

Student feedback was solicited via multiple formats, as described above. From anonymous, formal university-wide course and instructor evaluations, students quantitatively responded to rating-scale prompts regarding various aspects of the two courses. A subset of items applicable to this project are included in Table 3.

	Biofabrication Lab (BIOE 306)	*Quantitative Physiology Lab (BIOE 303)*
Student response rate	8/8 (100.0%)	49/63 (77.8%)
Rate the overall quality of this course. [Exceptionally Low … Exceptionally High]	4.50 ± 0.53	4.40 ± 0.54
Did you improve your ability to apply principles in new situations? [No, Not Much … Yes, Significantly]	4.63 ± 0.52	4.45 ± 0.58
The relevance between the subject matter and real life situations was emphasized. [Not At All … To A Great Extent]	4.63 ± 0.52	4.43 ± 0.71

Table 3. Compiled quantitative results from anonymous university-wide course and instructor evaluations, presented as mean values ± standard deviation. Students responded to rating-scale prompts on a 5-point scale.

In addition, quantitative results from student self-evaluations administered at multiple points throughout the study (before the product pitch guest lecture, after the product pitch guest lecture and before students began experimental projects, and at the completion of the project) were collected in BIOE 303 (Table 4).

Finally, students were also asked to complete informal course surveys created by the instructor to provide further insight in addition to what could be gleaned from the formal university evaluations. This qualitative project-specific feedback was solicited after students completed the project and pitch. Representative comments from both courses are included in Table 5 and organized by themes.

	Before guest lecture	*After guest lecture, before project*	*After project and pitch*	*% increase from earliest to latest study point*
PRODUCT PITCH **Overall**	**2.82 ± 1.0**	**4.13 ± 0.8**	**4.17 ± 0.8**	**47.73**
Understand the purpose of a pitch	3.5 ± 0.9	4.38 ± 0.8	4.3 ± 0.7	22.86
Analyze differences between various pitch formats	2.44 ± 0.9	3.9 ± 0.8	4.02 ± 0.9	64.75
Explain the primary components of a pitch	2.66 ± 0.9	4.3 ± 0.7	4.12 ± 0.7	54.89
Practice writing an engaging pitch	2.58 ± 0.9	3.98 ± 0.8	4.1 ± 0.7	58.91
Practice effectively communicating a technical idea through a non-technical context	2.94 ± 0.8	4.1 ± 0.7	4.32 ± 0.7	46.94
LAB SKILLS **Overall**		**4.12 ± 0.8**	**4.46 ± 7**	**8.16**
Read and understand a BIOPAC protocol	*	4.34 ± 0.7	4.54 ± 0.6	4.61
Follow a BIOPAC protocol	*	4.36 ± 0.7	4.6 ± 0.6	5.50
Acquire physiological data	*	4.18 ± 0.9	4.46 ± 0.7	6.70
Analyze physiological data	**	3.96 ± 0.8	4.3 ± 0.8	8.59
Present physiological data (lab report, poster, oral presentation)	***	3.76 ± 0.8	4.38 ± 0.7	16.49

Table 4. Compiled quantitative results (mean values ± standard deviation) from self-evaluations administered throughout the study. Students responded to rating-scale prompts (1 = no knowledge of this topic, 5 = expert on this topic) for each item in two different categories: product pitching and lab skills. Overall averages combined from all items within each separate category are also included in bold (n = 50). Color scales for average values indicate lowest (red) to highest (green) values. Significance is indicated by * = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$ (student's paired t-test). Shown at right are percentage increases (grey-scaled according to value) from the earliest to latest study point for each item and also from combined overall categories.

Theme	*Comments from BIOE 306, Spring 2023*	*Comments from BIOE 303, Fall 2023*
Overall project design	● "I like the CAD design paired with our idea pitch. Every component is well designed." ● "If the presentations are able to be continued, I think that the assignments are well constructed." ● "I like the interaction of lab, assignments and pitch." ● "It was a lot to do overall, but it was a fun experience!"	● "[I] enjoyed carrying out our experiment [and] being able to add our own element to the experimental design." ● "I liked the opportunity to be creative about devices that could be created based on data collection techniques we perform in lab."
Background and resources from instructor and guest lectures	● "I think it is straightforward enough." ● "The protocol was good, […] clear and fun to do." ● "[It was] helpful to understand the fundamentals of delivering a pitch."	● "An example good pitch from previous years would help." ● "Resources were sufficient [and] the BIOPAC [experimental] protocols and lectures were helpful."
Product pitch	● "I think we should have a discussion section of [the] mini pitch during the lecture." ● "I liked it, it was different than a traditional lab report and let us physically learn more on how to pitch an idea. Maybe we could've used a bit more practice or maybe more resources […]" ● "The [introductory] lecture was good, but with the grade given for our group, I wish there was more clarity on what was expected in the pitch." ● "I think it is a nice variation of assignment to practice presentation skills while making it fun."	● "I would suggest providing more resources and examples of pitches." ● "I could have used stronger guidelines for what a product pitch should look like, but otherwise it was fun." ● "[I would have liked] practice opportunities with TAs for feedback." ● "I would have liked to see more emphasis on the […] idea [of] a product pitch. I found it difficult to get out of the engineering/lab report mindset."
Project timeline	● "[The project was] spread out, making it hard to forget originally what we had done. I still think the press release [and] pitch assignments were good but, in the future, if we want to tie in [what was done] in lab, [move] the assignments forward, don't push them over the span of a month."	● "I thought there was adequate time to prepare and complete all tasks, and the open lab sessions were very helpful." ● "Timeline was good. We had enough time to get data, analyze, and create the pitch."

Table 5. Representative student feedback from course surveys in BIOE 306 and BIOE 303

Discussion

Student work products and feedback revealed both what was successful as well as what might be improved upon in future iterations of the project. First, there were multiple items from the BIOE

306 student evaluations (Table 5) that prompted amendment to the BIOE 303 project in the following semester. In BIOE 306, students described the need for enhanced clarity for project expectations: “The [introductory] lecture was good, but with the grade given for our group, I wish there was more clarity on what was expected in the pitch” and “Unless more [materials and details] were given on what is considered for the rubric, the product pitch may be a bit too heavily weighted considering it is very short to do in execution and there really wasn't much preparation and familiarity with such an assignment.” More clarity and description were subsequently added to the product pitch scoring rubric in BIOE 303 (Appendix). Additionally, some students raised concerns about the overall span of the project timeline; however, when asked whether the timeline for completing the assignment was fair, the students in BIOE 306 (100%, n = 8) responded via survey that there was adequate time to complete all the project requirements.

Overall, students responded positively to the novelty of the project (especially as an alternative to writing a traditional lab report) and the opportunity to creatively design and incorporate the accumulation of their learning from both the lab and lecture components of the course. However, qualitative results from both courses also show requests for more detailed project guidelines, indicating that some students might not be accustomed to or comfortable with more open-ended projects that require innovation and novel ideation. This might be due to the rarity of assignments like this in many STEM courses, or an unfamiliarity with topics such as entrepreneurial mindset in a technical or laboratory context that can traditionally contain prescribed or formulaic experimental modules. Incorporating preemptive, smaller creative assignments earlier on in the curriculum or course might alleviate some of the apprehension students might have when approaching this type of project. Even with a more specific rubric, multiple students requested additional preparation, or an example of what success would look like in this type of assignment (e.g., “I would suggest providing more resources and examples of pitches”); these opportunities for informal practice sessions and resources could be provided in the future from past versions of the project as described here.

Quantitative survey results demonstrated that the guest lectures were beneficial in preparing students for the project. Overall, students self-reported an average increase of 47.73% in their knowledge and familiarity with skills related to product pitching from the beginning to the end of the project, with the largest impact seen because of the guest lecture (Table 4). Average scores did not increase as greatly from that point until the completion of the project, but still demonstrated that the students maintained their confidence in pitching skills throughout their work on the project (which helped to solidify that learning). It is important to note that this additional content from a guest lecturer only required allocating a small amount of instructional time and did not impede the original technical content of the course. Although guest lecturers were utilized to deliver the additional content in these courses, providing valuable expertise from varied perspectives and different departments, the content could also be delivered by the primary instructor after sufficient preparation if resources or collaborations were lacking. One benefit to this method would be the instructor's ability to more intentionally connect the new content to the project assignment and overall course objectives during the project-focused lectures.

Students in BIOE 303 were also asked to quantitatively evaluate their laboratory skills related to the course objectives and previous physiological experimentation (n = 50; Table 4). Self-reported knowledge and familiarity in understanding and following a protocol, acquiring and analyzing physiological data, and presenting the data in different formats all increased significantly throughout the project timeline, with the largest percentage increase (16.49%) in skills related to data presentation. Overall, a higher percentage increase was observed in product pitching skills compared to lab skills (47.73% versus 8.16%, respectively, though compiled lab skills were higher on average overall at the project completion). This is likely because students already possessed some experience with physiological experimentation (as opposed to product pitching) throughout that semester before the project, though the project did help to hone those skills.

Because its assessment is not constrained to specific technical content, this project can be adopted in a variety of engineering laboratory settings and with many different topics, as shown here in a Bioengineering department. We demonstrate the adaptability of such a project in two different laboratory environments: one that provided experience with 3D printing and advanced cell culture techniques in a small wet lab setting, and one that drew on experience with physiological data acquisition and analysis using commercially available hardware and software in a larger core class. The project requirements could be scaled in scope and grading weight, and the breadth of learning objectives could be adjusted accordingly. For example, students in BIOE 306 (a small class size of 8 students) were asked to present a product pitch within 4-5 minutes using only 1-2 slides in teams of 2; in BIOE 303, the limitations of the class size (nearly 60 students) and grading staff necessitated more students per groups but allowed slightly longer time (10 minutes) for the product pitches. The flexibility of an entrepreneurial-oriented project means that it can be incorporated into lab courses of varying levels and areas of engineering focus, many of which value and benefit from an entrepreneurial mindset.

The format of the two laboratories described here provided a venue for the students to demonstrate the depth of their understanding of the project along with the thoroughness of their research and preparation. Students were compelled to not only consider the feasibility of their technical designs, but also the value they were creating for potential users of their technology. Additionally, this assignment gave the students a brief introduction to the necessity of describing their scientific work in a multifaceted way that appeals to a mixed audience of both experts and nonexperts, which they will undoubtedly find to be an indispensable skill for a wide range of their future potential careers.

Conclusion

Laboratory experiences enhance student learning through hands-on experiments and the opportunity to practice the process of innovation. These environments of experiential learning also have the potential to provide opportunities for students to learn about emerging needs in their fields of specialization, appreciate the process of technology commercialization, and understand how to design and promote an engineering device for specific audiences. Undergraduate engineering students pursue a wide range of professional careers after graduation, and many of these paths involve designing products that will be brought to market in various capacities. Because of this, there is an opportunity to expose students to this process through project-based learning even within required laboratory courses without compromising technical engineering content, ABET standards and student outcomes, or course learning objectives.

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Appendix

Product Pitch Scoring Rubric

	Points
BACKGROUND	
• Overview of experimental objectives and any pertinent background information (including physiological or clinical relevance). • Brief introduction to the methods & materials. • Analyzed quantitative results and short discussion of importance.	15
VALUE	
• The information provided is sufficient to help the audience understand the existing need or problem. • The value of the idea/product is conveyed.	5

SOLUTION	
• The solution to the problem is clearly demonstrated and explained in a convincing pitch of the new product or device.	10
PRESENTATION	
• *ORAL:* Delivery, clarity, professionalism, and ease of following along are exhibited. Pitch is clear and persuasive, with equal contribution from all students. • *VISUAL:* Overall neatness, organization, aesthetic appeal, and use of images to support the pitch in the slides.	5 10
COMMUNICATION TO A BROAD AUDIENCE	
• *ORAL:* Presentation is effective in conveying a technical idea through a non-technical context.	5
TOTAL	*50*

Product Pitch Survey

Students completed the following survey before the product pitch guest lecture, after the lecture, and at the project conclusion. The instructions asked the students to consider their knowledge and familiarity with the topics below, using the following scores: 1 = no knowledge of this topic; 2 = some knowledge; 3 = working knowledge; 4 = very knowledgeable; 5 = expert on this topic.

Topic	*Score*				
Understand the purpose of a pitch	1	2	3	4	5
Analyze differences between various pitch formats	1	2	3	4	5
Explain the primary components of a pitch	1	2	3	4	5
Practice writing an engaging pitch	1	2	3	4	5
Practice effectively communicating a technical idea through a non-technical context	1	2	3	4	5

Lab Skills Survey

Students were asked to complete the following survey after the guest lectures (i.e., before starting the project) and at the conclusion of the project. The instructions asked the students to consider their knowledge of the topics and familiarity with them, using the scores as detailed above (1 = no knowledge of this topic; 5 = expert on this topic).

Topic	*Score*				
Reading and understanding a BIOPAC protocol	1	2	3	4	5
Following a BIOPAC protocol	1	2	3	4	5
Acquiring physiological data	1	2	3	4	5
Analyzing physiological data	1	2	3	4	5
Presenting physiological data (in a lab report, poster, or oral presentation)	1	2	3	4	5