Empowering Future Engineers by Integrating Science Communication Into Undergraduate Labs

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***Abstract*— This Innovative Practice full paper describes the introduction of science communication into design-based projects in undergraduate engineering laboratory education. In most engineering disciplines, experiential learning and laboratory courses are vital components of undergraduate instruction. Historically, student aptitude is assessed through protocoled experimentation followed by written assignments such as technical lab reports; however, this format does not usually allow students to demonstrate competence in open-ended engineering design or non-technical communication skills that can prepare them for future project-based courses, graduate school, product commercialization, or a myriad of careers. Effectively exchanging technical information is remarkably important as engineers are increasingly called upon to provide recommendations in many areas of society. The efficacy with which engineers can adequately convey scientific ideas in these exchanges has the potential to inform decisions that shape research funding, healthcare, laws, and more. The potential to address these issues is what makes science communication a critical part of general science education: it demystifies complex subjects and makes topics accessible to a wide range of audiences. Science communication is a highly important skill, but one with which very few scientists have practical experience. In this paper, we demonstrate resources to introduce the basics of science communication into two upper-level instructional laboratory courses (Quantitative Physiology Lab and Biofabrication Lab) during two consecutive semesters in a bioengineering department at a large public university. In both courses (which ranged in topic, scope, size, and general organization), a design-based project was incorporated. Through guest lectures from both a science communication and marketing professional as well as experts within the technical fields, student teams learned to apply these new concepts by performing an independent hands-on experiment, designing a bioengineering-related device, and writing a non-technical press release to disseminate their results. Here, we document the timeline and process of implementing this module in both courses, as well as examples of student work. Feedback was solicited at various stages of the project through qualitative and quantitative surveys. Students were assessed separately on technical content and writing assignments within the project. Results and survey responses indicate that this type of module could be incorporated into design-based projects or existing curricula within many undergraduate disciplines to broadly enhance engineering-related communication skills.**

Keywords—science communication, writing, design, laboratory

I. Introduction

The Accreditation Board for Engineering and Technology (ABET) standards outline specific student outcomes for engineering education. Experimental laboratory courses are effective at meeting ABET-based criteria for conducting experimentation, applying new knowledge and engineering design, solving complex problems, and functioning on a team [1,2]. Communication skills are a crucial component in the education of students within a variety of engineering disciplines [3]. Traditional technical writing and verbal assignments, such as lab reports or presentations based on hands-on experiments, provide skill development in conveying information and data to scientific audiences. However, while these assignments teach practical skills in technical communication, they often do not give students experience with sharing scientific or engineering-based information to non-technical audiences from diverse cultural or societal backgrounds. These skills may be relevant in upper-level project-based courses such as a culminating engineering design class and valued by future employers or graduate schools. In this paper, we discuss the implementation and outcomes of a new project-based assessment that emphasizes science communication in two distinct undergraduate bioengineering laboratory courses.

A. *The Importance of Science Communication*

Science in its many forms has become an integral part of modern life, yet the average American's trust in science has significantly diminished [4]. The onset of greater technological availability was predicted to increase scientific appreciation and understanding, but it appears to have had the opposite effect. This increase in skepticism towards science has played a pivotal role in the rise of politically relevant issues such as anti-vaccine conspiracy theories [5], climate change denial [6], and an overarching belief that scientists may not be acting in the public's best interest [4]. Improving the general population's perception of science can only be achieved through increasing scientific understanding and empowering the public to confidently make informed decisions. Former CEO of the American Association for the Advancement of Science (AAAS) Alan Leshner wrote: "The centrality of science to modern life bestows an obligation on the scientific community to develop different and closer links with the general population" [7].

One of the simplest and most practical ways to fulfill that obligation is through effective science communication. When successful, it demystifies complex subjects and makes formerly intimidating topics accessible to a wide range of audiences, regardless of background or interest. This ability to effectively communicate to a varied group of people is essential as scientists are increasingly being called upon to provide recommendations [8] to policymakers and leaders without a scientific background. The efficacy with which these scientists can convey scientific ideas has the potential to inform decisions that shape healthcare, economic policies, research funding, and more. Therefore, a consistent science communication module in undergraduate lab courses could serve to broaden student learning and to strengthen the relationship between the scientific community and the public in the future. Additionally, students can develop their abilities to actively distill new topics into understandable components, seek out overarching themes, and identify the big picture when encountering new information; all valuable skills as they progress through their fields and careers.

Research has been undertaken to determine the outlook and best practices for incorporating technical and science communication instruction in university classes, at both the undergraduate and graduate level. This includes incorporating content into existing engineering courses throughout the curricula [9]. Significant findings highlight that this instruction must be mindful of inclusion, equity, and intersectionality [10]. It should also be continuously reevaluated and refined to ensure that only the most up-to-date information and approaches are taught [11]. A variety of teaching methods have been found to be successful, such as requiring students to develop a portfolio of science communication materials alongside their work and incorporating leadership or teaching-based projects into the course [12]. Notably, the literature supports the supposition that science communication is a highly important skill but is one with which very few scientists have any practical experience [13]. As a result, there is a significant and documented need for increased instruction in science communication.

B. *Relationship to Instructional Laboratories*

Science communication is a broad field that is not limited to the more traditional expressions of scientific thought, such as writing. A wide variety of formats are possible, such as the creation of videos, podcasts, editorials or blogs, active presentations, and many more, which can even be disseminated on social media. This flexibility highlights significant potential for both the creative incorporation of this subject in the classroom and the active engagement of students as they are encouraged to express their own creativity while developing numerous skills that will set them apart in their respective careers. Training undergraduate students in science communication also holds the potential to improve the relationship between the scientific community and the public.

To build students' experience with science communication, a project module was incorporated into two upper-level laboratory bioengineering courses at the University of Illinois Urbana-Champaign (Table I) to replace traditional lab reports and presentations of an experimental design project. First, students were introduced to the importance of science communication and marketing to non-expert audiences through expert guest lectures. They then conducted a hands-on experiment and used collected experimental data to design engineered solutions to a specific problem of their choice. Finally, they applied science communication skills by writing a non-technical press release meant to share the impact of their results and the proposed innovation with a general audience. Students also participated in a mock product pitch competition to present their innovation and justify its value to a technical but non-expert audience, as described previously in [14]. Surveys were administered to students at multiple points during the final project module to assess their self-reported expertise on aspects of science communication. End-of-semester anonymous course evaluations were also administered. Here, we outline the design projects implemented in both courses, describe methods for introducing students to science communication, and analyze observed outcomes. This paper presents evidence of project implementation in engineering courses with different sizes, topics, and organization to validate translatability between many STEM-based laboratory and design courses.

II. METHODS

A. *Course Backgrounds*

This science communication project was integrated into courses offered in the Bioengineering department. It was first piloted in an upper-level elective Biofabrication Lab course. Given positive feedback, it was repeated the following semester in an upper level required Quantitative Physiology Lab course. In both courses, written lab reports are a common course metric to assess students' abilities to understand experimental design, analyze quantitative data, interpret experimental results, and discuss observed findings with connections to literature and known physiological or biological research models (Table I).

TABLE I. COMPARISON OF COURSES

	Biofabrication Lab (BIOE 306)	**Quantitative Physiology Lab (BIOE 303)**
Term, Enrollment	Spring 2023, 8 students	Fall 2023; 63 students
Level / type	Elective, open to third- and fourth-year students	Required, for third-year students
Course objectives *(from syllabus)*	• Design objects with complex geometries using computer-aided design (CAD). • Quantify biocompatibility in culture. • Deliver heterologous genes to cells in culture by lentiviral infection. • Effectively grow mammalian cells in 3D culture environments. • Design, build and test biological machines. • Quantitatively analyze experimental results and prepare scientific reports.	• Explain basic terminology, anatomy, and physiology of several major human systems. • Design experiments to test models. • Analyze and interpret measured data to describe system behavior. • Describe methods of measurement and monitoring of physiological systems. • Work in teams to address design, testing, and presentation of a measurement technique for a physiological system or model validation.

Biofabrication Lab (BIOE 306) introduces students to translational bioengineering by providing experience with computer-aided design (CAD), prototyping, additive manufacturing, and advanced cell culture. By working in pairs to design experiments, perform wet lab and computational tasks, analyze data, and report findings, students develop hands-on skills and gain experience in an environment similar to a graduate level research lab [15]. All students have taken a prerequisite cell and tissue engineering laboratory course [16–19], and many have independent research or design experience.

Quantitative Physiology Lab (BIOE 303) is a required laboratory course that covers neural, cardiovascular, respiratory, muscular, endocrine, and renal systems using simulations and BIOPAC software [20] to translate physiological measurements into quantitative signals. Third-year students work in groups to acquire human physiological data and appropriately report scientific findings.

B. Introductory Lectures

This project aimed to introduce students to practical science communication intended for both general audiences and non-expert audiences with some technical knowledge. As a result, an entrepreneurial product design was used as a framework that pushed student teams to communicate scientific ideas to audiences with mixed levels of technical background and understanding. At the beginning of the module, students received a lecture from the Bioengineering department's marketing and communications coordinator. This lecture walked students through a standard science-based press release and shared best practices for writing about scientific topics in a way that is most engaging for a reader with no associated background. Specifically, this emphasized the inverted pyramid method of writing organization, which first offers readers the general outline of what is being discussed and why it is important before gradually becoming more specific, to draw readers into the story while remaining true to both the broad strokes and the technical details of the subject. This lecture also provided tips on best practices for science communicators (i.e., ways to rephrase scientific buzzwords and jargon, methods of making highly technical subjects more relatable to those outside of the field, and the importance of word choice in a field where statements must be supported by facts and findings). The lecture also addressed the growth of Artificial Intelligence (AI) and its potential to aid in science communication (e.g., by improving readability) as well as its risks if relied upon (such as suggesting data from unverified sources or making false claims).

C. Introduction to Projects and Assessment

Next, students were given a list of eligible topics from which to identify a relevant problem, develop a solution, and conduct experiments to support their claims. This project built on experimental skills previously gained in both courses (Fig. 1). In BIOE 306, students produced living neural organoids using a provided protocol, then identified an issue hindering advancement of the field and developed a solution using 3D printing techniques [15]. In BIOE 303, students independently designed and performed various physiological experiments based on given protocols, then used collected data as justification for a hypothetical biomedical device that addressed specific needs within the field.

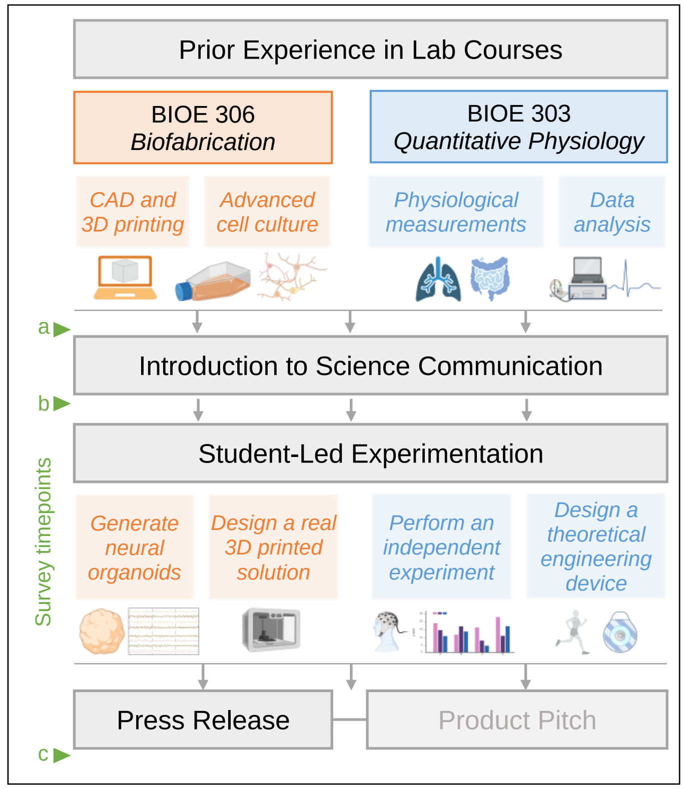


Fig. 1. Timeline of projects in two bioengineering lab classes. Image made with BioRender.com.

Teams were assigned two separate deliverables to present their innovation and results: an entrepreneurial product pitch [14] and a press-release style publication aimed at a non-technical audience. Here, we discuss the latter. Students wrote a two-page press release featuring the results of the experiment as well as an introduction to the novel device or product. They were encouraged to describe their projects in an understandable and engaging manner for a broad non-scientific audience by explaining why the project was important, how it could impact daily life, and what the next steps and broader opportunities might be. Images, figures, and accessible data plots were encouraged. Multiple examples of published press releases from various engineering and biomedical fields were provided.

Project requirements were provided to students when first assigned. BIOE 306 students were also graded on the design and completion of the experimental module, with comparatively less weight. The press release (50% of the project grade, equal with the product pitch presentation) was first submitted as a draft and graded only for completion. The course instructor and departmental marketing and communications coordinator provided written feedback to the groups within a week, allowing for editing time before the due date. The final press release was evaluated for clarity, readability, engagement, and accuracy in terms of the product's value and the proposed solution.

D. Data Collection and Analysis

Feedback was solicited from students in three formats:

1) Quantitative surveys: Before and after the "Science Communication" expert lecture (timepoints a and b, respectively; green arrows in Fig. 1), and at the conclusion of the project (timepoint c; Fig. 1), students self-evaluated their knowledge and familiarity with various topics using the following scale: 1 = no knowledge of this topic; 2 = some knowledge; 3 = working knowledge; 4 = very knowledgeable; 5 = expert on this topic. These topics included: (1) Science communication: what it is; (2) Science communication: why it matters; (3) Writing formats in journalism and marketing; (4); Technical versus non-technical writing styles; (5) Conveying scientific results to a broad audience; (6) Writing a press release (7); Marketing a product or research result to a broad audience in the field; and (8) Marketing a product or research result to a broad audience outside of the field.

2) *Qualitative project-specific surveys:* At the completion of the project, students responded to open-ended prompts regarding project timeline, resources provided, suggestions for improvement, and favorite aspects of the project.

3) *University-wide evaluations:* Course- and instructor-specific evaluations requesting both quantitative data as well as open-ended comments were solicited at the semester's completion and shared anonymously with the instructor.

Quantitative and qualitative student feedback was downloaded and de-identified by the instructor. If a student did not complete all the quantitative surveys, their responses were excluded from further data analysis. Course staff quantitatively analyzed de-identified responses in Microsoft Excel and GraphPad Prism. The university provided anonymized data from the standardized course and instructor evaluations. The Institutional Review Board of the University of Illinois Urbana-Champaign's Office for the Protection of Research Subjects deemed this study exempt (NHSR Determination #24477).

III. RESULTS

A. *Project Outcomes*

In response to the problem statements issued in each course, students engineered potential solutions. Here, we include representative press releases from one team in each course.

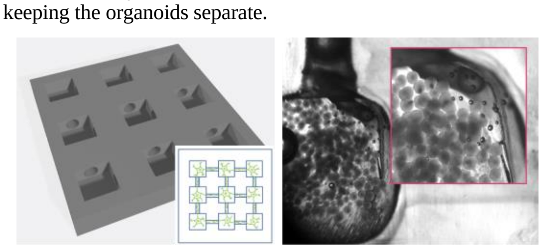
In BIOE 306, teams addressed barriers in neural tissue engineering [15]. One group attempted to solve a common issue: the merging of organoids into one large cellular mass when grown in culture. While organoids containing neural cells are useful research tools [21–23], the ability to study cell-cell interactions related to synapse formation, extension of neurites, and organoid interconnectivity is often hindered if the organoids merge [24,25]. This student group thus developed a 3D printed device containing multiple wells in which organoids could be cultured. The design of "Neuronet" also featured internal channels permitting the formation of neural networks and synapses for cellular communication (Fig. 2).

In BIOE 303, one group studied electrogastrograms (EGGs, or electrical signals from the stomach) to observe how exercise and diet impact digestion, by both the nature of the consumed meal and whether a post-meal workout would influence the detected signals. Increases in digestion were observed after eating and in the absence of rigorous exercise (as measured by percentage difference in EGG activity from baseline). The results also demonstrated a higher frequency of signals from the stomach after eating a meal, compared to after eating a snack. These data inspired students to propose "Electrobyte," an app that pairs with machine learning to customize the user's workout plan and diet around their schedule (Fig. 3).

3D Printing Device Could Revolutionize Neuronal Network Formation from Organoids!

Though it may seem like science fiction, growing a brain straight from a petri dish could be possible in the near future. Two Bioengineering [undergraduates] have developed a groundbreaking new 3D printed device designed to aid in the formation of neuronal network connections between neural organoids.

Organoids are small, 3D tissue structures that are grown *in vitro* from stem cells, and their use in research labs has aided in the study of human biology and disease models. When grown in close proximity, these organoids can clump together which hinders their ability to receive proper nutrients from their environment […]. The system […] is designed to help researchers study the network formation of neural organoids (sometimes called "mini brains") while limiting cell death. The engineered device features a 3D printed micro network that simulates the expansive, branching, and interconnective pattern of neuron networks in the body and channels that allow neuron connections to grow while keeping the organoids separate.



The potential impact of this device is significant. With better communication between organoids, researchers can more accurately simulate the complexity of human organs and gain new insights into how they function and how diseases develop. Moreover, creating accurate and replicable disease models is a challenge […], and the development of devices like this is aiding in the ability to research […] neurodegenerative disorders like Alzheimer's and Parkinson's, without the use of human or animal subjects.

To use this device, the students adapted a protocol to generate neural organoids […].They first induced the differentiation of human pluripotent stem cells, and then formed organoids from differentiated cells in a microwell plate [… which allowed them] to harvest single organoids from these wells to be placed and tested in the device. To better examine the organoids' activity, they then imaged the device under a microscope which enabled them to track the growth and activity of the cells with high resolution as well as see the axonal projections grow through the device. "This product is a game-changer," said [student A]. "It has allowed us to observe the internal connection of neuronal networks closely, and has already unlocked new insights into the development and function of the mini brain organoids."

"We're thrilled to introduce the 3D printing network to the scientific community," said [student B], the developer engineer of the product. "Our team has worked tirelessly to develop a device that can help researchers make breakthrough discoveries into the complex process of neuronal network formation. We believe this device has the potential to revolutionize this field of research and we're eager to see its impact."

Fig. 2. Representative press release from Biofabrication Lab. *Left*: Images of the Neuronet 3D printed device (with and without organoids) from [14].

ElectroByte^{TM}: Taste the Future of Nutrition

Balancing nutrition can be challenging for everyone, but it is one of the most influential parts of your health. However, with so many different diets and trends, it can be overwhelming to plan meals around an already busy day. A new product made by […] engineering students called ElectroByte^{TM} uses electrical signals in the stomach to track individual digestion and suggest dietary plans so that users have one less decision on their plate.

Electrogastrography (EGG) is a technique used by researchers to analyze digestion. Frequencies from digestion signals correspond to how quickly the stomach contracts to digest food in a certain amount of time. Higher frequencies mean that the stomach is working harder to digest. The bioengineering students conducted EGGs in order to study the effects of food and exercise on digestion. […] The students observed noticeable differences in the signals before and after the participants ate a meal […] containing carbs, protein, and fat. The […] frequency of the signals increased after eating food, with the magnitude depending on the type and amount of food eaten. After eating and exercising […], the frequency appeared to decrease again.

According to Mayo Clinic, it is important to schedule meals around exercise to avoid feeling sluggish or weak. It is important to wait 1-3 hours after snacks (and 3-4 hours after most meals) before exercise, but this also depends on how big the snack or meal is as well as the intensity of the exercise. This was reflected in the data, [which showed a decrease in digestion] with intense exercise right after eating a snack. Overall, research has shown that light to moderate exercise after eating has a positive impact on digestive ability, blood sugar regulation, and general gut health and functioning […].

EGG measurements provide valuable data that can help people live healthier lives. However, conducting these measurements can be time-consuming and require professional use and interpretation of results. Given these challenges associated with acquiring and interpreting EGG results, the students leveraged this measurement system to create a portable EGG device and an associated app [where] anyone will be able to quickly and accurately measure their digestion. The app will then analyze the data, output easy-to-digest graphs, and provide dietary and exercise advice and reminders. The device integrates personal demographics and syncs the user's Google Calendar to be used in the machine-learning algorithm, [which] generates optimal mealtimes and ideas, and takes into account the user's food preferences, [and using] baseline EGG data from the user [to] plans time to eat and exercise around their busy schedules. […] "We are excited to make personalized nutrition care more accessible," [said] one of the student researchers.

Fig. 3. Representative press release from Quantitative Physiology Lab.

Other student projects from BIOE 303 included:

- Sideline SafeGuard, a lightweight physiologic data-based solution to keeping athletes safe from concussion using electrooculographic (EOG) eye-tracking software;
- Exosonomis, a non-invasive over-ear device that senses brain activity through electroencephalography (EEG) and responds with vibrations to keep the subject alert;
- FatigueGuard, a device to track muscle fatigue in order to improve fitness performance and prevent injury; the device displays real-time integrated electromyography (EMG) to plan workout and recovery strategies while warning the user at signs of overtraining;
- MyoSinc Athleisure, combining EMG with compression leggings to facilitate muscle repair after injury by active sensing and recording of electrical activity (Fig. 4).

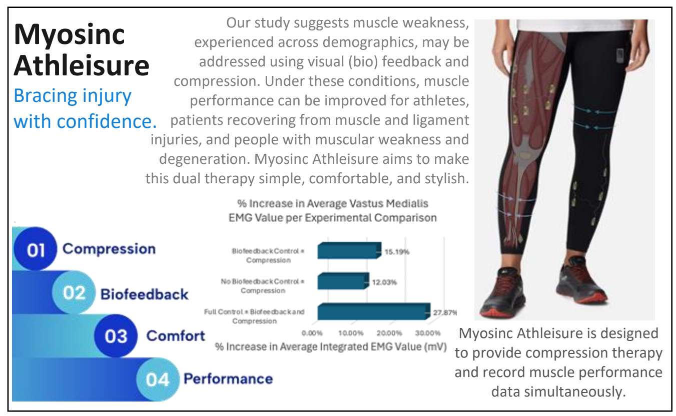


Fig. 4. Representative product solution from BIOE 303.

B. *Student Evaluations and Survey Data*

Student reception to the project was collected in multiple ways. Formal university-wide course and instructor evaluations yielded rating-scale responses (1 lowest; 5 highest) to questions about various aspects of the courses in general. A subset of questions and responses is included in Table II, with results presented as mean values ± standard deviations.

For additional insight beyond the formal university-specific evaluations, qualitative surveys designed by the instructor asked students in both courses for feedback on the project after its completion (Table III). These surveys prompted students to respond to various project themes including the experimental protocols, lectures, assignments, and timeline. When queried about their favorite aspects of the project, students' responses fell under six categories, listed below with percentage of responses in each category (out of total positive submitted replies) and representative quotes from students in BIOE 303.

- Sharing ideas with classmates (32%); e.g., "hearing other pitches and seeing new opportunities for innovation" and "being able to see [others'] products".

TABLE II. COMPILED QUANTITATIVE RESULTS FROM ANONYMOUS UNIVERSITY-WIDE COURSE AND INSTRUCTOR EVALUATIONS, BASED ON A LIKERT SCALE OF 1-5.

	Biofabrication Lab (BIOE 306)	**Quantitative Physiology Lab (BIOE 303)**
Student response rate	8/8 (100%)	49/63 (78%)
How much have you learned in this course? *[Very Little ... A Great Deal]*	4.63 ± 0.52	4.43 ± 0.58
Did you improve your ability to solve real problems in this field? *[No, Not Really ... Yes, Significantly]*	4.38 ± 0.52	4.31 ± 0.68
The instructor challenged students to think broadly about academic topics. *[Never ... Very Often]*	4.63 ± 0.52	4.12 ± 0.78
The instructor encouraged students to understand multiple perspectives. *[Strongly Disagree ... Strongly Agree]*	4.38 ± 1.06	4.16 ± 0.72

- Marketing and communication (24%); e.g., “brainstorming ideas with [our] team and taking a fun business and marketing approach to our product” and “working with my team and strategically discussing how to […] effectively communicate”.
- Creativity (24%); e.g., “thinking in a creative manner, and making the project fun itself”.
- Design component (20%); e.g., “seeing new opportunities for innovation” and “the freedom to work with my group members to design our product and prepare an engaging presentation”.
- Teamwork (18%); e.g., “collaborating with peers”.
- Independent lab experimentation (14%); e.g., having the opportunity to “analyze and interpret data in a less formal format” and to “perform our own experiment”.
- Real-life application (6%); e.g., “applying the data we gathered during the semester [which] can be useful and applicable outside of the classroom”.

Responses regarding least favorite aspects were similarly categorized. For students who responded with a negative attribute, the top themes are listed below with percentage of responses in each category (out of total negative submitted):

- Limited freedom with experimental protocols (24.3%); e.g., “Finding a way to [connect a product to the experiment] felt challenging […] I think more freedom with the experiment would make it even better.”
- Presenting to classmates (18.9%); e.g., “I am not a strong presenter, so speaking to the class was not very fun although it was great experience and will make me a little more comfortable for next time” and “I found the questions [from the audience] to be stressful.”
- Independent lab experimentation (13.5%); e.g., “data collection and analysis”.
- Team size (13.5%); e.g., “There may have been too many people in a group” (6 students per team in BIOE 303).
- Design component (10.8%); e.g., “coming up with a product that would reflect our limited data”.

Other themes were Marketing and communication (10.8%), Time commitment (5.4%), and Unclear expectations (2.7%).

Finally, quantitative responses to consistent rating-scale prompts were collected at various points during the project in BIOE 303 (Fig. 5). For all 8 topics, students’ self-evaluations reflected an average increase of 48.2%, or 1.24 points (on a scale from 1-5: no knowledge of this topic to expert on this topic) before and after the guest lecture. Scores then further increased an average of 6.1% by the end of the project.

IV. Discussion

Results indicate that embedding a science communication module into undergraduate lab courses does serve to broaden student learning and strengthens the ability of students to communicate effectively to a non-technical audience.

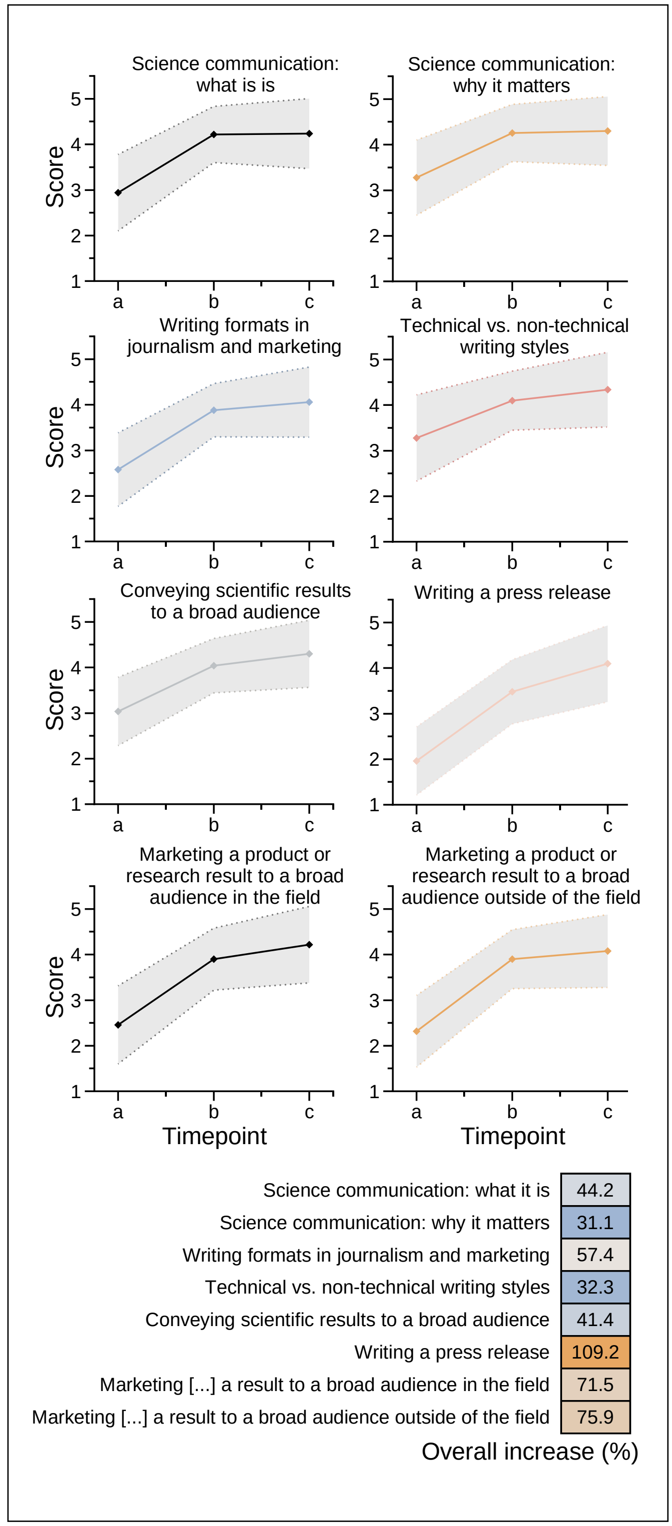


Fig. 5. *Top*: Rating-scale survey responses (1-5) collected during the project in BIOE 303: before and after the guest lecture (timepoints a and b), and after the project (c). *Bottom*: average percent increase from timepoints a to c.

TABLE III. REPRESENTATIVE FEEDBACK FROM PROJECT-SPECIFIC SURVEYS.

Theme	Biofabrication Lab (BIOE 306)	Quantitative Physiology Lab (BIOE 303)
Overall project design	• "Doing both a press release and [pitch was] a lot on top of designing our own solution for the project. Especially since […] we had to think and adjust our initial problem according for the projects. Picking one assignment and making more detailed requirements would be […] better."	• "[My favorite part was] getting to be creative and work on a product with a group while also applying my knowledge from the whole semester." • "I think that it was good way of us being able to show what we learned." • "[The project was] well formatted because of opportunity for feedback."
Resources	• "Having the additional resources [… was] a necessary part of completing the associated assignments." • "It [was] helpful to receive criticism and the opportunity for revisions."	• "I found the example press releases helpful because I've never really written one before." • "Guest lectures were well received! […] It would have been nice to go through an example [press release]."
Press release	• "[It] was different from writing lab reports […] and allowed us to learn more about how to apply our inventions to the real world, to a population who isn't as technical as [we are]." • "Maybe there's a way we can make the press release public as a way to showcase our idea." • "The assignment made us be more creative and tap into a different side of our writing skills."	• "[We] enjoyed trying to write in an accessible way to a broad audience." • "I thought this assignment was clear and I liked that we got feedback." • "Make the directions a bit more specific. It was [difficult] to understand how much we were trying to sell the product in the press release." • "[It] wasn't horribly difficult, but definitely took some thinking." • "I enjoyed writing this assignment. • "[I] enjoyed the different challenge from the typical assessment."
Timeline	• "Yes, it was enough time [to complete the experiment]."	• "The timing was great. There was plenty of time to prep and ample time to run experiments."

Longitudinal quantitative survey responses collected at multiple points throughout the project (Fig. 5) demonstrate that students self-reported an increase in their knowledge and understanding of the original module learning objectives. Most prominently, from timepoints a to c, students increased their ability to write a press release (109.2% increase), marketing […] a result to a broad audience outside the field (75.9%), as well as to a broad audience inside of the field (71.5%).

It is interesting to note that student growth most readily occurred in the time period immediately before to immediately after the expert guest lecture (Fig. 5). A few conclusions can be drawn from this result. First, the expert developed the learning objectives and then intentionally crafted the lesson to meet these objectives. It is evident from the survey results that the lecture was effective in teaching to these objectives. Second, there is evidence that students did continue to refine and develop these abilities from their involvement in the project. In particular, students self-reported that their ability to write a press release increased significantly both from the lecture alone (77.6% increase) as well as from project work (17.8% increase).

Third, thematic analysis of student evaluation data provides insight into other ways in which student growth occurred that can be attributed to the project. Regarding favorite aspects of the project, students identified sharing ideas with classmates, the creativity and open-ended aspect, the innovative design element provided through the project instructions, working in a team, the freedom to work on independent and novel lab experimentation, and the real-world application of the project deliverables. Although these areas were not direct objectives of the science communication module, they are important non-technical, ABET-aligned goals for holistic development of engineering students. Student growth in real-world application was further substantiated through results of the anonymous university-wide course and instructor evaluation through the question "Did you improve your ability to solve real problems in this field?" This specific question resulted in an outcome of 4.38 ± 0.52 (BIOE 306) and 4.31 ± 0.68 (BIOE 303) on a Likert scale. Though the university-wide questions pertained to the courses as a whole, these skills were emphasized in the project objectives.

Course surveys were also instrumental in the identification of opportunities for modification and improvement. The representative feedback provided in Table III highlights that the project workload could be adjusted to better fit the grade weighting. Students did discuss that adequate resources, including the guest lectures and example press releases, were provided to accomplish the project requirements (i.e., press release and pitch), but that perhaps student teams could select only one deliverable to work on more extensively rather than complete both. This is an interesting suggestion and should be decided by the course instructor(s) based on the overall course learning objectives, time available, and overall logistics. How many credit hours is the course? At what level? What is the weighting of the project compared to other assignments and assessments? Could one course in the curriculum focus on guiding students to pitch ideas to non-technical audiences while another course focuses on science communication and writing a press release so that students are ultimately exposed to both but given more time and attention to each as separate entities?

Finally, students overall found benefit in the experience of writing a press release, and one even hoped for "a way we can make the press release public as a way to showcase our idea." This could be accomplished by sending the final work products to a larger audience (e.g., other department faculty, industry experts, etc.) for feedback, developing a website or blog showcasing the press releases, or creating an event in which the press releases and other project deliverables are displayed for a wider audience to view. The course instructor(s) could also consider whether a different mode of communication would be a better avenue for their specific course goals instead of science journalism, or for varying engineering disciplines to broaden the scope. For instance, students could develop a museum exhibit with written and hands-on components to demonstrate how environmental engineers manage water supplies to control and monitor pollution. A civil engineering lab course may ask students to write a semi-technical brief for local policymakers regarding the best materials or methods of construction in a city infrastructure project. Material science or electrical engineers could develop outreach materials for a general audience working in extreme environments to explain why a novel fuel cell or battery concept would be safe for use in those environments. Though we successfully demonstrate this module's usefulness in bioengineering classes ranging from 8-63 students, instructors in other departments may need to consider possible issues with translation, expansion, or challenges unique to larger courses.

While this paper utilized lab courses in bioengineering to study the effectiveness of a science communication module on student learning, this specific module—consisting of an expert lecture and subsequent technical team project embedded with creative ideation and the writing of a press release—can be easily adapted and inserted into a variety of engineering laboratory settings, fields of study, and levels. The guest lecture that introduces students to the fundamentals of science communication can be effectively done by academic or industry professionals with roles in marketing and communication or the content could be studied and taught by the primary course instructor using the aforementioned outline of topics. The press release assignment can be modified and scaled as needed to become part of an existing course project or as an assignment with a shorter duration or grade weighting.

V. Conclusion

Laboratory courses provide engineering students with unique opportunities to develop hands-on experimental skills, practice design and innovation processes, and gain experience with tailoring scientific communication for specific target audiences. Not only is scientific communication a valuable skill for undergraduate engineering students in their professional careers, but it is also essential training for improving public trust in science and general scientific literacy. This project experience provides specific examples of how to integrate scientific communication into lab courses while augmenting student outcomes and learning objectives in their technical areas.

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