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WIP: Evaluating the impacts of an integrated, project-based approach to biomedical engineering laboratory teaching

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Introduction

Engineering laboratory courses serve as a vital component of the engineering education experience, bridging the gap between theoretical concepts and practical application. These courses often employ various teaching methods, including demonstration-based, collaborative, inquiry-based, and experiential learning, to engage students in hands-on experiences that connect classroom theory with real-world engineering problems [1-9]. Currently, the University of Georgia Biomedical Engineering Lab follows a demonstration-based approach, where students perform isolated experiments designed to illustrate specific theoretical principles. We intuit that this method is effective for helping students learn to apply individual course concepts in controlled settings, but it may limit students' ability to transfer knowledge between experiments and apply concepts across broader, real-world contexts. To address and assess our intuition, we plan to transition the course to a project-based model next semester. As engineering education evolves, there is a growing recognition that integrated, project-based learning (PBL) offers a more holistic approach, promoting critical thinking, increased ability to integrate engineering concepts, and better preparation to solve real-world problems in industry [10-12]. Compared with other common inductive learning methods in engineering (e.g., inquiry-based learning, case-based learning, and simulation-based learning), PBL allows students to gain practical experience in a structured and team-based setting, facilitating both learning of theoretical concepts and understanding of real-world project considerations [13].

This study investigates the impact of project-based learning compared to the traditional demonstration-based method in a biomedical engineering laboratory course. Project-based learning, where students work on a semester-long project that incorporates multiple course concepts, may better simulate the iterative processes found in real-world research and development. Our goal is to evaluate how each teaching approach influences student outcomes, including self-efficacy, teamwork, collaboration skills, and knowledge communication. By comparing the learning outcomes of both approaches, this research aims to provide valuable insights into effective teaching strategies for biomedical engineering laboratories. It will guide future curriculum development to enhance student preparedness for professional engineering challenges.

This WIP paper reports findings from the first part of a two-part study, where the same course is taught using both teaching methodologies (demonstration-based in Fall 2024, project-based in Spring 2025). Through a dual-methods approach, data from student self-efficacy surveys, teamwork evaluations, and final reports will be analyzed to assess the overall impact of each teaching style on student learning. By understanding the strengths and weaknesses of both demonstration-based and project-centered learning, this study seeks to contribute to the ongoing conversation on best practices in engineering education. We address the following research questions in this paper:

To what extent did students in the demonstration-based laboratory course…

1. …develop self-efficacy to apply the skills gained during lab?
2. …effectively communicate course topics through their final reports?
3. …articulate how course topics interact with one another in their final reports?

Interventions

In our overarching research, we will examine the impact of two different teaching methodologies in UGA's BIOE 4750 biomedical engineering lab course. This paper discusses results from the

Fall 2024 semester, which utilized the current demonstration-based approach, where students performed individual, unconnected experiments throughout the semester. These experiments covered foundational topics such as lab basics, bacteria, and antifouling. Each experiment was conducted independently, with no direct integration between them, allowing students to focus on specific skills and techniques relevant to each topic, without an overarching project or connection between the various lab activities. This method reflected a more traditional laboratory teaching style, where each experiment serves to reinforce a specific set of theoretical concepts.

In contrast, the Spring 2025 semester will implement a project-centered approach, where students will be assigned a semester-long biomedical engineering project. This project will require students to conduct a series of interconnected tests on a biomedical device to determine its efficacy, simulating real-world engineering challenges. The project will span multiple topics, including lab basics, biomechanics, antifouling, bacteria, and cytocompatibility, with each experiment building upon the results of the previous one. This progression will mimic industry R&D processes, where iterative testing and refinement are essential for the development of medical devices. For example, students may begin with fundamental experiments on material properties and progress toward more advanced tests assessing the biocompatibility and efficacy of the device in various biological conditions.

Both semesters will culminate in the students submitting a final group end-of-term report. These reports will synthesize the students' understanding of the material and how the skills they develop can be integrated to solve real-world engineering problems. We hypothesize that the Spring 2025 students will demonstrate a more integrated understanding of the various experiments and theoretical concepts underpinning them.

Methods

In Fall 2024, students were required to submit a final group end-of-term report based on their laboratory experiments. We evaluated the reports on how well they communicated understanding of the course material, and student reflections on how the skills they learned during the course can allow them to solve real-world biomedical engineering problems.

Students also submitted two instances of a Likert scale-based questionnaires that were developed to evaluate various aspects of student confidence and teamwork. The questionnaire focused on assessing students' self-confidence across key biomedical engineering competencies. As there was no existing questionnaire for this particular subject, we developed this questionnaire by following the same question structure as the SE-12 Questionnaire for measuring medical student self-efficacy for clinical tasks [14]. Students were asked to rate their level of agreement with statements that gauged their confidence in applying technical knowledge in the field, including laboratory basics, biomedical device challenges, antimicrobial practices, cytocompatibility, and mechanics. The self-efficacy questionnaire was administered at the beginning and end of the semester. Each instance of the questionnaire took 20-30 minutes to complete. In Spring 2025, the same measures will be used.

For data analysis, both quantitative and qualitative methods will be employed. Quantitative analysis will focus on descriptive and inferential statistics to evaluate changes in student outcomes, comparing pre- and post-course self-assessments as well as examining differences between the two semesters. Qualitative analysis will be used to identify themes from the open-ended responses, allowing for a deeper understanding of the students' experiences, their perceptions of the course design, and any challenges they encountered. This dual-method approach ensures a thorough exploration of how the different teaching methods influence learning, engagement, teamwork, and overall course effectiveness.

This project was approved by our institution's Institutional Review Board. Students were required to submit the surveys and assignments for the course but could choose not to consent to their assignments being used for research (18 of 22 students consented.)

Results

The pre-lab questionnaire yielded a wide spread of student self-efficacy levels regarding different topics and skills (Table 1). The post-lab questionnaire revealed extraordinary gains in nearly every topic and skill, with students expressing high confidence in all topics and skills except for their ability to perform industry-level research and biomedical device tests with respect to biomechanics. We found differences pre- and post-lab survey results to be statistically significant at $p < 0.05$ for all knowledge and skills except for the knowledge of what cells are, in which most students already expressed extremely high confidence during the pre-lab survey. The greatest gains (2 or more Likert scale points) were in knowledge of biofouling, cytocompatibility, and the ability to perform experimental tests to assess both. Interested readers can find an Appendix table with all questions our full statistical analysis, as it was too large to include in the main body of this work-in-progress paper.

Table 1: Stratification of student self-efficacy levels for different topics and skills. Each skill was rated on a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

	Low confidence (average rating 2-3)	**Medium confidence (average rating 3-4)**	**High confidence (average rating 4-5)**
Pre-Lab Survey Results:	• Knowledge about biofouling, cytocompatibility, and biomedical device tests with respect to several topics. • Ability to perform industry-level biomedical research.	• Knowledge of biomechanics & experimentation. • Knowledge of the impacts of biomechanics & bacteria on biomedical devices. • Knowledge of biomedical device efficacy and issues. • Ability to plan a biomedical project.	• Knowledge of serial dilutions, cells, bacteria, biomedical devices, & basic lab procedures. • Ability to perform serial dilutions. • Ability to identify & address objectives of biomedical lab activities.
Post-Lab Survey Results:	• None	• Knowledge about biomedical device tests with respect to biomechanics. • Ability to perform industry-level biomedical research.	• All other topics and skills

The final lab reports provided valuable insight into the students' progression in self-efficacy, communication, and integration of course concepts (Table 2). Students demonstrated clear growth in their ability to apply laboratory skills and communicate results effectively, as evidenced by well-articulated experimental reasoning and alignment between objectives and outcomes. However, while most groups were able to articulate that the goals of each experiment were connected in terms of biomedical device design, no group articulated how results from their experiments synergized to produce meaningful insights about device design.

Table 2: Summary of Report Findings

Aspect Evaluated	**Observations**	**Representative Quote from Report**
Individual Experiment Analysis	4 out of 5 reports provided detailed analysis for each experiment.	"The treated surfaces showed consistent higher contact angles compared to the control, indicating enhanced hydrophobicity. For treated samples, the goal was to achieve a sliding angle below 20^{o}, as this degree suggests that the surface is sufficiently slippery. The sliding angles of the treated samples were measured below this threshold, demonstrating that the treatment was effective in making the surface slippery"

Connections Between Experiments	3 out of 5 reports acknowledged that experiments interact to inform biomedical device design	"Various tests including protein adsorption analysis, static surface wettability, and sliding angle measurements were conducted to evaluate the antifouling properties of the coating. These strategies aim to ensure that the coating can effectively reduce the risk of thrombosis and enhance the biocompatibility of the medical device."
Synergistic Conclusions	No reports successfully combined findings across experiments to propose cohesive conclusion on the overall biomedical device design.	"The purpose of the first part of the lab was to introduce and practice common lab procedures...The goal of the second experiment was to show that the polymers with antifouling would have less protein adsorption than the control polymers." (Negative evidence)
Writing and Communication	The reports were generally well-written, with replicable methods, clearly articulated experimental reasoning, and well-aligned independent empirical conclusions.	N/A

Insights Thus Far

Our preliminary findings indicate that students who experienced a demonstration-based biomedical lab made significant strides in their understanding of individual course concepts, laboratory methods, and instruments. However, results from their final reports indicated that they struggled to bridge the gap between isolated experiments and comprehensive engineering workflows. This disconnect highlights a critical insight for the design of biomedical engineering education laboratories. Without a continuous, integrative experience, students are less prepared to link theoretical understanding to practical applications in real-world scenarios.

Specifically, students described how the skills they developed in the demonstration-based course could be used to solve real biomedical engineering problems, but they described different problems that each experimental method could help solve. Few discussed how skills developed across experiments could combine to solve more complex problems. This lack of integration is problematic for the development of biomedical engineering expertise [15]. Students who develop knowledge structures that isolate concepts from one another struggle to retain knowledge in the long term or reconcile apparent contradictions they encounter in the future [16-19]. Similarly, students who see engineering tasks as a series of sequential events will struggle to apply their knowledge in situations that fail to resemble those sequences [20, 21]. To develop robust expertise that will serve them in real-world settings, students need exposure to tasks resembling the real-world integration of skills, which will allow them to build the strongly interconnected knowledge structures necessary to succeed in those environments [15].

Overall, our findings suggest that while demonstration-based learning effectively introduces students to foundational concepts, it may fall short in fostering the depth of understanding and integrative thinking required to apply these concepts confidently and creatively in complex, real-world contexts.

Next Steps

Moving forward, the Spring 2025 semester will implement a project-centered approach to assess its impact on student knowledge, teamwork skills, and integrative expertise development in a biomedical engineering context. As part of this initiative, students will partake in a semester-long project focusing on the development and evaluation of a biomedical device. This course design will require them to conduct a series of interconnected experiments to determine the device's efficacy. We aim to simulate real-world engineering challenges and to observe how a progression of interconnected experiments influences students' self-efficacy and application of complex topics.

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Appendix: Self-Efficacy Questionnaire & Two-Tailed, Paired T-Test Results

Likert scale: 1 (Strongly Disagree) – 5 (Strongly Agree)

Question	Pre-Survey Average	Post-Survey Average	Difference in Averages	p-value
I can perform 1 or more tests to determine the efficacy of biofouling biomedical devices.	2.12	4.88	2.76	<0.001
I can explain 1 or more tests for determining the efficacy of biofouling biomedical devices.	2.24	4.88	2.65	<0.001
I can explain 1 or more tests for determining the cytocompatibility properties of biomedical devices.	2.12	4.71	2.59	<0.001
I can explain biofouling's impact on biomedical devices.	2.41	4.94	2.53	<0.001
I can perform 1 or more tests for determining the cytocompatibility properties of biomedical devices.	2.06	4.59	2.53	<0.001
I can perform 1 or more tests to determine the efficacy of antimicrobial biomedical devices.	2.41	4.88	2.47	<0.001
I can explain 1 or more tests for determining the efficacy of antimicrobial biomedical devices.	2.53	4.88	2.35	<0.001
I know what biofouling means.	2.82	4.88	2.06	<0.001
I know how cytocompatibility pertains to biomedical devices.	2.76	4.82	2.06	<0.001
I can perform 1 or more tests to determine the properties of biomedical devices with respect to biomechanics.	2.12	3.75	1.63	<0.001
I can explain 1 or more tests for determining the properties of biomedical devices with respect to biomechanics.	2.35	3.94	1.59	0.001
How confident are you in your knowledge of biomedical engineering experimentation?	3.41	4.47	1.06	<0.001
I can explain bacteria's impact on biomedical devices.	3.82	4.88	1.06	0.002
How confident are you in your ability to perform industry level research and development?	2.94	3.94	1.00	0.004
I can explain what makes an effective biomedical device in industry.	3.59	4.59	1.00	0.010
I can explain the impact of biomechanics on biomedical devices.	3.12	4.06	0.94	0.004
I know what biomechanics is.	3.29	4.18	0.88	0.003
I can perform serial dilutions.	4.06	4.94	0.88	0.011
I know what issues are associated with biomedical devices.	3.82	4.71	0.88	0.009
How confident are you in your ability to successfully create an agenda or plan for a project in your field of biomedical engineering?	3.47	4.29	0.82	0.034
I know what serial dilutions are.	4.35	5.00	0.65	0.037
I know what biomedical devices are.	4.35	4.88	0.53	0.003
How confident are you in your ability to successfully identify and address the key issues and objectives of your biomedical engineering lab during discussions?	4.18	4.71	0.53	0.008
How confident are you in your knowledge of basic laboratory procedures?	4.41	4.88	0.47	0.002
I know what bacteria is.	4.47	4.94	0.47	0.015
I know what cells are.	4.94	5.00	0.06	0.332