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Integrity independent lab into project: A modification made to the materials science Lab curriculum

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Integrity independent lab into project: A modification made to the materials science Lab curriculum

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Abstract

Traditionally, materials science labs were independent weekly labs, aiming to reinforce the lecture content and provide students with hands-on experience. The Union College Mechanical Engineering department has been redeveloping the curriculum to make it more inclusive and meet the college-wide general education goal, one of which is connecting disciplinary content with complex global challenges. This paper presents the approach of consolidating the 3–4 independent materials science labs into one project that addresses real world challenges. In the materials-based project-based lab（PB-Lab), students work in groups and identify the provided materials (morphological, structural, property, process) to create solutions for a scenario in an ongoing global crisis with set timeframes and constraints. The curriculum design of PB-Lab engages students with active learning and authentic learning; they see how what they are learning in materials sciences can be applied as working engineers. Students experience the interdependent and integrated nature of the materials development process in the lab and generate their own concepts about addressing global challenges. In summary, PB-Lab engages students in identifying problems, developing potential solutions through materials characterization and analysis in the lab, and delivering effective communication in the form of lab reports or presentations.

1. Introduction

Materials science (MER 213/lab) at Union College is a sophomore-level course integral to understanding the properties and applications of materials across various engineering disciplines. The principles formulated in materials science allow engineers to understand the nature and behavior of a wide variety of engineering materials through both lecture and lab components. As stated in the learning objectives "Everything in our built world is made of something. Engineers need a strong understanding of materials science to design better and safer products." In this course, student will explore how the behavior of materials is directly linked to their structures, and how structures and hence properties may be altered through processing. Properties, processing, design and environmental protection and degradation will be considered." Weekly hands-on practice in the lab section not only reinforces the lecture material students through their own operation and observation, but also exposes them to modern characterization techniques. Traditional materials science labs provide students with very clear and detailed lab instructions like objective and operation steps. On the one hand, the field of materials science is dynamic and forever-evolving, demanding innovative approaches to education that mirror the complexity and interdisciplinary nature of the discipline. On the other hand, Union college proposes to create an inclusive community for intellectual growth, experimentation, and academic success that emerges from engagement with diverse and global perspectives through a general education curriculum with global challenges and other aspects [1].

The field of materials science is dynamic and forever-evolving, demanding innovative approaches to education that mirror the complexity and interdisciplinary nature of the discipline. In today's educational landscape, fostering a deep understanding of materials properties and behavior is paramount. Traditional lab setups often struggle to capture the intricacies of real-world scenarios, and as educators, it becomes our responsibility to bridge this gap. Therefore, we propose to make modifications implemented within the lab part of course structure — the integration of multiple traditional independent, highly instructional labs into a partially open-ended collaborative project through a gradual, well-balanced approach. This modification seeks to address this challenge by infusing the curriculum with an integrity independent lab, offering students a more holistic and authentic learning experience. This manuscript outlines this pivotal modification to the traditional materials science lab curriculum at Union College – the integration of multiple traditional stand-alone labs into one project-based lab (PBL), which is a more student-centered collaborative approach. This is often related to and misconstrued with Problem-Based Learning (PBL), the distinction lies in the outcomes: Problem-Based Learning centers on presenting solutions to authentic problems, where the objective is provided and very specific, while Project-Based Learning requires students to identify the challenge have the potential to be addressed, which is partially open-ending [2,3]. Recognizing the efficacy of project-based lab designs in fostering creative engagement and deep learning, this modification aims to bridge the gap between traditional, instruction-centric labs and student-directed projects. The project-based laboratory design is intended to motivate students towards deep learning, advanced engineering skills, and high-level learning outcomes while preparing them well for open-ended labs at the senior level [4,5]. In addition, students will work as a group and focus on provided materials (i.e., graphene oxide membrane, aerogel) in this project-based lab to encourage communication and peer learning. Moreover, the selection of materials for the project is drawn from faculty research, offering students the opportunity to engage with cutting-edge research and inspiring them to pursue undergraduate research or graduate studies. The intended outcome contains three-fold: to design an efficient and sustainable strategy for engineering laboratory modification, to develop effective methodologies of project-based learning, and to stimulate student interest in research.

In summary, this manuscript elucidates a pedagogical transformation in materials science labs, incorporating project-based learning principles to enhance student engagement, skill development, and a deeper understanding of materials science in the context of real-world challenges. Our modification represents a significant step towards enhancing the materials science lab experience at Union College, fostering creativity, engagement, and deeper learning among students.

2. Project-based laboratory design

At Union College, Materials Science Lab is planned weekly to reinforce student understanding about the lecture content through hands-on experience in accordance with the lecture content. Therefore, all the lab content has a good match with lecture content. A detailed list about lab content designed for book chapters can be found in Table 1 below.

Table 1 Lecture content and matching lab content

Chapter #	Lecture Content	Original Lab content
1	Introduction	Lab safety & Measurement
2	Atomic Structure	AFM
3	Crystal Structure of solids	XRD
4	Imperfection	Microscope
5	Diffusion	Permeability determination
6	Mechanical Property	Hardness measurement
7	Strengthening mechanism	Cold work and Annealing
9	Phase Diagram	Heat treatment
10	Phase Transformation	Microstructure determination
12&13	Ceramics	Oral presentation
14&15	Polymer	Oral presentation
22	Environmental and societal issue in Materials	Local Recycle facility visit

Taking inspiration from successful integrations of thermal treatment, hardness measurement, and microstructure determination in one tool steel lab before, the manuscript delves into the amalgamation of characterization labs into a project-based framework, using advanced materials as case study. We explore balancing traditional characterization labs into one project-based laboratory. The redesign of the materials science laboratory is anchored in the principles of project-based learning, with a focus on merging traditional stand-alone labs into a cohesive, student-centered project. The rationale behind this shift is to enhance the development of advanced skills and critical thinking, and to align with Union College's commitment to addressing global challenges through a lens of justice, equity, identity, and difference. Traditionally, stand-alone labs excel in teaching instrumentation and report writing, whereas project-based labs excel in cultivating open-ended problem-solving skills. Given that materials science is a sophomore-level course, concerns arose about the potential difficulty in transitioning students from clear-instructed high school labs to the more demanding, self-directed university-level labs. To do so, a carefully structured project is introduced, where students propose strategies to tackle global challenges using provided materials.

At the beginning of the lab, each group of students will be required to propose a potential solution to one of the global challenges identified by the end of the three-week lab session. This is considered a half-open-ended problem. To address open-ended global challenges in need of solutions with potential solutions provided by advanced materials will stimulate students to think actively, focus on different problems, and propose various solutions even with the same materials. Beginning the lab with a partially open-ended laboratory can be more motivating by requiring students to intrinsically motivate themselves to search for knowledge of real-world problems, build personal interpretations of experimental results, and form persuasive communication based on experience and interaction. A half-open-ended problem is particularly suitable for materials science labs where students are often required to address engineering problems from a materials aspect. Not only does it require students to integrate knowledge and experience from different courses to understand real-world problems, but it also demands the use of multiple characterization technologies to comprehend a material. Specifically, conversation with chat GPT is allowed and encouraged in this stage of the lab. The materials science lab is materials-based, and the materials of faculty research are chosen for lab modification.

One of the primary distinctions lies in the evolution of the lab's objectives. Instead of solely focusing on familiarizing students with characterization equipment, their operation, and data analysis, the updated lab aims to cultivate essential skills necessary for project-based learning. At the outset of the project-based-lab, students engage in discussions to formulate their project goals, shaping the direction of their exploration. Over the course of three to four weeks, students delve into various advanced materials, notably graphene oxide and silica aerogel, chosen for their accessibility and relevance. Despite differing potential applications, each group receives identical materials for characterization. For instance, graphene oxide showcases versatile applications such as supercapacitor fabrication for clean energy needs and dye filtration for wastewater management. The lab curriculum maintains exposure to fundamental techniques including microscopy (optical, scanning electron, and/or atomic force microscopy), X-ray diffraction analysis, and permeability measurement. These aspects serve as essential components of the lab experience. Moreover, students are encouraged to deepen their understanding by exploring additional techniques like cyclic voltammetry for capacitor/supercapacitor applications and filtration tests for addressing global water crises. Throughout the process, students connect material morphology and structure, elucidated through techniques like X-ray diffraction, with their potential applications. This synthesis of theory and practice culminates in comprehensive lab reports and poster presentations. Toward the end of the lab, an academic poster will be designed and delivered from each group.

3. Assessment of learning outcomes

This study addresses three primary questions: (1) Can integrating multiple traditional stand-alone laboratory experiences into a project-based laboratory be efficient, effective, and sustainable in achieving the required learning outcomes? (2) Is a half-open-ended project-based laboratory sufficient to motivate students towards deep and active learning in a laboratory course? (3) Will students find the project interesting and be inspired to engage in undergraduate research after completing the course?

Given Union College's status as a Primarily Undergraduate Institution (PUI) without teaching assistants, all lab reports and presentations were evaluated by both instructors and peers using the same rubric. Additionally, course evaluations, featuring numerical and comment-based questions, were conducted at the end of each term, covering aspects such as lab instruction, challenge, interaction, student effort, and information. Here, student evaluate their skill in each area from 1 (lowest) to 5 (highest). From the college-wide course evaluation, it was observed that lab instruction was perceived as clear and challenging. While students considered lab reports time-consuming, they acknowledged the value gained. Comments emphasized the practical skills acquired and the overall positive impact on learning. Notably, students found the lab section to be the most interesting part of the course, aiding their comprehension of the material.

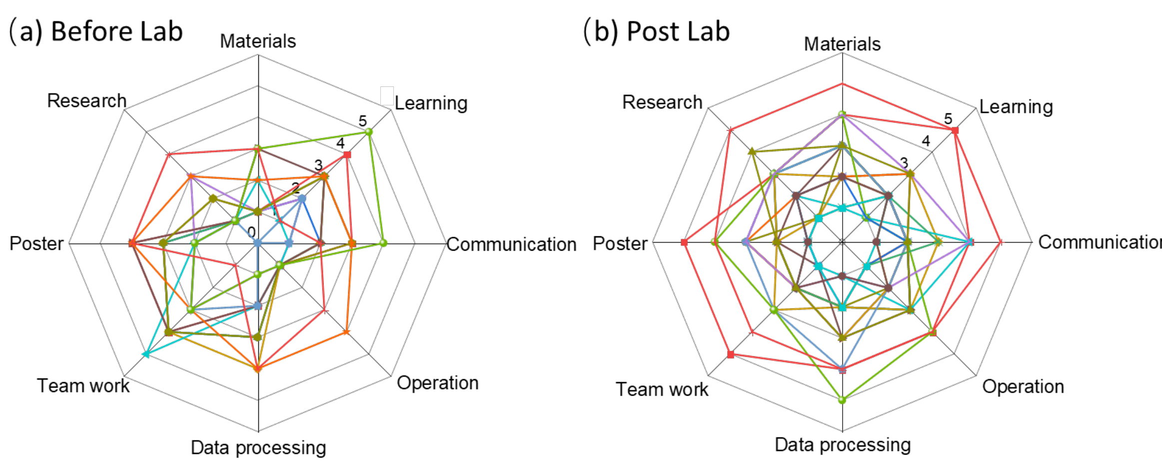

Figure 1. Radar Plot of student self-evaluation before and post taking PBL (Scale 1-5).

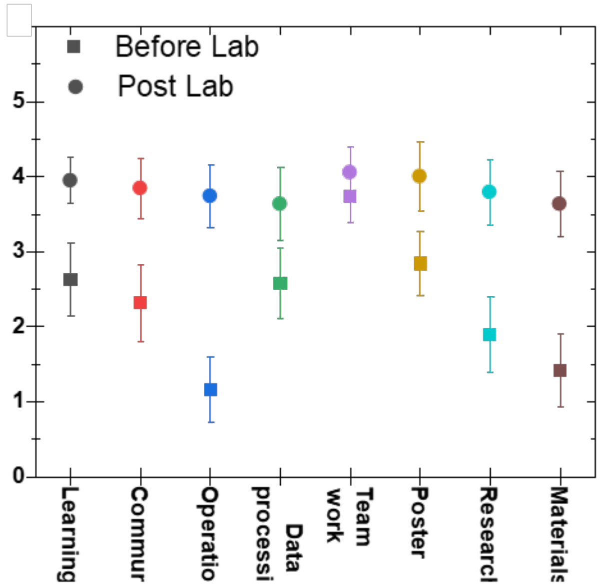

Figure 2 Compare the self-evaluation before and post PBL in mean and standard deviation form.

To further assess the effectiveness of the PBL approach, additional student feedback was collected through anonymous exit tickets at the end of the winter and spring terms of 2023. The exit tickets covered eight skill statements, focusing on areas such as learning from external resources, communication, equipment operation, data processing, teamwork, poster presentations, research projects, and familiarity with materials chosen for PBL. Again, student evaluate their own skill develop before and after take the course from 1 (lowest) to 5 (highest) in each category. Most specifically,

- **Learning** about new materials from resources outside the textbook.
- **Communication** through oral presentation and lab report.
- Materials characterization and equipment **operation** covered in the Lab.
- Data process and validation. Determine whether data is reasonable and what could cause it.
- **Work** in a **team** on a problem or project. Serve as both team member and leader.
- Make an academic **poster** and present it to the audience.
- Comfortable work on the materials related **research** project.
- Get to know the **materials** chosen for PBL through a three-week lab period.

The radar plot in Figure 1 depicts students' self-evaluations before and after engaging in the Problem-Based Learning (PBL) approach, further summarized as mean and standardized deviation in Figure 2. The data indicates a general enhancement in skills, with students expressing heightened confidence and comfort in achieving the designated learning outcomes. It is crucial to acknowledge the diverse backgrounds of college students, leading to uneven skill levels, as illustrated by the absence of a circle shape in Figure 1a. Notably, most sophomore engineering students exhibit proficiency in teamwork and internet-based information retrieval. While they possess experience in oral and poster presentations from their freshman engineering course, their confidence in these skills remains a work in progress. Conversely, handling new equipment, materials, and independent research represents novel challenges for our students. The final radar plot (Figure 1b) showcases more uniformly developed skills, suggesting increased confidence in specific areas with additional effort.

Teamwork: Teamwork emerges as a strength among engineering students, albeit with perceived limited improvement in this aspect during the PBL. While students practiced teamwork skills acquired previously, the lab could benefit from future emphasis on leadership, collaboration strategies, and issue resolution.

Learning: Our sophomore engineering students exhibit openness to new knowledge, having familiarity with search engines and open AI. This is reflected in the highest self-evaluation scores even before the lab session commenced. The lab strategically incorporated databases from the college library, highlighting their importance for finding peer-reviewed publications and ensuring proper citation in reports. Most students observed an improvement in learning skills through lab practice, with only a couple having prior experience in search and citation.

Communication, Poster, & Data: Sophomore students already had experience about oral presentation, which includes poster presentation, data processing in the freshman year from their intro to engineering course at Union college. Students feel they already come with a basic knowledge when they step into the course. This PBL aimed to reinforce these skills by providing clear grading rubrics, offering opportunities for peer grading, and allowing students to make adjustments and resubmit reports with marked errors. Additionally, students were encouraged to seek clarification during office hours regarding data processing, expression, explanation, and validation.

Operation: Among the eight evaluated aspects, research capability, equipment operation, and knowledge about new materials initially showed lower values. However, the PBL, incorporating active learning and group discussions, facilitated a deeper understanding of materials and their applications. Introducing modern equipment, such as scanning electron microscopes and atomic force microscopes, necessitated a deliberate and gradual approach to ensure effective use. Peer learning played a pivotal role, with students teaching each other, enhancing the overall learning experience.

Research and Materials: research can sound “scary” if students have not even done it yet. Stepwise guided lab will help students part of the materials they are studying. But those results are easily forgotten if there is no deep understanding formed. Addressing global challenges through active learning and group discussions emerged as a crucial aspect. Normally, we have a global challenge or engineering problem first, then we go looking for a materials solution. This reverse process, wherein materials are provided before engineering problems, encourages students to identify problems that assigned materials can address. This is considered a half-open-ended question or reverse ending question in this lab design. Addressing global challenges through active learning and group discussions in the context of materials helps students understand the properties of materials and their applications. In conclusion, the PBL approach effectively enhances a spectrum of practical skills and research capabilities among students, marking a significant contribution to their overall academic development.

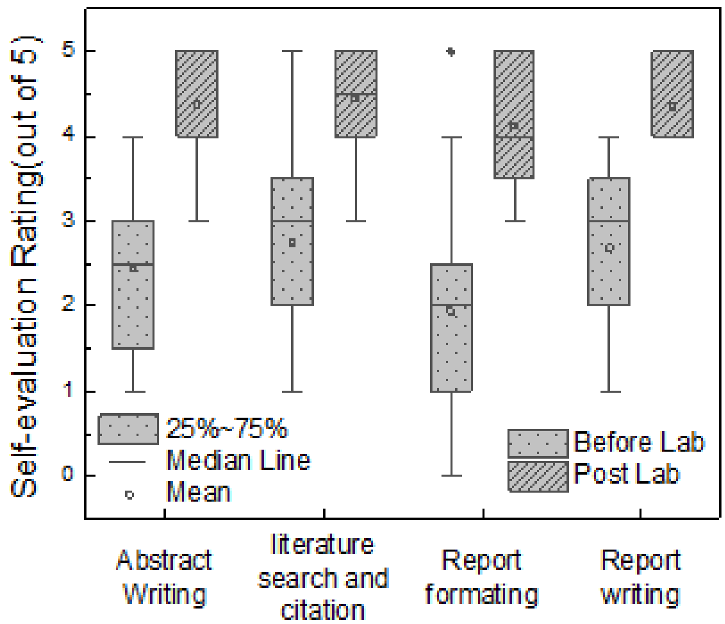

Figure 3. Box chart of student evaluation

Both semesters, students were required to write a full lab report in the format of journal publication for their project as a team. Exit ticket also contains a part for students to evaluate their writing skill improvement. A box-whisker plot was utilized to illustrate the distribution of student self-evaluations across both semesters. The boxes represent the interquartile range (25th to 75th percentile), with the median marked by a vertical line. Whiskers extend to the minimum and maximum values. According to Figure 3, students reported improvements in their abilities after completing the lab project as a team. Specifically, enhancements were noted in literature search and citation skills, lab report writing and formatting proficiency, as well as teamwork effectiveness. Evaluating self-assessment before the lab revealed varying capabilities among sophomore students. Focusing on median and mean values, most students had prior exposure to report writing and literature search and citation from high school and freshman year. A few students exhibited advanced skills in lab report writing from prior training before college. However, a notable number of students felt their skills were below the 25th percentile, highlighting the diverse skill levels within the cohort. An encouraging outcome was the majority of students falling within a similar narrow range, indicating consistent progress.

The final objective of the lab aimed to expose students to the process of designing, conducting, and presenting a research project. This objective aimed to inspire students toward pursuing research opportunities and potential careers. Remarkably, 3 students expressed post-lab interest in furthering research in the form of carry out independent study with a research professor, each in a distinct direction. Notably, during the winter semester, one student delved into the energy storage application of graphene oxide, while another focused on understanding the influence of New York humidity variation on the structure and permeability of graphene oxide membranes. In the spring semester, one student explored the sensing application of graphene oxide, while another delved into understanding the self-assembly behavior of graphene oxide sheets when forming membranes. The latter student not only advanced research but also created an education kit connecting the assembly process with the auxetic behavior of graphene oxide.

3. Conclusion and Future work

In conclusion, our transition from traditional stand-alone labs to project-based laboratory (PBL) format in the materials science Lab course has yielded promising results. This project-based laboratory design not only facilitates meaningful engagement but also proves advantageous for student learning. It fosters active participation, encourages awareness of global challenges, and motivates undergraduate students to actively participate in research endeavors. Built upon the constructivist learning framework and authentic design principles, this student-centered and assessment-centered experiential learning approach enables students to establish stronger connections between real-world problems, underlying theories, and hands-on laboratory work. Consequently, it enhances overall learning outcomes and advances engineering skills. The outcomes of this study, coupled with positive student feedback, suggest that combining traditional stand-alone labs into project-based laboratories could represent a more effective, efficient, and sustainable pedagogical approach for engineering laboratory courses. This study not only provides valuable insights but also proposes a pedagogical design that can guide future improvements in laboratory teaching. By introducing students to the open-ended lab experience at the junior level, this approach facilitates a seamless transition to more advanced project-based laboratories in senior courses. It is noteworthy that traditional laboratories can still effectively and efficiently deliver content-intensive learning outcomes and promote skill development when thoughtfully designed. This comprehensive pedagogical strategy offers a foundation for enhancing student learning and refining laboratory teaching practices, laying the groundwork for continued improvements in future laboratory instruction.

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