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The Significance of Project-Based Learning in the Understanding of Material Properties in a Sophomore Class

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Familiarization with construction materials and understanding their properties is essential for civil engineering students. However, this subject matter is often perceived as challenging to engage students. This study examines how incorporating a hands-on project activity helped sophomore students become more interested and gain a better understanding of the properties of fresh and hardened concrete, as well as the effect of the addition of Pozzolans and varying water content. This activity also introduced the students to the fundamentals of experimental design. The study also includes the results of a survey conducted among students to assess the impact of project-based learning (PBL) on their understanding of concrete and Pozzolan properties. The student survey findings indicate that PBL helped our students in applying the knowledge from classroom to lab, increasing their understanding and memorizing of the material properties, critical thinking, problem-solving skills, experimental design and engineering judgement. This paper can potentially help other faculty who are interested in incorporating hands-on activities in the materials class.

Key words: Project based learning, material properties.

Introduction

Sophomore year is a pivotal time for engineering students as they transition into more challenging coursework that requires a deeper understanding of complex concepts. During this phase, students also face a heavier workload with multiple assignments, quizzes, exams, and often part-time jobs. For civil engineering majors, the construction materials/structural materials class is a required course that is generally perceived as lighter compared to other courses that push their intellectual limits. Most students at our university enroll in this class during their sophomore year following the declaration of their major.

While understanding the properties, behaviors, and applications of different construction materials, such as concrete and supplementary cementitious materials (SCMs), is essential for civil engineering students, this course is often perceived as "boring" by many. Past semesters have shown that lectures on concrete properties, the effects of varying concrete composition, SCMs, and different water-cement ratios (w/c) have been viewed as monotonous.

To address this, a project-based learning (PBL) approach was introduced as supplementary instruction. Literature suggest that PBL has emerged as a transformative educational approach that significantly enhances student understanding, student engagement, knowledge retention, and the development of stronger interpersonal and communication skills ([1], [2], [3], [4]). According to [4], PBL motivates students to take more responsibility of their own learning as it helps to bridge the gap between theory and practice [4]. Some other studies [5], [6] reported that PBL plays a significant role in developing critical thinking and problem solving skills, which are essential for engineers. The study on engineering education [6] also reported that PBL helps to improve interpersonal skills along with analysis, synthesis, and evaluation of information, which is great for teamwork later in their engineering profession. In civil engineering education, PBL has shown to improve students' comprehension of structural design, material behavior, and fluid mechanics [7]. Another study reported that engineering students involved in PBL performed better on problem-solving tasks compared to those in traditional lecture-based classes [1]. [5] highlighted the importance of faculty's involved in PBL to guide students through project phases and providing timely feedback. The hands-on nature of the PBL along with relevant, real-world challenges helps to improve student motivation, and engagement significantly in engineering courses [8]. The study reported that PBL fosters a deeper commitment to the students' learning journey as they develop a better sense of ownership over their projects.

Overall, the literature reiterates that PBL is a highly effective approach for preparing engineering students with the technical knowledge, problem-solving capabilities, and interpersonal skills needed to succeed in both academic and professional settings.

Implementation of PBL

The course focused on the theoretical aspects of material properties and concrete mix design, among other topics. To supplement the curriculum with practical experience, the course included lab sessions, though it was not a standalone lab course like others typically found in the engineering curriculum. Upon completing the lecture and labs covering concrete properties and compressive strength testing, students were assigned a project designed to help students meet the following objectives based on Bloom's taxonomy as shown in Figure 1.

The objectives for using PBL in structural materials course are as follows:

- Recall the material properties and relevant testing standards presented in lectures.
- Comprehend the significance of different tests and the material properties they measure along with mastering the ASTM standard testing procedure, which can be beneficial for American Concrete Institute's "Concrete field-testing certification" in the future.
- Demonstrate the application of knowledge gained from both lectures and laboratory sessions in real-world or hands-on scenarios.
- Analyze and interpret data collected from laboratory experiments.
- Evaluate experimental data, create visual representations (e.g., graphs), and apply engineering judgement to make informed judgments based on the results.
- Formulate properties based on the trend in the data.

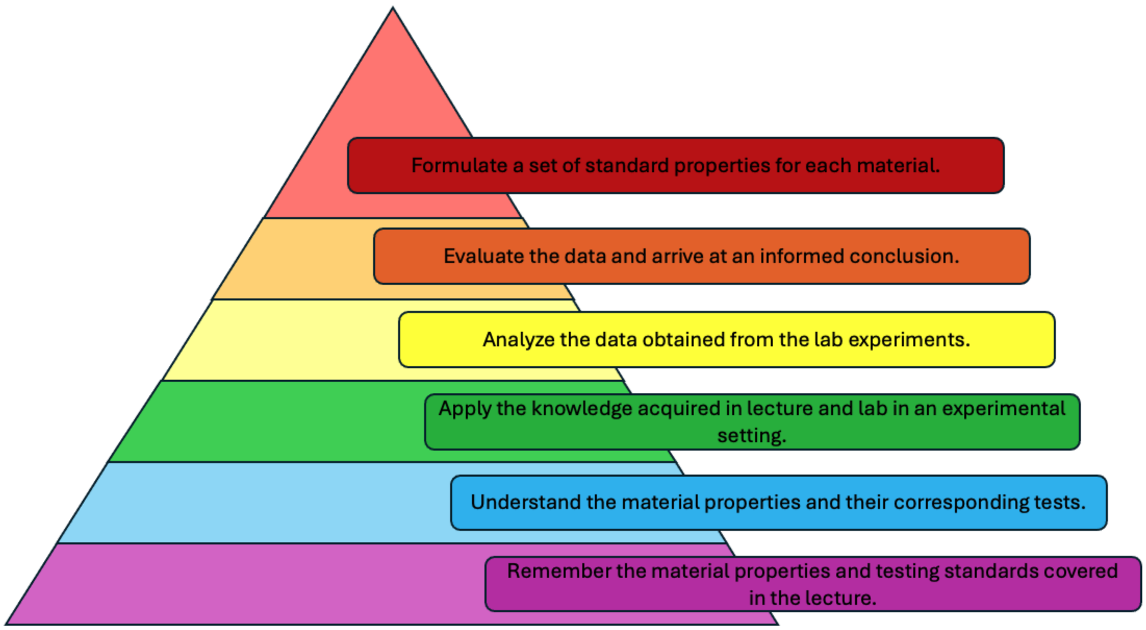

Figure 1. Bloom's Taxonomy used to meet student objectives.

A project to determine the effect of varying water content and addition of pozzolans on the properties of concrete was introduced to the sophomore structural materials class as a strategy to promote active learning and to deepen students' understanding of the concepts. The project was introduced after covering related topics in the lecture and lab, allowing students to apply the theoretical concepts to practical scenarios.

For the project, students were divided into groups and initially tasked with identifying commonly used pozzolans and their associated effects on the properties of concrete along with compiling a list of all the experiments to evaluate the properties of fresh and hardened concrete and its associated ASTM standards. The list is given in Table 1. The students collaborated with their peers to generate various ideas, and based on classroom knowledge, they identified several potential pozzolans. Due to material availability constraints in the lab, the groups were assigned fly ash as the pozzolan for the project.

Table 1. Tests for properties of fresh and hardened concrete and corresponding ASTM standards

Tests	ASTM Standards
Tests for Fresh Concrete	
Temperature of concrete	ASTM C1064
Workability of concrete- Slump test	ASTM C143
Density of concrete	ASTM C138
Air content by the pressure method	ASTM C231
Making and curing concrete test specimens in the field	ASTM C31
Tests for Hardened Concrete	
Compressive strength- 1 day	ASTM C39 & C1231
Compressive strength- 7 days	ASTM C39 & C1231
Compressive strength- 28 days	ASTM C39 & C1231

The students had to design an experiment to determine the effect of water content and pozzolans in concrete. However, they were not familiar with the design of the experiments part. So, to facilitate their comprehension of experimental design, a relatable hypothetical situation involving the evaluation of the effect of a secret ingredient in cake baking was discussed. That discussion helped to ignite their thought process and it also gave an opportunity to discuss the need to have a control group when designing experiments. Following the cake ingredient discussion, student groups discussed during lecture how to devise experiments to find the effect of water content and pozzolans. With our guidance, they formulated plans to determine the effect of varying water-cement ratios (w/c). As outlined in Table 2, three different w/c were selected for the project.

Table 2. Different categories of w/c and pozzolans selected for the project

Material	**Test Categories**		
	Test A	Test B	Test C
Water-cement ratios (w/c)	0.45	0.50	0.55
Pozzolans	Add 33% fly ash by weight of cement	Replace 33% cement with fly ash by weight of cement	Control

In addition, Table 2 also shows three different categories (Tests A, B and C) identified for testing the effect of pozzolans. Eight student groups were randomly assigned to three categories. The effect of water content and pozzolan was determined separately. The groups mixed one cubic yard of concrete based on the w/c that was assigned to their group and performed the tests outlined in Table 1 for measuring the properties of fresh concrete and cast three 4”x8” cylinders= for later compressive strength testing.

To check the effect of pozzolans, a consistent mix proportion of 1:2:3:0.5 was used for all student groups as they changed the amount of fly ash. The same set of experiments were repeated to assess the properties of pozzolan modified concrete also.

Results

This section discusses the results of the experiments obtained by the students and how they visually represented them. Furthermore, this section discusses the influence of this project on student understanding of the material properties, as assessed through data collected via an Institutional Review Board (IRB) survey.

Table 3 displays the average values of temperature, slump, and density corresponding to the three test groups (A, B, and C). Based on the shared data, students calculated averages and standard deviation for each measured variable to determine if results were reasonable or if further testing was required.

Table 3. Effect of water content on the properties of fresh concrete

Properties	Test A	Test B	Test C
Temperature	82 F	82 F	81.5F
Slump (in)	0.75	4.5	8
Density (lb/ft^3)	142.65	147.2	145.04
Air content	2.85	4.5	4.45

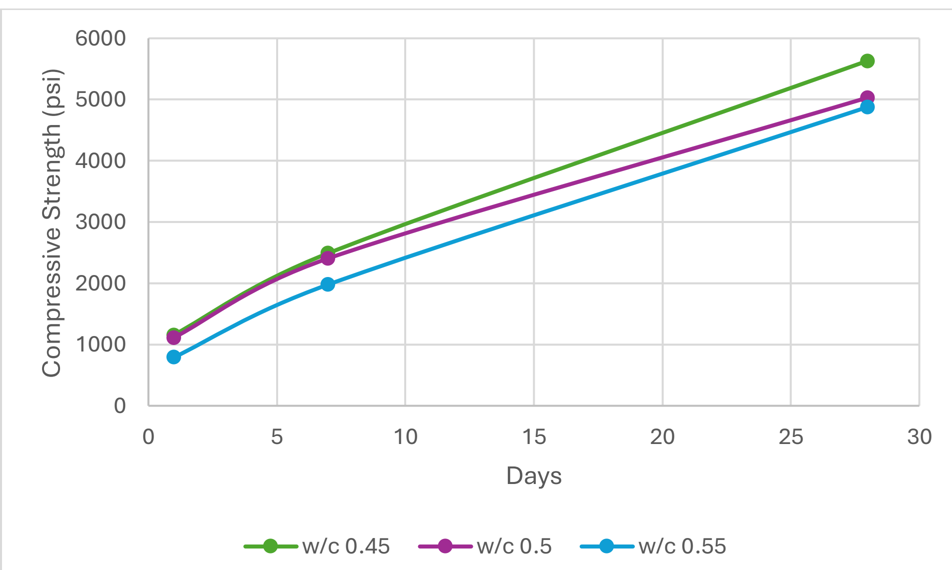

Figure 2. Compressive Strength vs Age for different water-cement ratios

All groups were given access to the raw data for analysis. The student groups initially summarized the data into tables, calculated mean and standard deviations and then explored different methods of visually representing the data. This approach allowed them to gain hands-on experience with Microsoft Excel, a program which the majority of the sophomore students were not very familiar with. Based on their tables and graphs, each student group applied their engineering judgement to draw conclusions regarding the effect of varying water content on the strength properties of concrete over time.

Effect of pozzolans on the properties of concrete

Table 4 shows the effect of addition of pozzolan on the properties of fresh concrete. Test A and B correspond to the addition of 33% pozzolan by weight of cement and the replacement of 33% of cement with pozzolan respectively.

Table 4. Effect of fly ash on the properties of fresh concrete

Properties	**Test A**	**Test B**	**Test C**
Temperature	81.5 F	82 F	82F
Slump (in)	6.5	8.25	4.25
Density (lb/ft^3)	146.5	144.4	144.1
Air content (%)	1.25	2.5	2.38

During the discussion session after the project submission, it was evident that they understood benefits of pozzolan addition, including its role in lowering the heat of hydration, improving the workability of concrete (as indicated by higher slump value), decreasing density and decreasing air content. However, students were still confused on how the addition of pozzolans will increase the strength of concrete as the compressive strength values observed on days 1, 7, and 28 indicated that control group (Test C) has higher compressive strength compared to Test A and B. To address this, data from additional tests conducted for 45 days and 60 days compressive strength by teaching assistants, were provided to students.

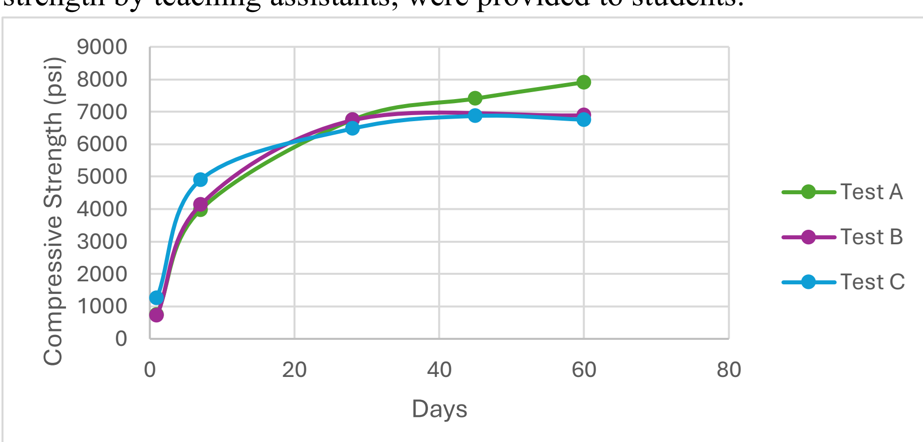

Figure 3. Compressive Strength vs. Age for Pozzolan modified Concrete

This information was included along with the student group data to plot Figure 3, and it helped them to comprehend the later strength development properties associated with pozzolan modified concrete.

Methodology- Assessing the effectiveness of PBL

To assess the effectiveness of the project in enhancing student understanding of the effects of varying water-cement ratios and addition of pozzolans on the properties of concrete, a questionnaire survey was developed. The questionnaire was submitted for Institutional Review Board (IRB) approval before data collection from the students. The survey utilized a Likert scale ranging from 1 to 5, where 1 represents "strongly disagree" and 5 represents "strongly agree." The results of the questionnaire are presented in Figures 4-10, with each figure's title indicating the corresponding question from the student survey.

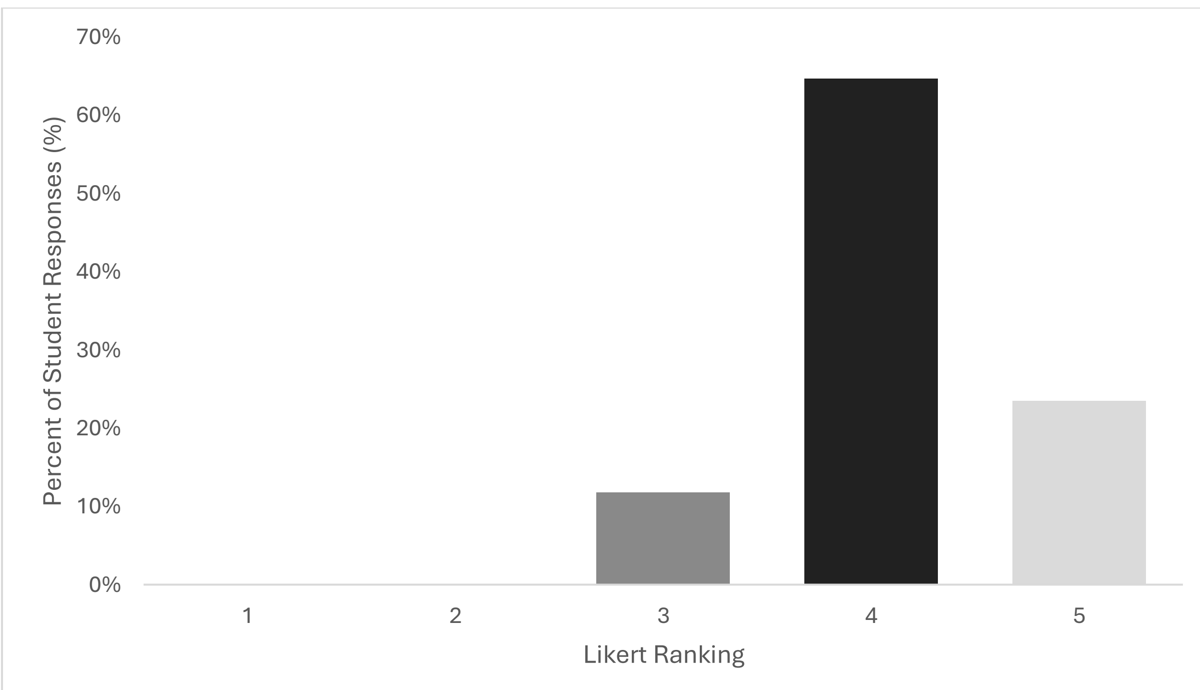

Figure 4. Results of survey question: The project helped me to remember the material properties related to concrete and pozzolan discussed in the lecture.

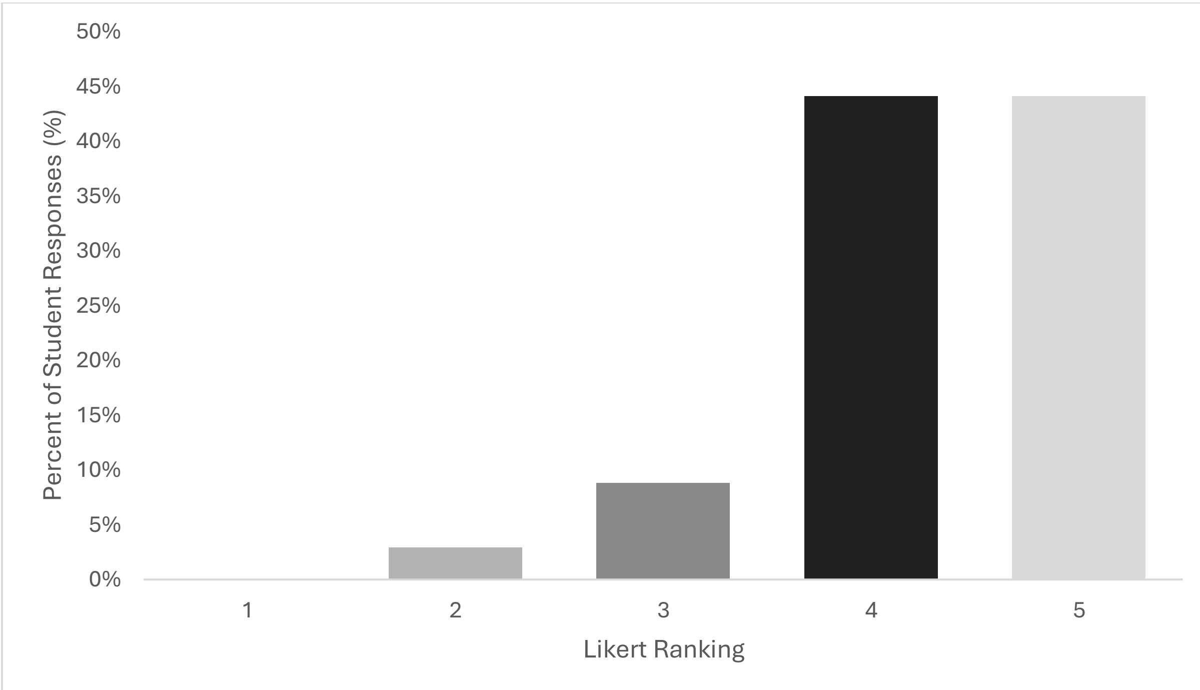

Figure 5. Results of survey question: The project helped to improve my understanding of the properties of concrete and pozzolans.

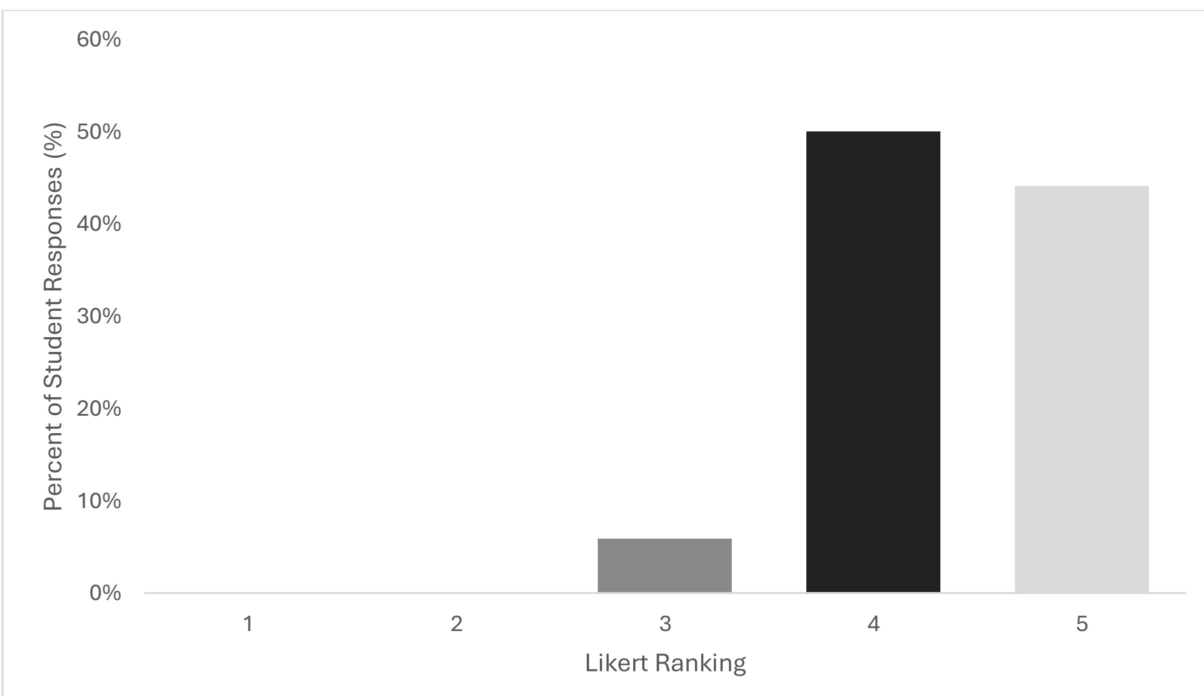

Figure 6. Results of survey question: The project gave me a chance to apply the knowledge acquired in the lecture related to concrete properties in an experimental setting.

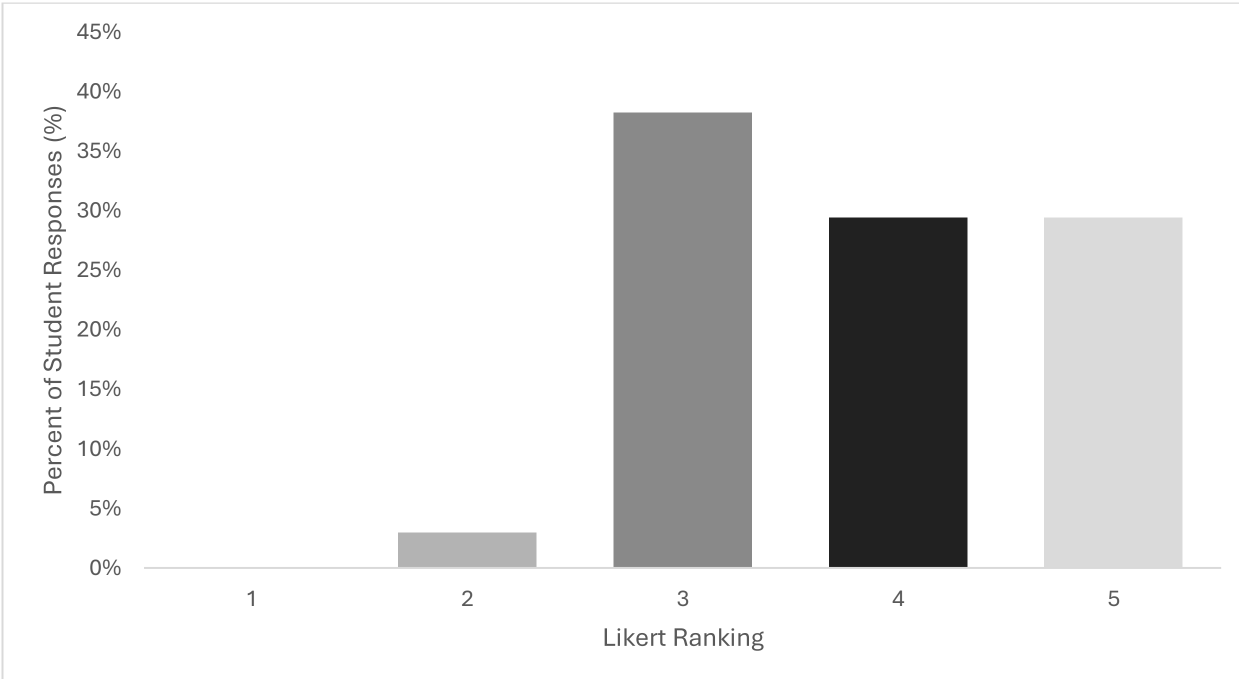

Figure 7. Results of survey question: The project helped to improve/practice my skills to develop graphs to represent experimental data effectively.

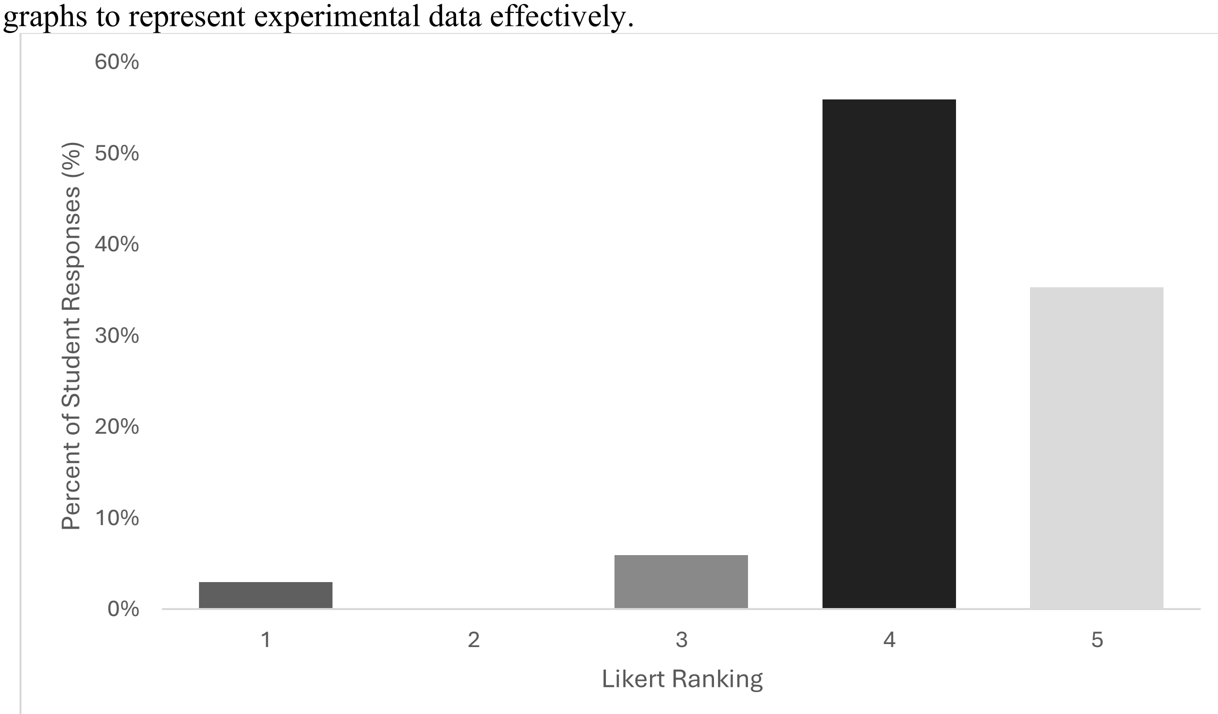

Figure 8. Results of survey question: The project helped me understand how to make an informed conclusion based on the data collected from the experiment.

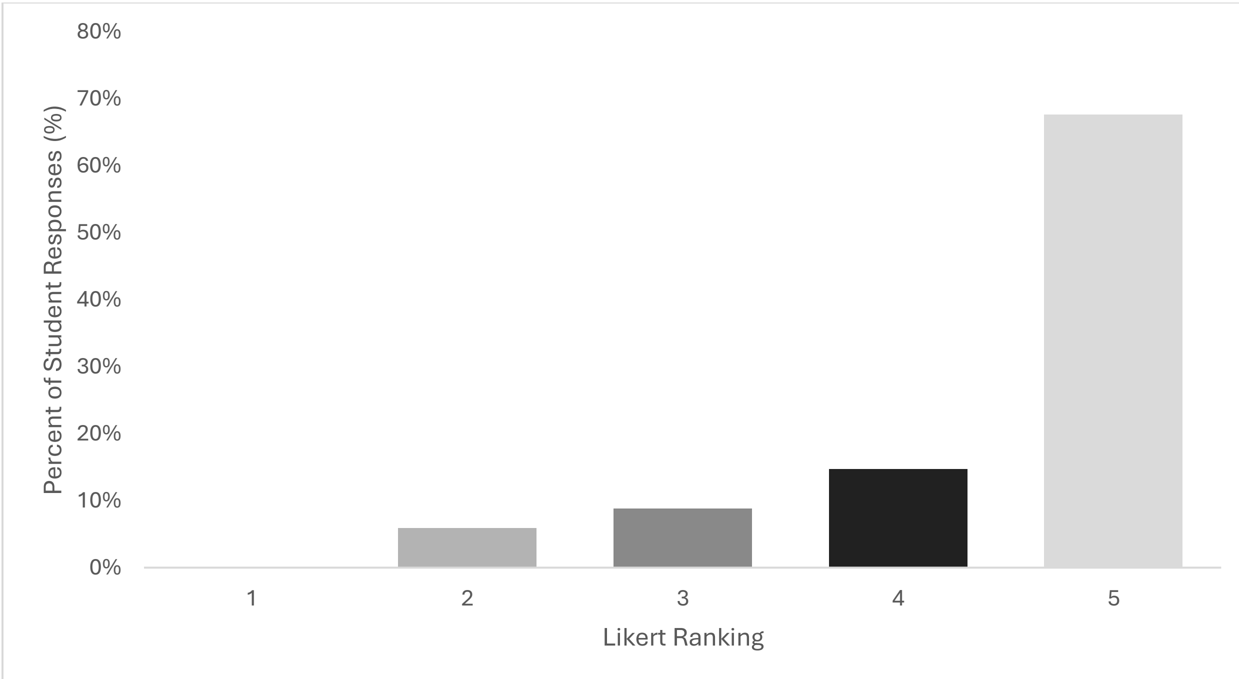

Figure 9. Results of survey question: Working in groups for the project helped me bond with my team members.

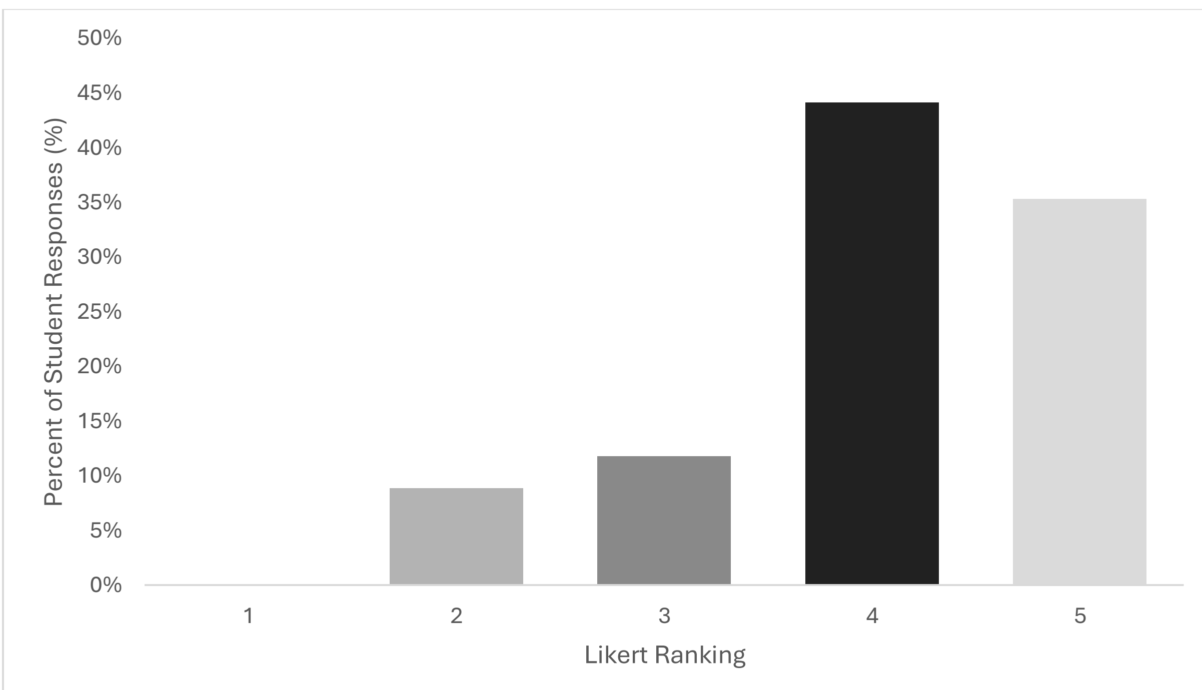

Figure 10. Results of survey question: The project report writing helped me remember/understand the material properties, corresponding ASTM standards, test procedures, and develop good report writing skills.

Figures 4-10 illustrate the student ratings on a Likert scale from 1 to 5. It is evident that the majority of responses fall within the "Agree" and "Strongly Agree" categories. The analysis of the responses in Figures 4-10 clearly demonstrates that the students benefited from Problem-Based Learning (PBL) in various areas of focus, effectively addressing the objectives outlined in Figure 1.

Conclusion & Discussion

The results of the student survey shows the effectiveness of PBL in our structural materials sophomore class. PBL helped our students in applying the knowledge from classroom to lab, increasing their understanding and memorizing of the material properties, critical thinking, problem-solving skills, experimental design and engineering judgement. PBL is a significant pedagogical approach in engineering education, especially in teaching classes like structural materials that students commonly perceive as boring or not engaging. Also, by engaging students in real-world projects, PBL prepares them for the challenges they will face in their professional lives. As engineering education continues to evolve, integrating PBL into curricula can lead to the development of well-rounded, competent engineers ready to address complex global challenges. Future research should continue to explore innovative PBL strategies and their long-term impact on student success and engineering practice.

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