# Innovations in an Undergraduate Laboratory to Increase Engagement

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***Abstract— Contribution:*** **This full innovative practice paper presents a series of pedagogical interventions implemented to enhance student engagement, preparedness, and writing skills in a laboratory setting. It integrates Perusall assignments, peer reviews, peer mentoring, and a specification grading system into the curriculum, offering a structured but still flexible approach to laboratory education.**

***Background:*** **Many students struggle with scientific writing and find the lab work process challenging and disengaging. Previous works have utilized peer-assisted learning and digital tools, but there remains a need for the use of new strategies to address these challenges in a laboratory environment.**

***Intended Outcomes:*** **The primary goal is to improve students' readiness for lab sessions, increase engagement through collaborative learning, and enhance their scientific writing skills. The interventions are designed to create a supportive learning environment that encourages active participation.**

***Application Design:*** **The interventions were implemented over three academic quarters. Students were required to prepare for lab sessions by annotating lab manuals via the Perusall platform, which grades engagement automatically. Peer reviews were conducted with structured rubrics. Peer mentoring was incorporated into lab sessions, with initial guidance from the instructor followed by student-led training. To provide opportunities for report revision based on feedback, the specification grading system was used by categorizing lab reports as complete or incomplete.**

***Findings:*** **Student performance and a Likert scale survey were used to measure the outcome of the interventions. Over 80% of students reported that Perusall assignments enhanced their understanding of lab concepts, and more than 70% felt they learned effectively from their peers. Peer review was not received favorably with only 25% finding it helpful. The majority felt that peer mentoring significantly increased lab engagement. The specification grading approach resulted in a higher rate of reports meeting initial submission standards, particularly in later sessions, indicating improved writing quality. Overall, these methods demonstrated a positive impact on student learning and engagement in laboratory courses.**

***Keywords—Laboratory; Peer mentoring; Writing; Redesign***

## I. Introduction

Laboratories are the most important classes in engineering fields. Laboratories create experiences for the students through which they recognize the complexity [1] of the experimental work, develop scientific reasoning [2], and improve skills such as teamwork and technical writing [3] [4]. However, there are some barriers to fully using the potential of these opportunities. To address those issues, some structural changes are necessary. To make sure the changes will be effective, first, the issues in instruction need to be identified clearly before deciding on the interventions [5]. In our lab, three issues were recognized to be addressed to improve students' learning. The identified issues were student preparedness before the lab sessions, students' disengagement during the sessions, and technical writing after the sessions.

### A. *Preparedness*

The first issue was students' preparedness. Although the lab manuals were provided to the students before the class, they often read them after the class for report writing. Consequently, students did not know the objectives and basic concepts of each experiment. Therefore, they could not reflect on the results and interpret the data especially when the experiments did not go as expected, which led to not practicing scientific reasoning in class.

### B. *Disengagement*

The second issue was related to student disengagement which was attributed to the high ratio of students to instructors and students to instruments. Insufficient instruments lead to the formation of waiting lines and a lack of hands-on experience.

### C. *Technical writing*

The third issue was related to report writing. It has been observed that although students were receiving feedback on their reports, the quality of the reports did not improve noticeably.

The above problems resulted in the loss of an opportunity to provide a rich learning experience for students. To address these issues, the lab assignments, grading approach, and two of the lab sessions in a *Mechanical Behavior Laboratory* were redesigned. In this process, the goal was to use evidence-based teaching approaches without increasing the budget and to empower the students by enhancing their autonomy [6] and competence. In this work, the old design of the course is described first, and then it will be discussed how approaches such as peer teaching and problem-based learning, and the use of technology were used to redesign the course. Finally, students' feedback on the interventions is presented. Problem-based learning is defined as using problems as the starting point for learning [7], [8].

## II. Lab Redesign

The redesigned class is the *Materials Behavior Laboratory* which has 3 sections, each having 9 to 15 students. There are 5 experiments in this class: impact testing, visco-elastic and linear elastic behaviors, metallography, tensile testing and hardening mechanisms, and hardness testing. Peer mentoring was used to redesign the metallography and hardness testing labs to remove waiting times and provide more hands-on opportunities to students. The changes in the metallography lab are explained elsewhere [9], and here the changes in the hardness lab are explained. The redesign was done gradually over 3 quarters.

### *A. Traditional Class*

The traditional class structure consisted of sharing the lab manual with the students before the class. These manuals included the objectives of the lab and the theories and procedures of the experiments. Each session started with a short lecture that reiterated the objectives and procedures of the experiments. Afterward, the students observed the experiment that was performed by the instructor and collected the data for their report. The students worked in groups of three to four on their report and submitted it within a week. The reports were graded by a teaching assistant (TA). The TA left comments for the students regarding their data analysis, data presentation (quality of figures and tables), and whether the objectives of the lab that were explained in the manual and lecture were addressed in the report. In this format, most of the students learned about the objectives in class and usually did not demonstrate a good understanding of the underlying theoretical concepts. In addition, since the instructor did the experiments, students missed the opportunity to have a hands-on experience. Also, they did not have an opportunity to apply any revisions to their reports based on the received feedback.

### *B. Redesigned Lab*

Changes to improve student experience were deemed necessary once the above shortcomings in the traditional design came to light. In order the achieve the desired outcomes from these changes, we decided to use technology and evidence-based pedagogical approaches. First, to address the preparedness issue we used Perusall.com, a platform that allows students to annotate texts and communicate with each other by asking questions about the texts. The effectiveness of Perusall in student learning and engagement has been investigated in [10], [11], [12]. Lab manuals were made available to students via Perusall, and the students read and annotated them before each class and it was worth 10% of their final grade. To address the writing issue, students were tasked with peer-reviewing reports. The idea behind this assignment was that the students will be exposed to the works of others in the class and, by evaluating them, their writing will improve. The peer review consisted of answering the following 5 questions:

- What did you like about this report? What parts were strong and the most effective?
- Where in the report are the objectives of this lab mentioned and explained clearly? Which objectives are not mentioned, if any?
- What are the authors' justifications in the discussion and conclusion sections to explain the experimental data? Which one is the strongest justification, and which one is a weak justification?
- What are the three most important things the author should do to improve the draft?
- What questions do you have for the authors?

Since this was a new activity for most of the students, the students discussed how peer review should be done, came up with some general rules, and then practiced by reviewing a sample report in the first session. The other change that was applied to enhance student writing skills was in the grading approach. In the new approach, the reports were marked as complete or incomplete. If a report was marked incomplete, the students needed to apply the changes that were requested by the TA and resubmit the report until it was accepted as complete. As demonstrated by Buswell et al. [13] time constraints and lack of resources make it difficult to have writing assignments in engineering courses. To address this, the criteria that the TA was focused on were limited to report structure, quality of images and tables, clear description of experiment objectives, and data analysis and conclusion. It is worth mentioning that the TA was trained at the beginning of the class to grade the reports systematically and consistently and to understand the grading criteria. Students were also provided with examples of acceptable report structure and graphs.

To improve student engagement in the hardness testing assignment, each section was split into two groups and scheduled at different times. In this lab, the instructor gave a short lecture for each group and demonstrated how hardness testing is done. However, all of the samples were tested by the students as they were collaborating in using the instrument. To challenge the students, samples with different hardnesses were provided to them. Since each hardness method, e.g. Rockwell A, B, C, etc., has an acceptable range and cannot be used for all the samples. If a wrong method is used, they will get an error from the instrument, therefore, the students had to switch from one method to another, i.e., from Rockwell C to Rockwell A or B, to obtain meaningful results. This ambiguity in the validity of their data created discussions in groups and challenged their scientific reasoning and problem-solving skills. In this process, the instructor was present as a facilitator and offered suggestions if asked for one.

## III. STUDENT FEEDBACK, RESULTS, AND DISCUSSION

The were asked to respond to a survey to evaluate the effectiveness of our approach and their impressions of their experiences at the end of the course. To better understand student preparedness, they were asked how many times they read the manuals on Perusall before coming to class. Out of 37 responses, 43.2% indicated that they read all five lab manuals before class. Also, 5.4%, 5.4%, 32.4%, and 13.5% said they read four, three, two, and one of the manuals, respectively. Interestingly, no one indicated that they did not read any of the manuals before the class. Although we don't have any similar data from the traditional design since manual reading was not graded we believe the new reading assignment was successful as it prepared more than 40% of the students for all the classes, and more than 50% came prepared for more than half of the labs.

Figure 1 shows student responses to the other survey questions that are provided in Table 1. The number of responses for questions one to five was 27 students, and for questions six and seven was 37. To interpret the data, the sum of the number of responses with strongly agree and agree were considered together, as well as strongly disagree and disagree. The first two questions regarding Perusall assignments show that, although about 80% of the students said that it helped them to understand the objectives of the labs, only about 30% think that it should be used in other classes. About 70% of the students said that the lab manuals helped them to understand the objectives.

This response indicates that a well-written handout that clearly describes the objectives can help students come to class knowing what to expect to learn.

In question four, only about 30% of the students indicated that peer-review assignments helped them to develop feedback-giving skills, about 32% disagreed with the statement, and the rest responded as neutral. To understand this feedback further study needs to be performed, however, it is anticipated that this can be because students did not have previous experience in giving feedback and did not have a reference point to compare the growth in their feedback skills. Another factor can be that they did not receive any feedback on their reviews from the instructor or the TA. Similarly in question five, only 25% believed peer review improved their report writing skills while 25% disagreed with this statement. This response can be explained by considering the students' skills in writing. It is reasonable to assume that the majority of the students have similar skills as they are all sophomores. As a result, reading their peer's work does not provide new information. From the responses to questions four and five, the peer review activity was not as effective and changes to that should be considered. Finally, the hardness testing lab proved to be effective since students in questions six and seven indicated that it helped them to use their problem-solving skills and collaborate with their team members. This latter skill is particularly important as it creates a more equitable class environment for the students.

TABLE I. LIKERT SURVEY QUESTIONS.

| | |
|---|---|
| 1 | Do you feel reading the manuals helped you to understand the concepts before coming to class? |
| 2 | Do you think Perusall should be used in other classes other than the labs? |
| 3 | Do you feel the objectives of each lab were clearly explained in the lab manuals? (did you know what you are expected to learn in each lab after reading the manual?) |
| 4 | Do you feel peer review helped you to improve your ability to give productive feedback? |
| 5 | Do you feel peer review helped you to write better reports? |
| 6 | Do you feel lab 5 (hardness test) helped you problem-solve the designing and running of an experiment? |
| 7 | Do you feel lab 5 (hardness test) encourages participation by all members of your group? |

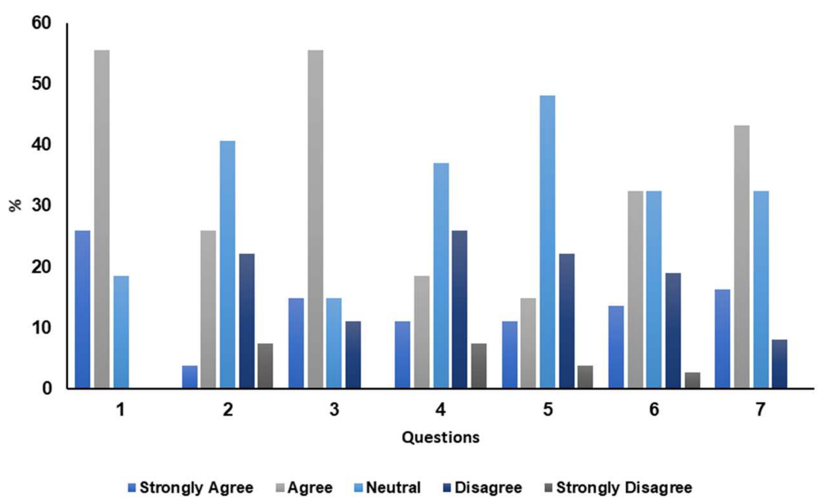


Fig. 1. End-of-class survey results measuring students' agreement with the effectiveness of the changes.

The grading style improved the quality of the reports significantly. In the first experiment, none of the reports were accepted. However, more and more reports met the criteria and were accepted upon the first submission for the following laboratory sessions. For the last laboratory exercises, no report was rejected because of its structure, the rejections were due to data analysis and interpretation only.

Since the grading approach has changed, it is not possible to compare grades from different classes to determine how students' learning has changed. However, other approaches such as interviews can be used to determine how student understanding of the concepts and hands-on skills have changed due to these interventions.

## IV. Conclusion

We recognized three problems: student preparedness, engagement, and writing skills, that needed to be addressed in a *Mechanical Behavior of Materials Lab* to create a more effective learning experience for students. This lab course was redesigned by introducing Perusall reading assignments, and peer-review assignments, changing the grading style, and incorporating peer mentoring activities in experiments. Student performance and feedback indicated that the new grading approach, Perusall assignments, and new lab activities were successful in enhancing student engagement, learning, and writing skills. However, students did not identify peer review as an effective way to improve report writing or a practice of giving constructive feedback.

This work did not measure and compare the change in student understanding of the concepts and hands-on skills. Further research is needed to understand students' perceptions and experiences of these approaches. This deeper insight can be gained through interviews with the students.


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## References


[1] C. G. L. Veale, V. Jeena, and S. Sithebe, "Prioritizing the Development of Experimental Skills and Scientific Reasoning: A Model for Authentic Evaluation of Laboratory Performance in Large Organic Chemistry Classes," *J. Chem. Educ.*, vol. 97, no. 3, pp. 675–680, Mar. 2020, doi: 10.1021/acs.jchemed.9b00703.

[2] L. S. Blumer and C. W. Beck, "Laboratory Courses with Guided-Inquiry Modules Improve Scientific Reasoning and Experimental Design Skills for the Least-Prepared Undergraduate Students," *CBE—Life Sci. Educ.*, vol. 18, no. 1, p. ar2, Jan. 2019, doi: 10.1187/cbe.18-08-0152.

[3] J. A. Rudd, V. Z. Wang, C. Cervato, and R. W. Ridky, "Calibrated Peer Review Assignments for the Earth Sciences," *J. Geosci. Educ.*, vol. 57, no. 5, pp. 328–334, Nov. 2009, doi: 10.5408/1.3559673.

[4] T. J. Greenbowe, J. A. Rudd, and B. M. Hand, "Using the Science Writing Heuristic To Improve Students' Understanding of General Equilibrium," *J. Chem. Educ.*, vol. 84, no. 12, p. 2007, Dec. 2007, doi: 10.1021/ed084p2007.

[5] A. Saeidi, A. Williams, N. Buswell, D. Mumm, and K. Denaro, "Can adding discussion-only active learning increase student learning in materials science class?," in *2018 IEEE Frontiers in Education Conference (FIE)*, San Jose, CA, USA: IEEE, Oct. 2018, pp. 1–4. doi: 10.1109/FIE.2018.8659146.

[6] F. Guay, "Applying Self-Determination Theory to Education: Regulations Types, Psychological Needs, and Autonomy Supporting Behaviors," *Can. J. Sch. Psychol.*, vol. 37, no. 1, pp. 75–92, Mar. 2022, doi: 10.1177/08295735211055355.

[7] D. Alt and N. Raichel, "Problem-based learning, self- and peer assessment in higher education: towards advancing lifelong learning skills," *Res. Pap. Educ.*, vol. 37, no. 3, pp. 370–394, May 2022, doi: 10.1080/02671522.2020.1849371.

[8] *Essential Readings in Problem-Based Learning: Exploring and Extending the Legacy of Howard S. Barrows*. Purdue University Press, 2015. doi: 10.2307/j.ctt6wq6fh.

[9] K. L. Armstrong, L. A. Genova, J. W. Greenlee, and D. S. Samuel, *Teaching Gradually: Practical Pedagogy for Graduate Students, by Graduate Students*. Stylus Publishing LLC, 2021.

[10] M. Li and J. Li, "Using Perusall to motivate students' curriculum-based academic reading," *J. Comput. Educ.*, vol. 10, no. 2, pp. 377–401, Jun. 2023, doi: 10.1007/s40692-022-00234-y.

[11] S. C. Lee and F. M. Yeong, "Fostering student engagement using online, collaborative reading assignments mediated by Perusall," *Asia Pac. Sch.*, vol. 3, no. 3, pp. 46–48, Sep. 2018, doi: 10.29060/TAPS.2018-3-3/PV2000.

[12] A. J. Sigmon and M. J. Bodek, "Use of an Online Social Annotation Platform to Enhance a Flipped Organic Chemistry Course," *J. Chem. Educ.*, vol. 99, no. 2, pp. 538–545, Feb. 2022, doi: 10.1021/acs.jchemed.1c00889.

[13] N. T. Buswell, B. K. Jesiek, C. D. Troy, R. R. Essig, and J. Boyd, "Engineering Instructors on Writing: Perceptions, Practices, and Needs," *IEEE Trans. Prof. Commun.*, vol. 62, no. 1, pp. 55–74, Mar. 2019, doi: 10.1109/TPC.2019.2893392.