

## **Enhancing Laboratory Learning: Integrating Virtual Laboratory with In-Person Laboratory Class**

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## Introduction

Laboratory courses are crucial in engineering education, providing students with hands-on experience and essential practical skills for their future careers. The COVID-19 pandemic posed significant challenges to engineering education, leading to an immediate shift in pedagogy and a rapid transition to remote methods. While remote teaching typically demands considerable time and investment in online course content development, the experience gained during the pandemic is expected to bring substantial benefits when integrated into in-person instruction. Instructors are realizing that online resources complement in-person instruction, with the anticipation that in-person classes will make better use of time for activities such as discussion, debate, and guided practice post-pandemic [1].

Bashir et al. investigated how students experienced remote learning during the lockdown, with a particular emphasis on the effects on their mental health and overall quality of life. The study shows that most students had positive experiences with remote learning, but the shift to remote learning revealed conflicting preferences, with students expressing a desire for more interactive lectures but only half feeling comfortable using video cameras for interaction [2].

Transitioning to online instruction during the COVID-19 pandemic was challenging for the laboratory course, as it typically requires students to meet in person to conduct experiments and collect data. In recent years, there has been a shift towards integrating digital resources and virtual laboratory developed during the pandemic as supplements to traditional laboratory instruction. A recent study shows that laboratory natural science courses can be successfully delivered through online or distance education platforms. Analysis of student performance data reveals that students enrolled in online courses performed as well as or better than those in traditional courses. Furthermore, the study demonstrates that students who concurrently take both lecture and laboratory components outperform students who only take the lecture [3].

Sarvary et al. studied the components of laboratory courses to be more student-centered after the pandemic [4]. Their research shows that students' preferences vary, with a preference for online lectures and tests, but a desire for face-to-face interactions for laboratory sections and group assignments. Retaining some online elements offers advantages such as increased accessibility and flexibility but could create challenges in student-student and instructor-student interactions. The researchers suggest that as colleges return to face-to-face instruction post-pandemic, careful consideration of student preferences is recommended in shaping the course format [4].

Online course materials created during the pandemic have been integrated into blended in-person lab sessions for engineering education laboratory courses. The goal of this study is to understand students' perspectives on blended engineering laboratory courses, with the aim of enhancing course design and providing a better learning environment. The result shows that students generally have positive opinions about the use of digital resources in engineering laboratory courses. Additionally, student feedback emphasizes the importance of virtual lab materials that

are interactive, excellent, and well-organized. The findings of this study lead to recommendations for further enhancements in the integration of digital resources in blended engineering laboratory courses.

## Method

To gather information on students' perceptions and experiences with digital resources and virtual labs in laboratory courses, a survey was developed and distributed to engineering students. A total of 219 students completed the survey (100 students from Civil Engineering (CE) courses and 119 students from Engineering (ENGR) courses). The CE courses included introduction to environmental engineering laboratory, geotechnical engineering laboratory, and materials for CE & construction engineering laboratory. Additionally, the ENGR courses included the strength of materials laboratory and fluid mechanics laboratory. The survey consists of both multiple-choice questions and open-ended questions. The survey is limited in scope to assessing students' perceptions regarding the usability and effectiveness of the online component in their laboratory experiences. The survey is shown in Figure 1.

<b>How Digital Resources Enhance the Learning Experience in Your Laboratory Course</b>	
Your Laboratory Course number _____	
1.	How often have you utilized supplementary digital resources, such as online simulations, videos, or interactive modules, in your laboratory course sessions? a) Rarely    b) Occasionally    c) Very often    d) 100% online course
2.	Do you believe that the integration of digital resources enhances your understanding of lab course material and helps replicate real-world experiments? (Yes/No)
3.	Are you typically provided with a variety of digital resources in your lab courses that are relevant to the course objectives and replicate real-world experiments? (Yes/No)
4.	How would you rate your experience with virtual labs in facilitating your learning when compared to traditional labs? a) Dissatisfied    b) Neutral    c) Satisfied    d) Not Applicable
5.	How effectively do instructors integrate digital resources into a lab course to replicate real-world experiments? a) Not effective    b) Somewhat effective    c) Moderately effective    d) Very effective
6.	What specific advantages do you find in using virtual labs? Please select ALL that apply. a) Accessibility    b) Convenience    c) Clarity    d) Repeatability e) Other benefits (please specify) _____    f) None of the above
7.	Which of the following are disadvantages or limitations you have encountered when using virtual labs as opposed to traditional labs? Please select ALL that apply. a) Lack of hands-on experience b) Limited interaction with real equipment c) Quality of audio and video components d) Other limitations (please specify) _____ e) I haven't encountered any disadvantages or limitations.
8.	In your opinion, do virtual labs provide adequate opportunities for collaboration with peers and instructors? (Yes/No)
9.	Are there any particular courses or subjects where you believe virtual labs are more suitable or effective than traditional labs?
10.	What improvements or suggestions do you have for enhancing the use of virtual labs in your learning experience?
11.	Can you provide an example of a digital resource that greatly contributed to your understanding of course content and helped replicate real-world experiments? Please describe.

Figure 1. Survey to Assess Student Learning Experience

## Results and discussion

The survey results are summarized in this section.

- The first aspect explored was the frequency of using supplementary digital resources such as online simulations and video recorded demonstrations on experimental procedures. It also investigated the impact of integrating digital resources into the lab course material. The survey results indicate that digital resources are used very often (38%) or occasionally (38%) in laboratory courses. An impressive 87% of surveyed students believe that utilizing digital resources helps them better understand the lab material, suggesting that students perceive these resources as valuable tools capable of enhancing their overall learning experience. However, 69% of students believe that the digital resources offered in lab courses are pertinent to the learning objectives and accurately simulate real-world experiments, compared to 19% who disagree and 12% who are unsure.
- Student satisfaction with virtual labs  
Differences in satisfaction with virtual labs were noted between the CE and ENGR courses. While 43% of CE course students reported satisfaction with their experience using virtual labs compared to traditional methods, only 20% of ENGR class students expressed a similar level of satisfaction. Students' perceptions of the effectiveness of instructors in integrating digital resources into their laboratory courses also showed variations between the CE and ENGR courses. In the CE courses, 40% of students believed that instructors were moderately effective in integrating digital resources into the course to replicate real-world experiments. On the other hand, in the ENGR courses, 43% of students saw the digital resources as somewhat effective.

The survey results may be influenced by the difference in specific focus and content between ENGR and CE courses. The ENGR laboratory courses generally cover engineering principles and are designed to provide opportunities for students to explore theoretical concepts, while CE laboratory courses are more focused on instructing students in standard testing procedures.

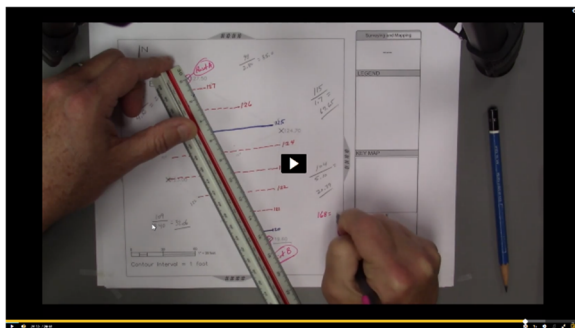
- Advantages and disadvantages of virtual labs  
Students highlighted specific advantages of using virtual labs, with 31% emphasizing the convenience, 25% citing accessibility, and 23% underscoring the repeatability of virtual experiments. These advantages align with the flexible nature of online learning environments, accommodating different learning styles and schedule and supporting a self-directed and self-paced learning approach.

Despite the advantages, students also reported disadvantages or limitations of the virtual labs, such as the "lack of hands-on experience" and "limited interaction with real equipment," mentioned by 76% of respondents. Additionally, 67% of students expressed that virtual labs did not provide adequate opportunities for collaboration with peers, indicating a need for improved features that facilitate interaction and teamwork in virtual lab environments.

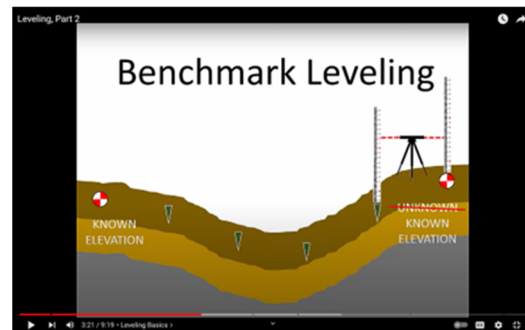
The open-ended response question provided students with the opportunity to offer input on how virtual labs could be improved to enhance their learning experiences. Many students find the pre-

lab videos very helpful in the learning process, especially for reviewing lab procedures before and after lab sessions. These resources also provide clear explanations of what needs to be done in the lab, making it easier to complete tasks. The students also emphasized the importance of more efficient use of video time, ensuring that important information isn't hidden by long introductions or unnecessary parts. Lastly, quizzes related to virtual lab exercises were suggested to test their understanding of the material.

Several students emphasized the need for additional interactive models that guide them through step-by-step calculations using given formulas. High-quality graphics, updated videos, and clear audio, accompanied by captions, were also mentioned as essential for creating engaging and informative virtual lab materials. A specific example mentioned was the Surveying Lab course. The instructor creates and records online materials for this course, guiding students through a step-by-step procedure (Figure 2a). Additionally, the instructor utilizes other available online materials in his class (Figure 2b). The instructor chose the online videos created by Mr. Todd Horton for the Illinois Professional Land Surveyors Association due to their clear, detailed instruction, interactive simulations, and real-world applications of the subject. The instructor contacted the creator to obtain permission before posting the video in his course. The video contents from the Illinois Land Surveyor Association are currently licensed under Creative Commons Attribution, allowing for reuse.



(a) Drawing contours



(b) Leveling lab

Figure 2. Video Content Examples in Surveying Lab Course

## Summary and recommendations

A survey was conducted to study engineering students' perceptions and experiences concerning digital resources and virtual labs in laboratory courses. The data indicates that the integration of digital resources is common in engineering laboratory courses and is generally well-received by students. The feedback highlights the significance of interactive, excellent, and well-structured virtual lab materials, even though most students believe these resources are helpful in expanding their understanding. The limitations of the online laboratory, identified as the lack of hands-on experience and reduced interaction opportunities, emphasize the need for further improvement in the integration of digital resources. It is crucial to address their limitations and challenges to ensure optimal learning experiences for students across diverse fields of study. Further research is needed to develop strategies that optimize the benefits of digital resources and virtual labs in laboratory courses.

Based on the survey results, the following recommendations are made.

- Provide pre-lab videos for reviewing lab procedures and offering clear explanations of the required tasks.
- Cover engineering principles in short video segments to optimize time utilization.
- Implement quizzes related to virtual lab exercises to assess students' understanding of the subject matter.
- Develop more interactive models to provide a hands-on, interactive experience.
- When integrating external videos into the course, maintain a balance with the instructor's own materials while also providing context around the external videos.

#### Reference

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