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Exploring Undergraduate Engineering Students' Perspectives on Laboratory Learning: Comparing Hands-On, Remote, and Virtual Environments

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Abstract

Engineering is a discipline dedicated to designing, developing, and optimizing production systems and relies heavily on laboratory experience. Laboratories play a pivotal role in facilitating coherent learning outcomes from theoretical knowledge and are particularly crucial in enabling engineering students to acquire empirical data for designing and developing products while evaluating their performance on hands-on, remote, and virtual laboratories are three distinct types used in engineering majors, each with advantages and disadvantages. Notably, remote and virtual laboratories have gained prominence in universities worldwide, especially in light of the COVID-19 pandemic. Remote laboratories have emerged as a primary mode of laboratory learning for engineering students, and remote laboratories are poised to remain a central trend in the future, even as the pandemic abates. The findings highlighted the reasons underlying students' attitudes. Transcripts of the interviews were analyzed using thematic and content analysis methods. The thematic analysis identified eight five main themes: (1) expectations and academic growth; (2) communication skills; (3) challenges in hands-on learning; (4) virtual learning experience; (5) personal growth and workplace readiness. Students' attitudes towards the three types of laboratories were varied. Hands-on laboratories were favored for essential practical experiences, while remote and virtual laboratories were perceived as efficient and convenient options. In conclusion, personal experiences, gender differences in lab preferences and experience, technological comfort, and individual learning styles all influence these attitudes, and the findings of this study have implications for improving engineering education and future laboratory development.

Keywords: *Engineering education, undergraduate students, laboratory use, perspectives, attitudes*

Introduction

This study delves into the diverse perspectives of engineering students regarding the three types of laboratories, recognizing the background and significance of laboratory experiences in engineering education. In a hands-on lab, both the instructor and students operate the machine directly in the laboratory (Ma & Nickerson, 2006). Additionally, hands-on laboratories can provide an engaging session for students to demonstrate their content and soft skills (Yeter et al., 2023). Furthermore, involving direct machinery operation within a physical space has traditionally been essential for providing practical experiences.

The evolution towards remote and virtual laboratories, averaging telecommunication technologies, and simulated environments, respectively, has become increasingly pronounced, especially in the context of the pandemic. Remote lab means the use of telecommunications to remotely conduct real (as opposed to virtual) experiments at the physical location of the operating technology whilst the scientist is utilizing technology from a separate geographical location (Heradio et al., 2016). Referring to the virtual lab is a simulated learning environment that allows students to complete laboratory experiments online and explore concepts and theories without stepping into a physical science lab (Lichtenstein & Phillips, 2021).

Significance of study

Laboratory experiences play an important role in connecting engineering students' theoretical concepts and practical knowledge (May et al., 2023; Yeter et al., 2023). Generally, the hands-on laboratory with machinery and a physical learning environment supports students' active engagement during learning. However, the later development of remote and virtual laboratories brings a more technology-based experimental environment. Student laboratories' use experience and preferences are essential for current teaching methods and experimental environments' adaptive development. This study can provide students' laboratory use experience and preferences, the potential factors influencing their experiences and preferences, the significance of using each type of lab, and the gender difference in students' lab use experience and preferences.

Research Questions

The present study explored engineering students' attitudes (lab use experiences and preferences), especially focused on levels of students' engagement in the three types of labs: hands-on, remote, and virtual laboratories. Based on this main research aim, there are four research questions (RQs) to be inquired:

- RQ 1. What are the attitudes of undergraduate engineering students toward different laboratory formats, including hands-on, remote, and virtual laboratories?
- RQ 2. How do students perceive the significance and utility of hands-on laboratories compared to remote and virtual laboratories in engineering education?
- RQ 3. What factors influence engineering students' preferences for specific laboratory modalities, and how do these preferences relate to their educational backgrounds and experiences?
- RQ 4. How do male and female engineering students perceive lab use in hands-on, remote, and virtual laboratory environments?
- RQ 5. How do different engineering major students perceive lab use hands-on, remote, and virtual laboratory?

Literature Review

Laboratories were applied to engineering education to provide students with hands-on learning experiences with a real and concert study problem. This practical problem-solving process of learning can facilitate a connection between theories and practice, which is a scaffolding for knowledge transfer (Ismael, 2023). The immersive laboratory environment promotes students' comprehensive understanding of abstract concepts. For example, hands-on laboratories have played a central role in engineering education. The hands-on lab can offer students direct exposure to physical equipment and machinery (Johnson & Barr, 2021). However, the remote and virtual laboratories appeared to respond to the engineering students' evolving learning needs and challenges of engineering education. For instance, students can conduct real experiments even in another country in remote laboratories with flexible access (Ismael, 2023). With the development of virtual reality technology, virtual laboratories were raised and put into engineering education. Students can take advantage of a virtual laboratory's immersive learning experience even without a physical hands-on lab (Heradio et al., 2016). Kolil and Achuthan (2023) have highlighted the interactive and immersive approach to enhance students' engagement and understanding. Other research on lab use experiences and preferences is lacking. However, researchers like Shana and Abulibdeh (2020) paid attention to the impact of hands-on laboratories on student academic performance. They addressed the importance of practical experiences in reinforcing theoretical concepts in engineering. Other research on remote and virtual labs mainly focused on accessibility and cost-effectiveness Polat and Ekren (2023).

Methods

Participants

13 Chinese undergraduate students from three different engineering majors, namely manufacturing (61.54%), electronic (23.08%), and chemical (15.38%), participated in the present study in China. Table 1 below demonstrates these students' demographics. Firstly, the students' age range is from 17 to 25. Their gender percentage shows a majority of male students (77%). Participated students are from different study years; most are from the second year (53.85%, then 23.08% of them are first-year students, and only two (15.38%) of them are from the third year and one from the final (fourth year) year study. Table 2 provides the details of each participant's gender and engineering major information.

Table 1. Demographics of participants

Characteristics	Number (%)
Age	
Range	17-25
Gender	
Female	3 (23%)

Characteristics	Number (%)
Male	10 (77%)
Race	
Chinese	13 (100%)
Year of Study	
First year	3 (23.08%)
Second year	7 (53.85%)
Third year	2 (15.38%)
Four-year and above	1 (7.69%)
Engineering Major	
Manufacturing	8 (61.54%)
Electronic	3 (23.08%)
Chemical	2 (15.38%)

Table 2 Individual participant information

Pseudonym	Gender	Major
Emma	Female	Chemical engineering
Lily	Female	Chemical engineering
James	Male	Electronic engineering
Gavin	Male	Electronic engineering
Alex	Male	Electronic engineering
George	Male	Manufacturing engineering
Oscar	Male	Manufacturing engineering
Ben	Male	Manufacturing engineering
David	Male	Manufacturing engineering
Jay	Male	Manufacturing engineering
Antigo	Male	Manufacturing engineering
Adrian	Male	Manufacturing engineering
Jones	Female	Manufacturing engineering

Data Collection, Data Analysis, and Limitations

This present study kept all participants' confidentiality and anonymity according to ethical guidelines. The ethical procedure was approved by the first author's research institution. The process of data collection was conducted by a focused interview with convenience sampling and participants' voluntary consent. Based on Braun and Clarke's (2006) thematic analysis procedure, transcripts were analyzed by identifying recurring themes, patterns, and insights related to participants' perspectives on hands-on, remote, and virtual laboratory uses and preferences.

This study has potential limitations of participants' diversity, including cultural, major, and gender aspects. This study has explored a specific Chinese undergraduate group. Most participants were manufacturing engineering majors, and a limited number of other branched engineering students were involved. The minority of female students engaged in this focused interview may be a lack of representation of female engineering students' perspectives, though certain data have already been collected from them.

Findings

A semi-structured focused group interview was conducted with 13 engineering students engaged to discuss their lab use experience and preferences. After data collection, the thematic analysis identified five main themes: (1) expectations and academic growth; (2) communication skills; (3) challenges in hands-on learning; (4) virtual learning experience; (5) personal growth and workplace readiness. These themes are explained individually based on the evidence identified in the analysis. The answers to four research questions (RQs) are structured based on the analysis.

RQ 1. What are the attitudes of undergraduate engineering students toward different laboratory formats, including hands-on, remote, and virtual laboratories?

All of the engineering student participants have various lab use experience. Around half of the students had virtual (47.06%) and hands-on labs (50.91%) use experience. Only limited students had the remote lab (2.03%)) use experience. Students in this study showed a significant preference for the hands-on lab with online instructions and learning materials. Nearly half of the students prefer the hands-on lab (47%), 14.70% consider the remote one their favorite, and only 8.83% choose the virtual one as their preference. However, this limited percentage of virtual lab preference was reported with students' positive attitudes and expectations of its future development. However, the hands-on lab now adores students' preferences as they can bring real operation practice.

RQ 2. How do students perceive the significance and utility of hands-on laboratories compared to remote and virtual laboratories in engineering education?

Exploring engineering students' perspectives on hands-on and virtual laboratories provides valuable insights into their preferences and considerations. *"Hands-on lab is my first choice to carry out electronic engineering study issues, though online one is also very efficient at processing stimulations.* (George)*"* The findings reveal a landscape where participants express an appreciation for both types of laboratories, emphasizing the need for a balanced approach to accommodating diverse learning needs: "*I do agree that the hands-on lab can help improve the practical problem-solving experience.* (Oscar)*"* Participants in the study conveyed a positive inclination toward both hands-on and remote laboratory formats. *"The hands-on lab usually generates the minor and acceptable inaccuracy of experimental results, that's why I like it the most.* (Ben)*"* The appreciation for hands-on labs stemmed from the opportunities they provided for tangible experiments, leading to unexpected discoveries. Despite this, there was a noticeable preference for online labs, primarily attributed to the logistical challenges associated with physical attendance with the representative expression:

> *"It's not like chemistry or electronic machines. You can have unexpected, good expectations. But I do prefer online stuff more than in person, mainly because of difficulty traveling sometimes.* (James)*"*

> *"Personally, I like both hands-on and online labs. There are some great labs like the stuff where you can perform little experiments.* (Emma)*"*

The discourse displays the broader question of whether virtual labs could authentically contribute to students' academic and personal development. Concerns were raised about the potential limitations of exclusively virtual experiences in fostering not only academic growth but also personal maturation. The overarching goal emphasized the need to mold students into well-rounded engineers capable of effective communication in both academic and professional, *"We can make everything virtual, but at the same time are we really going to help the students out? Or to not only grow academically but grow as a person*. (David)"

RQ 3. What factors influence engineering students' preferences for specific laboratory modalities, and how do these preferences relate to their educational backgrounds and experiences?

At the core of the conversation was the central theme of communication, highlighted as a crucial element essential for both personal and professional development. Participants underscored the paramount importance of effective communication for academic advancement, personal development, and success in the engineering workplace. Despite the convenience offered by virtual labs, participants emphasized the non-negotiable nature of developing crucial communication skills.

> "*That was not a good way to understand how to do a certain manufacturing process, how to grasp a computer when you're in person trying to mail a certain chapter*. (Jay)*"*

> *"…whatever you're trying to take off two millimeters when you're in person is a different feeling.* (Jones)*"*

Highlighted challenges associated with hands-on learning, citing potential inadequacies in understanding certain manufacturing processes through in-person experiences. Concrete examples, such as difficulties in milling and the nuanced tactile aspects of tasks like removing two millimeters, underscored the limitations of traditional hands-on approaches.

The study recognized the value of virtual labs for specific tasks, particularly in comprehending computer-based processes. Participants acknowledged that the virtual lab learning experience significantly differs from in-person approaches, as Lily shared her perspectives that "*virtual lab seems can help individual learning even without complicated application procedures of hands-on lab use but with timely instructional feedback.*" While certain aspects could be effectively conveyed virtually, participants stressed the importance of a nuanced, hands-on understanding of specific manufacturing processes. Adrian said, *"for practical problems in manufacturing engineering such as doing a lathe machining learning, it is difficult to completely* *handle the skills with virtual lab."* Participants acknowledged the role of labs, be they hands-on or virtual, in contributing to the personal growth of future engineers, as Gavin pointed out;

> "…so *they can be a great engineer in the future, as in engineering in the future or the workplace. I know some of you already work there, but it's all about communication. And being able to communicate well with others".*

The exploration extended beyond academic considerations, emphasizing the broader context of personal development. The consensus underscored that effective communication skills are indispensable for professional readiness in the dynamic engineering workplace.

RQ4. How do male and female engineering students perceive lab use in hands-on, remote, and virtual laboratory environments?

Referring to the gender differences in lab use experience and preference, this study didn't identify any significant differences. However, there are certain differences in lab instruction needs in these labs. Both female and male students prefer the hands-on lab for comprehensive practical operations experiences and might have less systematic bias and errors towards certain experiments. "*Because students have the accessibility to check and operate the experimental material and machines with manageable confidence.* (Antigo)" However, the virtual lab can be very convenient for students wherever and whenever they are.

> *"It would be so easy for us to try experiments during COVID without potential infection risks, and it is also great for independent study after COVID for its 24 hours and 7 days access. However, the technological issues and hardware problems did indeed happen occasionally.* (David)"

> *"For students who live very far from the campus and limited attempts to use the labs, the online and virtual labs are really the best way to solve the financial issue of lab use.* (Alex)"

However, female students pointed more to the interactive instructional needs when designing and using the online and virtual labs. "*The feedback is really important when doing experiments remotely online and virtual. I hope to see more detailed and timely feedback and instructions from the lab systems.* (Lily)" Male students highlighted the possible multiple experiments in the online and virtual labs.

> *"Currently, only very limited types of experiments can be done online or via virtual labs. Sometimes, I have to go to the hands-on lab to do an experiment to use the equipment that only existed in this lab.* (Alex)*"*

RQ5. How do different engineering major students perceive lab use hands-on, remote, and virtual laboratory?

Manufacturing engineering students prefer to use the hands-on lab, "*our manufacturing experiments are mainly done with hands-on lab, it is really necessary for our actual problem-solving, such as make a metal hammer. (*Adrian)"

Electronic and chemical engineering students favor virtual labs but have the most experience of using remote labs. "*I normally use the remote lab to do my electronic experiments but prefer to use a virtual lab to enhance the sense of remote control.* (David)" They need to keep a balance between flexible access and reliable experiment outcomes. When students from different branches of engineering, their experiment aims would influence their choice more. However, students still desired a lab that combines academic experimental functions and non-academic convenience, such as easy access without distance and time limits and social interactions in a real community.

Overall, for the lab preference, there is no significant gender difference. Still, they showed various suggestions on the current three types of use, such as the instructions, accessible learning materials, and types of online/virtual lab experiments. The findings present a perspective on the strengths and limitations of both hands-on and virtual labs. While participants value the tangible experiences provided by hands-on labs, they equally recognize the significance of effective communication and personal growth.

Discussion

This research explored diverse engineering students' perspectives on hands-on, remote, and virtual labs. The findings reveal that students have a significant preference for hands-on and virtual labs. Because the hands-on lab can bring tangible problem-solving learning processes compared to the remote and virtual ones. However, students agreed with the remote and virtual labs' flexible access and unlimited attempts, especially for those students who need more individual study and live very far from physical labs, such as during the COVID. Specifically, this present study agrees with Jahnke et al.'s (2023) study; they concluded that the potential improvements in providing instructional feedback and other communication functions in the future virtual lab. Additionally, Dunmoye et al. (2023) explored engineering students' practical learning process and outcomes and suggested restructuring the consistency of teaching aims and actual evolving learning needs. Specifically, the factors influencing various engineering students' preferences for labs, including academic and non-academic aspects.

Regarding the academic side, it relates to the experimental outcome bias and the knowledge understanding level; on the non-academic considerations, these are mainly for the convenience of access, the flexibility of using the lab, social communications, and other personal ability development needs. May et al.'s (2023) study indicates that teachers should pay attention to students' effective communication skills and reconsider the importance of lab in non-academic skills cultivation. Notably, the present study highlights the gender differences in lab use experiences. Thus, in terms of lab design, gender inclusion should be reconsidered, though there are no gender differences in lab preference. As Nunes et al.' (2023) addressed, there is a necessity to improve the gender balance in the engineering field to support current engineering system development. For example, the various user-experience needs of future labs should also show the inclusion of gender in engineering education. This inclusion could also consider more branches of engineering because each individual field of engineering has its mission and vision.

Conclusions

This study explored the various engineering students' lab use experiences and preferences. The findings show students' majors, learning aims and needs, and non-academic development expectations influence their preference for labs. The gender difference in lab use experiences was identified, but there were no differences in the lab preference. Most manufacturing engineering students choose the hands-on one compared with electronic and chemical engineering students. Most of the students involved consider the hands-on lab as their favorite one because the use experience of the hands-on lab can bring actual conceptual thinking and support to transfer abstract knowledge to the practical learning outcome. In the meantime, students suggested a need for more individual learning resources based on a virtual lab. However, compared to the hands-on lab, students were dissatisfied with the difference in experiment bias when using the virtual labs and limited options of experiment types. Therefore, it is urgent to improve the virtual lab with more experiment types and accuracy of experimental outcomes. Dunmore et al. (2023) insisted that more technologies should be applied to virtual lab design, such as simulation and augmented reality. Additionally, students from diverse engineering branches insisted on keeping a hands-on lab instead of replacing it with a virtual lab. Because the hands-on lab is a necessary role to cultivate students' real problem-solving abilities and non-academic skills, such as communication skills. May et al.' (2023) agreed that non-academic skills development is also worth being considered in the engineering curriculum design to guarantee consistency of the teaching aims, methods, content, and students' development needs.

Implications and Future Directions

According to the findings, the practical pedagogical implications are suggested for engineering education. These implications mainly relate to the lab development, corresponding teaching methods, and engineering curriculum design. Because the technology has promoted the related lab's development, for instance, incorporating technologies like simulation and augmented reality can enhance hands-on learning experiences and address challenges associated with traditional laboratory approaches. Moreover, the gender difference in the lab's use and development hints at the necessity of gender inclusion when designing all types of labs. Otherwise, these labs' development would lose its full potential as a learner-friendly and gender-inclusive showcase (Nunes et al., 2023). Overall, the study provides valuable insights into the preferences and considerations of engineering students regarding laboratory experiences.

This present study supports future research in the field of engineering education. More studies on the diverse backgrounds, study fields, and gender differences in lab preference and use experiences are worth conducting globally. Additionally, while there are efforts to investigate the K-12 educators' perceptions of using technological tools, for instance, virtual simulations (Yasar et al., 2016) and exploring the pedagogical impact on teaching labs online (Radloff et al., 2024), very limited studies explore such factors (Rathore et al., 2016); therefore, future research should investigate such parallel studies among college engineering instructors. These studies can track students' learning needs and preservatives to adjust and improve corresponding curriculum design, teaching methods, teaching objectives, and teaching environment. Creating more inclusive and effective teaching and learning settings with the evolving technologies and engineering students' learning challenges is necessary.

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