Students' Perceptions of Virtual Laboratories in University Physics Classes

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Abstract

The integration of virtual laboratories (VLs) in education has gained significant attention, especially post-Covid-19, due to their potential to augment learning experiences and facilitate distance education in higher institutions. This study evaluates students' perceptions of VLs effectiveness in undergraduate physics courses, addressing two key questions: How do students perceive VLs' effectiveness in understanding theoretical concepts? What are the reported advantages and disadvantages of using VLs compared to traditional on-site laboratories? A questionnaire-based approach was used, involving 80 undergraduate students enrolled in physics courses. The findings indicate a positive impact, with 57.5% of students favoring VLs over on-site laboratories. Students perceive them as valuable tools enhancing the learning experience. While acknowledging these positive outcomes, some students highlight disadvantages of VLs, emphasizing the importance of physical experiments. Consequently, adopting a blended laboratory approach emerges as a promising strategy for educational transformation. By sharing this experience, the authors aim to inspire other educators to explore the potential of integrating VLs to enhance their own courses.

Keyword: Learning Experience, Physics Courses, Virtual Laboratories

Introduction

Virtual laboratories (VLs) are free online educational tools that revolutionize science learning through the integration of visualization techniques, such as animations, simulations, and recorded videos (Diwakar et al., 2015; Nair et al., 2012; Radhamani et al., 2014; Scanlon et al., 2002; Tüysüz, 2010). These labs are designed as content-rich interactive materials, providing users with a real impression of the laboratory experience through click gestures that emulate experimental protocols (Diwakar et al., 2019; Salmerón-Manzano & Manzano-Agugliaro, 2018).

The initiation of the VL traces its roots to the late 20th century. Initially these laboratories have found utility among both teachers and students as complements to traditional on-site labs (Vasiliadou, 2020). With advancements in technology and improved internet connectivity, VLs have evolved to become more sophisticated and accessible. However, within the research community, varying perspectives emerge. Some studies disagree with the efficacy of this new educational tool, positing that students gain more information when using real equipment (Schubert et al., 2001; Schuemie et al., 2001), while others argue that virtual or remote labs contribute significantly to education (Dewhurst et al., 2000; Sicker et al., 2005).

In a traditional laboratory, students typically engage in lectures to grasp theoretical concepts, followed by hands-on sessions to apply these theories in practical scenarios (Nedic et al., 2008). However, if students struggle to comprehend the theoretical information conveyed during a laboratory experiment, they may resort to memorization, leading to a risk of course failure. Such setbacks can foster negative attitudes towards the course among students who have experienced academic challenges (Trundle & Bell, 2010). Achieving a deep understanding of scientific theories poses challenges with traditional teaching methods (Achuthan et al., 2018).

To address these challenges, VLs have emerged as solutions to the limitations encountered in on-site laboratories, functioning as supplements to classroom teaching. By providing an artificial working environment, VLs aim to enhance the learning experience more effectively (Bijlani, 2012; Trundle & Bell, 2010). Numerous studies have demonstrated that students' conceptual understanding in VLs is comparable to or even surpasses that achieved in traditional laboratory settings (Brinson, 2015; Nair et al., 2012; Raman et al., 2014). Moreover, these studies suggest that VLs not only contribute to improved learning but also prove more effective than traditional methods (Achuthan et al., 2017; Magin & Kanapathipillai, 2000; Raineri, 2001). Another body of research even indicates that VLs can adequately substitute traditional labs (Corter et al., 2011; Lang, 2012; Zacharia & Olympiou, 2011), achieving comparable learning outcomes to hands-on laboratories across various science education domains (Ma & Nickerson, 2006; Moosvi et al., 2019; Stahre Wästberg et al., 2019).

Additionally, the growing demands of using VLs became evident when educational activities were affected by the COVID-19 pandemic (Ekarattanawong et al., 2023; Gamage et al., 2020). While theoretical courses transitioned to online delivery, educational institutions had difficulty in fulfilling the program requirements related to laboratory experiments due to the closure of universities and their laboratories.

So, due to the rapid spread of COVID-19 and the delay in finding a vaccine, numerous universities have incorporated VLs as a resource to complement and reinforce the teaching and learning process before and during pandemic closures (García-Vela et al., 2020; Joshi et al., 2021; Radhamani et al., 2021). Various publications offer guidance to institutions on effectively integrating VLs into the education process and encourage their adoption by learners (Çivril & Özkul, 2021).

The use of VLs within the context of distance education has gained substantial popularity in learning (Dhawan, S. 2020) since they have many educational advantages (Fiscarelli et al., 2013; Rotimi et al., 2012; Rutten et al., 2012; Smetana & Bell, 2012; Tatli & Ayas, 2011; Trundle & Bell, 2010; Zabunov, 2013):

- Carry out experiments in a shorter time.
- Carrying out dangerous experiments in a safe environment.
- Low-cost solution: no equipment is needed for performing the experimentations, all the development work and the implementation are done by the computer.
- Enabling students to progress at their own pace, so improve the self-driven learning (Radhamani et al., 2015).
- Providing students with immediate feedback so that they can check their learning.
- Increasing the learners' motivation and their ability to self-study.
- Accessing the virtual laboratory by learners is allowed at all times and places that multiple learners can do the same experiment at the same time (El Kharki et al., 2021).
- Recreating events that would be difficult or impossible to observed in traditional laboratory (Mishra et al., 2020).
- Improve students' conceptual understanding (Gunawan et al., 2018).

Methodology

The study focused on the usage of VLs by undergraduate engineering students at the Mediterranean Institute of Technology (MedTech). As a private co-educational university, MedTech has a diverse student population, comprising approximately 2,000 undergraduates and graduates from over 10 different nationalities. MedTech's engineering school is part of the South Mediterranean University, an English-speaking educational institution in Tunisia, established in 2002.

This study is based on data collected from two distinct cohorts:

- First-year pre-engineering students enrolled in the classical mechanics course, a foundational component of the engineering curriculum. This course is essential for establishing a solid understanding of principles such as motion, moment of forces and conservation of energy in mechanical systems.
- Second-year pre-engineering students participating in the optics and waves course, a fundamental second-year course that delves into the principles of optics and wave phenomena in engineering.

Both physics courses have a biweekly laboratory component aimed at applying the theoretical concepts learned in lectures. As part of our approach, we chose to implement one of the laboratories in a virtual format. Following this virtual session, we conducted a survey to investigate the factors influencing students' acceptance of VLs.

The survey was administered in Spring 2023, involving 80 undergraduate students enrolled in physics courses, including two first-year groups and one second-year group. Before completing the web-based survey, students participated in one session of VLs. The survey respondents comprised 34 female students and 46 male students. The survey encompassed a combination of twenty 5-point Likert scale questions, ranging from 1 = strongly disagree to 5 = strongly agree, allowing students to express the extent of their agreement, along with one open-ended question.

To address the research questions, students gave their feedback anonymously relating to their laboratory experiences at the end of the virtual lab session.

For the first-year students, based on previous research (Radhamani et al., 2021), we decided to use the free platform Amrita (https://vlab.amrita.edu/index.php), which contains a lot of VLs in different fields including chemistry, physics, mechanics, and more. The learning objective of the virtual laboratory is to study the two types of collision: elastic and inelastic. Building on prior research (Abdjul & Ntobuo, 2018; Zulkifli et al., 2022), we opted to utilize the free PHET platform (PHET https://phet.colorado.edu/) for the second-year group to facilitate exploration of standing waves. This choice allowed for the observation and study of phenomena impractical in a traditional laboratory setting. Additionally, it fostered discussions on various resonant modes of vibrations and enabled the calculation of the fundamental resonant frequency.

Data Analysis

Quantitative Study

Derived from the survey outcomes, we present charts illustrating responses to selected questions below:

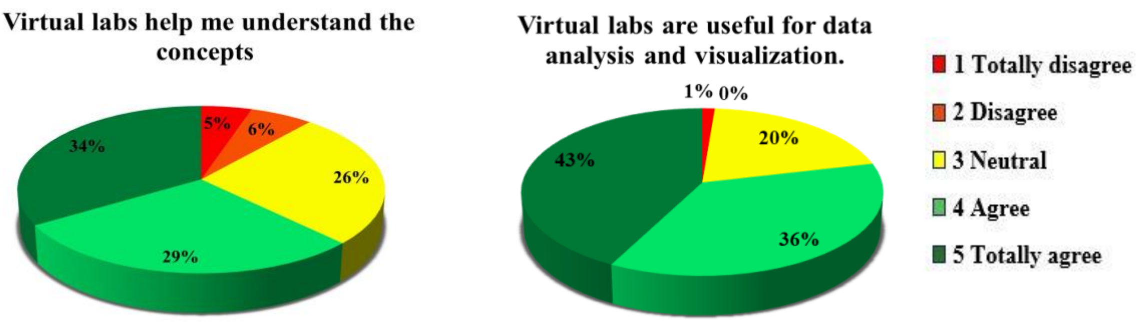

Figure 1: VLs are helpful and useful.

Observing figure 1, it's apparent that over 65% of students confirm the utility of VLs in understanding theoretical concepts. Additionally, a significant 80% affirm the effectiveness of VLs for data analysis and visualization. These findings strongly support the assertion that VLs serve as beneficial and valuable tools in the learning process.

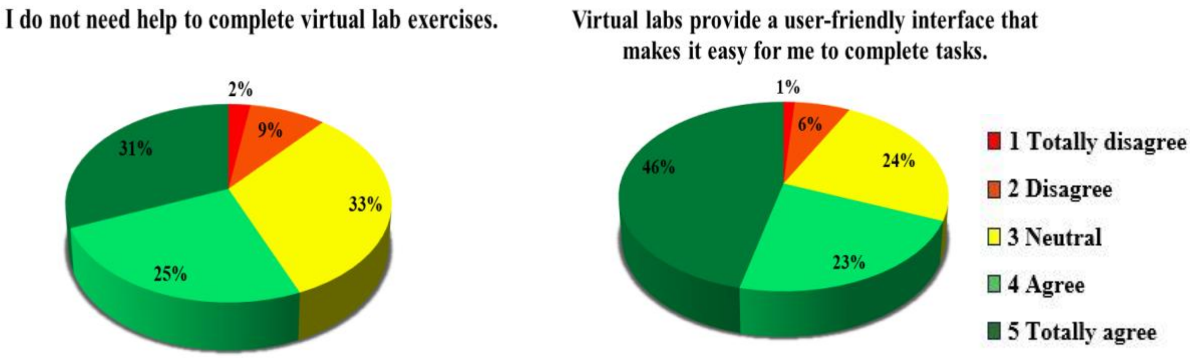

Figure 2: VLs are self-learning tools.

Here, over 50% of students express the ability to advance at their own pace when utilizing VLs. Furthermore, 70% of students affirm that VLs boast a user-friendly interface. These observations indicate that VLs contribute to enhancing learners' motivation and their capacity for self-study, thereby fostering a more self-driven learning experience.

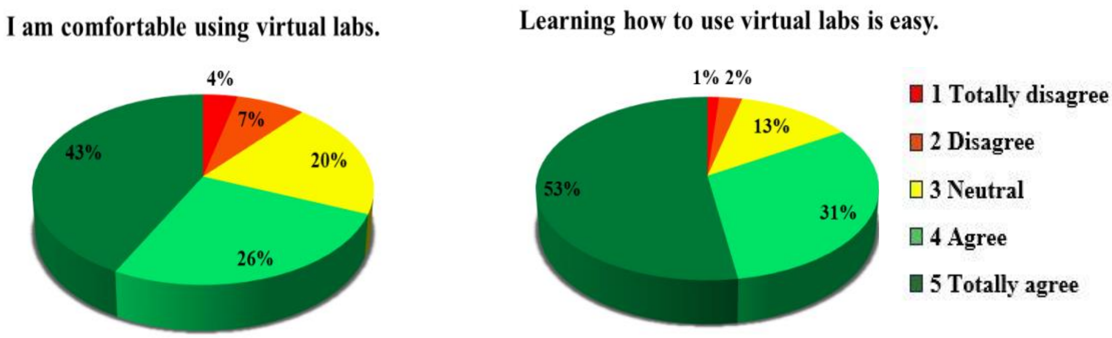

Figure 3: VLs are easy.

The data reveals that over 70% of students affirm the ease of use of VLs, expressing comfort in their utilization. This underlines that VLs are easy-to-use tools for both learning and practical application.

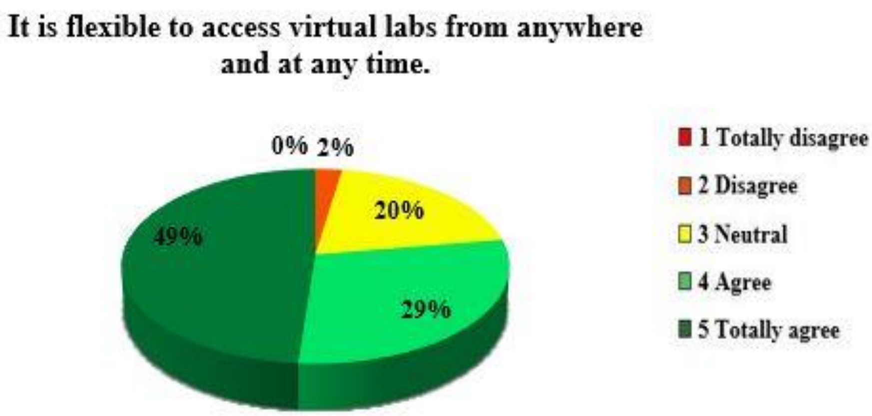

Figure 4: VLs are flexible.

A significant 80% of students acknowledge that access to the virtual laboratory is permitted at all times and locations, with 49% expressing complete agreement. This facilitation of flexible learning schedules is evident, providing students with the convenience of accessing resources according to their individual preferences and needs.

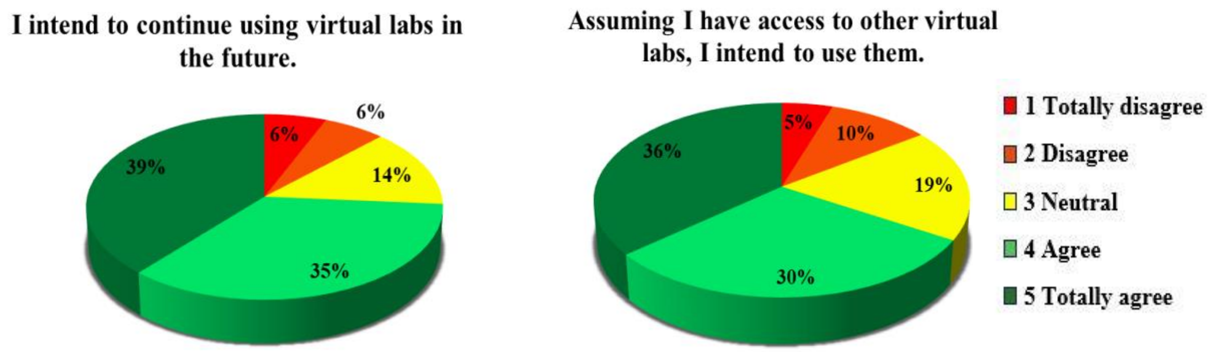

Figure 5: Continuity of use

75% of students confirm their intent to continue using VLs in the future and 66% express agreement with the use of other Virtual Learning Systems (VLS). These findings strongly indicate the remarkable effectiveness and appeal of VLs as valuable educational tools.

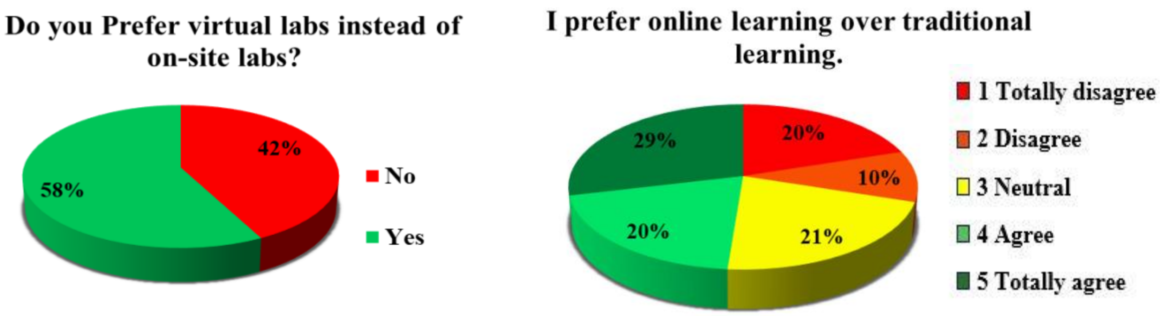

Figure 6: The preferred laboratory

Most students express satisfaction with the use of virtual labs, with 58% expressing a preference for VLs over on-site laboratories. This preference indicates a positive impact of VLs on students' perceptions and experiences.

However, when questioned about their preferred mode of learning, 49% of students lean towards online learning, while 30% favor traditional learning. To comprehend their choices, we conducted a qualitative study.

Qualitative Study

In the qualitative study, we deepened our understanding of the factors influencing students' preferences for learning modes. Through an open-ended question, "*do you Prefer virtual labs instead of on-site labs? Why? Please explain*."

We explored the effect of their experiences and perceptions with the aim of uncovering qualitative information that complements and enriches the quantitative results.

We resume below in Table1 and table2 the students' responses to the open-ended question in favor and against the use of VLs.

It is easier to plug in values and get accurate results with no human error
It’s very practical, useful, Easier, accurate and more efficient
Designed with the latest technology, virtual labs protect students from the dangers they face while conducting some dangerous laboratory experiments.
It is better
You can get more benefits since you are filly focused
It is more fun XD
Avoid the uncertainty of values
They are easier on the eyes for complicated labs, my eyes hurt trying to read big distances or setting small tolerances. And the simulations give much more accurate results anyways. On top of many other benefits like being very easy to access anywhere
Learning through gaming makes it easier, faster, and funnier
Because the values are more precise and exact
More flexible
It takes less time.
I like digital software
It's easier and we have to use technology to understand more.
I can practice more

Table 1: students’ response in favor of VLs use.

Students are totally supportive of the use of virtual labs (VL), as indicated by their positive responses in Table 1 and their preferences for this educational tool. They think that VLs are useful, helpful, practical, flexible, easier…tools to learn. The high level of agreement and approval on the part of students suggests a strong tendency to embrace virtual labs as effective and beneficial elements of their learning experiences. Which confirm the positive students' perception of the effectiveness of VLs.

Nevertheless, it is important to recognize that some responses indicate reservations or opposition to the use of VLs. A summary of these contrasting viewpoints is presented in Table 2 below. This comprehensive analysis allows us to understand the various perspectives and considerations surrounding the adoption of virtual labs in the educational context.

We love the reality and touching stuff
Because some experiments need face to face explain
I love the traditional learning more
It is better to see the experience in front of you
VLs does not make you understand everything and doesn't feel like actually experimenting
On site labs are more efficient and realistic
The experiment gives you the opportunity to try things physically
It's better to manipulate the materials
Sometimes VLs are not as concrete as the on-sites labs we prefer sometimes using the material, however if it is well explained virtual labs can be good too.
in face-to-face labs I can ask the professor a lot of questions and understand more
I love to do things by my hands
Traditional LAB shows us how the formula does work, and it make the subject more understandable.
While VLs are useful, I still prefer to experience the real-world experience to effectively prepare myself for professional life.
It is better to manipulate the material and do the experiments
Having a real experience is better
I prefer physical since we take more time and put in more effort working on it
I like seeing concrete evidence of an experiment
Physically we may ask the professor and understand more
I like hands on practice
Just a preference
Onsite labs are better in reality
Both are good but real-life labs are better seen
VLs likt Einstein
In traditional labs you can interact with the materials and understand the real physical phenomena
It always far better to learn with something that is tangible, you get to understand better the component itself
Because nothing can replace handling equipment with own hands
No when you are on site You are able to understand the lab better and actually get to manipulate stuff

Table 2: students' response against the use of VLs.

Some Comments in the table above affirm the preference of some students for traditional labs over VLs, for them it's more efficient to understand.

Some comments gathered from student responses show that in addition to preferring traditional labs, a significant group of students prefer a combination of virtual labs (VL) and traditional physical experiences. This indicates that students recognize that integrating the two approaches can provide a well-rounded and complete learning experience that combines the benefits of virtual tools with the practical and tangible aspects of traditional labs. The preference for this hybrid approach suggests an openness to exploiting the strengths of both virtual and physical experiences in teaching.

Therefore, the adoption of a blended lab approach, which combines both virtual labs and traditional physical experiences, appears to align with the preferences and needs expressed by students. This blended approach integrates the benefits of virtual tools and hands-on experiences, offering a more versatile and comprehensive learning environment.

Conclusion

In contemporary STEM education, VLs play a pivotal role, offering students a useful, helpful, flexible, easy, and self-directed means to explore and experiment across various scientific disciplines.

Overall, VLs play a crucial role in STEM education by offering students a useful, helpful, flexible, easy, and self-directed means to explore and experiment across various scientific disciplines. As students increasingly embrace VLs (Estriegana et al., 2019), traditional laboratories persist in their importance, providing a tangible and immersive learning experience. Traditional labs create a distinctive environment for students to explore, experiment, and gain practical insights into scientific concepts. Consequently, a blended laboratory approach, integrating face-to-face and online instruction (Graham, C. R., 2006), emerges as a promising strategy for educational transformation (Means, B., et al., 2009). This approach delivers a comprehensive and flexible learning experience, combining the benefits of hands-on experimentation with the accessibility and innovation offered by digital tools. Virtual labs act as complements to on-site teaching (Gregory & Di Trapani, 2012).

Recent research further underscores the advantages of blended learning for students including flexibility, student engagement, and motivation (Antonelli et al., 2023; Sasidharakurup et al., 2015; Setiawan & Rosli, 2023; Yu & Wang, 2023). This compelling evidence positions blended learning as a contemporary educational approach poised to enhance the overall learning experience for students in STEM disciplines.

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