Exploring Barriers and Challenges to Accessibility in Virtual Laboratories: A Preliminary Review

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Abstract

Virtual laboratories (VL) have become an essential tool for educational sectors, allowing students to develop practical skills in a remote environment. However, the accessibility of VL remains a significant challenge for learners. This research paper aimed to investigate the accessibility barrier in VL and explores potential solutions to overcome them. To achieve this, we conducted a comprehensive literature review spanning from 1997 to 2023, focusing on the accessibility of VL. Our search was conducted solely on the Scopus database, resulting in 164 papers, from which we carefully selected 21 primary studies for detailed analysis. The result indicates still there is high barrier to accessing VL. Based on the analysis, we identified four major barriers: technological, infrastructural, pedagogical, and cultural. To address the issues, a range of solutions have been proposed. These findings highlight the critical need to tackle accessibility barriers in VL, thereby enabling all students to have equal opportunities to develop their practical skills.

Keywords

Virtual laboratories, learning analytics, Accessibility barriers, Remote laboratories, Educational technology, Online learning, Accessible learning

1. Introduction

In recent years, technology has significantly shaped the education sector in several ways [1], [2]. For example, by improving access; through online classes [3], providing educational applications [4], and digitalizing textbooks [5], students learn from anywhere at any time, without the constraints of geography. In the learning process, doing laboratory experiments is one of the vital parts of education. This enhances students with hands-on experience and allows them to physically interact with equipment and materials to work together in groups, fostering teamwork and collaboration [6]. However, there are several limitations to traditional laboratories. First, to run hand-on the experiment they need physical space and equipment [7], which are expensive to maintain and update education, especially for students who do not have access to a well-equipped laboratory [8]. Second, students must physically be present in the laboratory to complete their experiments, making it challenging for all students to access the same opportunities [9]. Third, some physical laboratories specifically chemical and biomedical labs need safety and act according to guidelines [10] due to the laboratories contain a range of hazardous materials such as acids, bases, flammable liquids, and toxic gases. This leads to various accidents like explosions, and chemical burns [11]. For example, Lu Zisheng [12] analyzed student laboratory accidents in China in colleges and universities. According to the study, 197 safety accidents have happened in the past 39 years. They identified explosions, fire, radiation, chemical burn, electric injuries, and dangerous gas poisoning as the main accidents in the labs. Fourth, most traditional labs are designed to test specific hypotheses or theories [13] which leads students to miss a vital component of the experiment or required hardware [14]. Finally, the physical constraint of lab size [15] is the main issue.

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One of the most promising technologies to solve these issues is the development of VL [16], [17]. These labs allow students to conduct experiments with real-world experiments without the need for physical equipment [18]. For instance, a smart science lab [19], is one of the most known virtual labs for science education which uses videos, images, text, and interactive elements to provide lessons taught by real teachers. The lab incorporates different subjects such as biology, chemistry, and physics. This opened new possibilities for students who have no access to traditional laboratories or who have limited resources [20]. As a result, it appeared as an innovative way to supply practical training and experience to students as well as emerged as a solution to traditional lab issues. In addition, VL provide a safe environment for students to conduct experiments without the risk of injury or damage to equipment [21]. For example, in chemistry, VL are used to simulate experiments involving chemical reactions, titrations, and other practical applications that are too dangerous in traditional laboratories. Due to several advantages, these labs have been increasing usage dramatically over the past several years [22].

However, there are also important considerations to keep in mind when using VL and other tools, such as issues of accessibility and usability [23]. P A Hatherly et al. [24] argued that implementing a VL seeks to address the issues of the suitability of an activity for students who are geographically remote. Similarly, the study of B Balamuralithara [25] identifies, most VL lack realistic GUI and so that the effectiveness of the labs depends on user interactivity. Many studies have investigated and developed a virtual tool for various disciplines [26][27], but a thorough investigation is required to determine whether these tools provide the necessary experimental objectives, particularly in terms of accessibility [28]. Therefore, this paper aims to review the issues of accessibility in VL in the education sector. The main goal of our study is to provide insights into how to improve accessibility in VL for computing disciplines. To achieve this goal, the following research question were defined:

- RQ: What are the barriers to accessibility in VL in computing disciplines, and how can they can be overcome ?

The paper is organized as follows: The background section provides an overview of VL across different disciplines and the challenges of accessibility within them. The method section describes the process of developing the protocol, including the eligibility criteria, information source, search strategy, study selection process, data extraction, and synthesizing. The result section presents an overview of the selected studies, including accessibility barriers and how they were overcome. The discussion section analyzes the findings of the study and their implications. Lastly, the conclusion section summarizes the main findings and suggests future studies.

2. Method

2.1. Protocol

We developed our protocol using the methodological framework proposed by Arksey and O'Malley [29] for reviews. The protocol in the study consists of eligibility criteria, an information source, and search strategy, a study selection, data extraction, and synthesizing.

2.2. Eligibility criteria

To be included in this review, papers must meet the following eligibility criteria: 1) peer-reviewed journal articles, conference proceedings, or book chapters that report on original research; 2) papers that focus on VL designed to enhance accessibility; 3) studies that involve students, teachers, or other educational stakeholders who use or implement VL for enhancing accessibility; 4) papers that identify and describe barriers to accessibility in VL; 5) papers that propose or evaluate solutions to overcome the identified barriers to accessibility; and 6) papers written in English.

2.3. Information source and search strategy

To identify relevant studies, we conducted a literature search using the search terms ("virtual laboratory" AND "accessib*") search with title, abstract, and keyword in the Scopus database. Scopus was chosen due to the extensive range and nature of the research [29]. The search strategy was not limited by study design, year, and we initially aimed to include all fields of research or domains. However, we limited the search to the field of education.

2.4. Study selection

The study selection process began by importing the search results into our online systematic review software, Rayyan [30]. The inclusion criteria were developed a priori and imported into the software to screen a total of 164 studies based on their titles and abstracts for level 1 screening. An abstraction reading of 117 was performed and full-text articles were screened during level 2 screening using the same inclusion and exclusion criteria then reducing the result paper to 32.

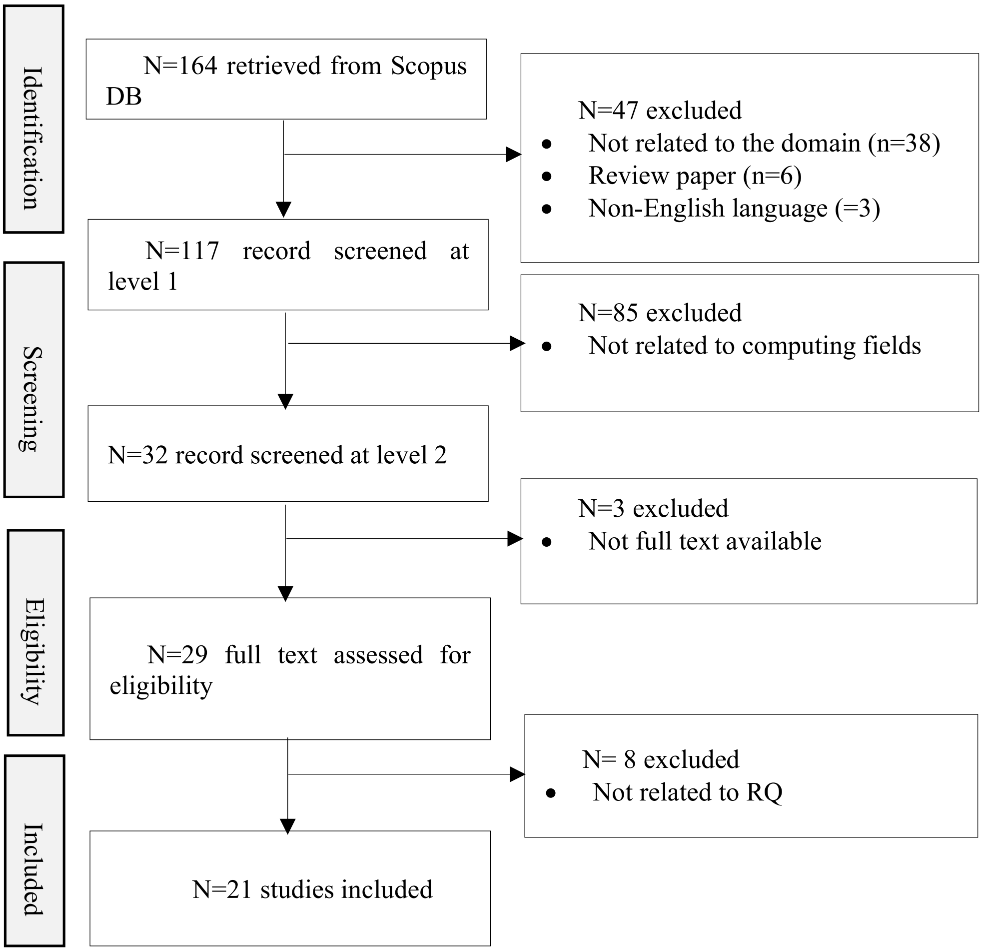

Figure 1: Study Selection Process

After the final screening process, 29 articles were identified as potentially relevant and were subjected to full-text review. However, after a thorough analysis, only 21 primary studies were included (Table 1) , as 8 papers that were not related to the research question were excluded.

2.5. Data extraction

We extracted data on several study characteristics from the included studies, including the authors, year of study, the objective of the study, identified barriers to the accessibility of the platform, and technique or tools implemented to overcome these obstacles.

Table 1:
Selected primary studies

Studies	Title	Aim	Year
[31]	Redesigning Cyber Security Labs with Immediate Feedback	To update and improve the hands-on and virtual lab environment for the Intrusion Detection Technologies course.	2022
[32]	Let's solve it: Designing an interactive online forensic science lab	To develop an online laboratory course in forensic science that is accessible to all learners.	2021
[33]	Low-Cost Remote Laboratory for Cyber-Physical Experiments	To present an approach to establish a cyber-physical remote laboratory that enables universal access to physical experimental platforms in engineering education from any location.	2021
[34]	Cloud and WebRTC-based TC-based laboratory solution for practical work in computer science for a traditional university	To propose and implement a virtual laboratory model that enables students to conduct practical work in IT using cloud computing technology.	2020
[35]	An internet of laboratory things	To develop a remote laboratory facility for universities that assists students in acquiring practical skills essential to their future careers.	2017
[36]	Building open virtual cloud lab for advanced education in networks and security	To evaluate the features and capabilities of Apache VCL, a virtual cloud platform, and provide insights on implementation costs through performance testing.	2017
[37]	A Cloud-Based Architecture for Robotics Virtual Laboratories	To propose a three-layer architecture for virtual laboratories in robotics projects for higher education institutions.	2017
[38]	Development of a virtualized networking lab using GNS3 and VMware workstation	To develop a virtual lab that addresses hardware and accessibility constraints in physical networking labs, facilitating better teaching experiences.	2016
[39]	Enhancing a virtual security lab with a private cloud framework	To integrate OpenNebula into the Tele-Lab platform, creating a more flexible, scalable, and faster virtual laboratory environment for cybersecurity training.	2013
[40]	Initial design principles for an educational, on-line information security laboratory	To propose design principles for e-learning platforms, specifically online information security labs, through a systematic process.	2013
[41]	V-lab: A mobile, cloud-based virtual laboratory platform for hands-on networking courses	To propose and evaluate the effectiveness of V-Lab, a cloud-based virtual laboratory that offers physical flexibility and can be remotely accessed by both desktop and mobile users.	2012
[42]	A distributed virtual laboratory architecture for cybersecurity training	To provide a remote virtual lab system for hands-on IT security training, accessible to everyone, to overcome the challenge of teaching practical-based system or network security, traditionally reliant on physical computer labs at universities.	2011
[43]	A distributed virtual computer security lab	To create a distributed virtual computer security lab environment for distance students, overcoming the limitations of virtual computer labs.	2011
[44]	VTE: The Virtual Training Environment: Advanced virtual lab authoring and delivery	To present the design and function of the Virtual Training Environment (VTE) virtual lab system, which includes descriptions of both student and lab author user experiences.	2010
[45]	Security in Tele-Lab - Protecting an online virtual lab for security training	To provide a comprehensive infrastructure for a remote virtual computing lab and its secure operation for hands-on IT security training.	2009

[46]	Implementing BGP-4 protocol scenario in VNLab open networking environment	To introduce a new approach for teaching TCP/IP networking in computer network courses through an efficient open virtual networking environment based on virtualization technology.	2008
[47]	Virtual lab for wireless sensor networks	To develop Virtual Lab (VL), an experimental system that enhances education and research in wireless network technologies.	2008
[48]	Teaching experiences with a virtual network laboratory	To describe how the Open Network Laboratory (ONL), a virtual network laboratory, can achieve the objectives of a modern networking laboratory course and enhance students' understanding of fundamental networking concepts.	2007
[49]	A combined virtual and remotely accessible microprocessor laboratory	To create a remote-access microprocessor lab that offers the same features as a traditional lab, serving as a virtual alternative for distance education students.	2004
[50]	REAL: A virtual laboratory for mobile robot experiments	To provide remote access to a mobile robots infrastructure through a virtual laboratory called REAL (Remotely Accessible Laboratory).	2003
[51]	Creating a virtual network laboratory	To develop a virtual network laboratory that students can access remotely, eliminating constraints such as time, geography, and cost in networking education.	1997

2.6. Data synthesize

The aim of data synthesis is to provide a concise overview of the outcomes obtained from the primary studies, which can effectively address the research questions. Considering the research objectives and the chosen primary studies, this paper is categorized as a qualitative study, and a descriptive synthesis of the gathered data was carried out. We examined both the individual studies and the collective set of studies as a whole.

3. Result and Discussion

This section outlines the results obtained from the 21 selected primary studies. First, we provide relevant descriptive statistics of the selected studies and their characteristics. Additionally, we present the responses to the research questions based on our analysis.

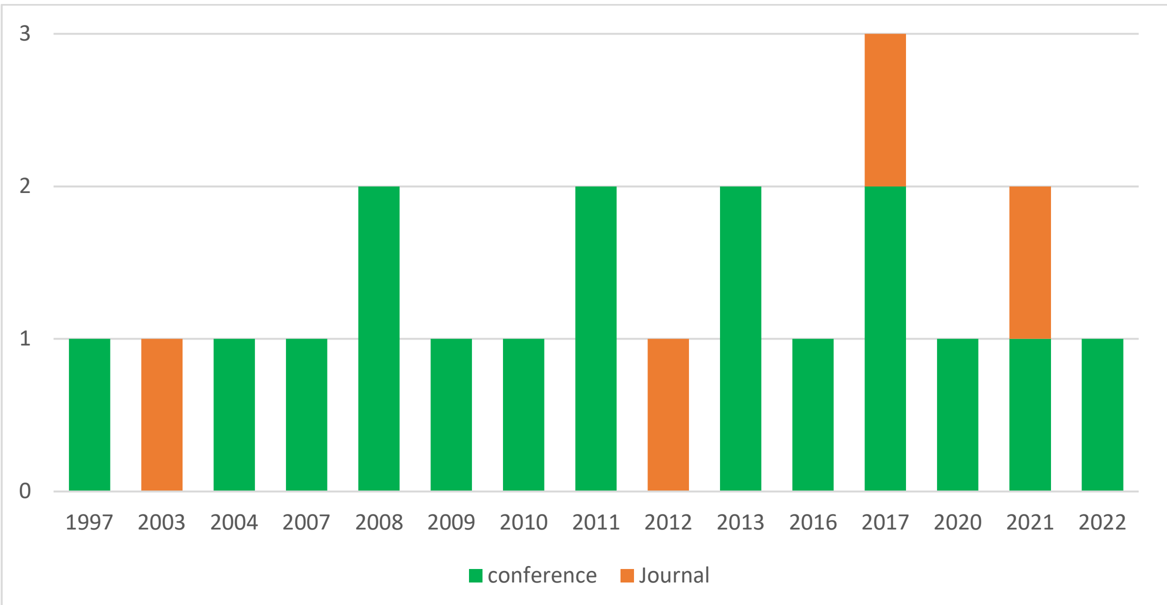

Figure 2: Year-wise distribution of included papers

3.1. Overview of selected studies

Based on our study, we obtained the included studies from various sources, including 17 conferences, and 4 journals. Our search was not restricted by year, resulting in the inclusion of papers published between 1997 and 2022. Figure 2 shows the year-wise distribution of the studies included in our analysis.

3.2. RQ: What are the barriers to accessibility in virtual laboratories in computing disciplines and how can they be overcome?

In this study, we used a qualitative approach to summarize the findings of selected primary studies. The primary studies that were analyzed identified four themes of accessibility barriers and proposed solutions for accessing VL, including technological, architectural, pedagogical, and cultural barriers (Table 2). From a technological perspective, security threats, and compatibility issues were significant barriers that made it challenging to conduct experiments in the labs (e.g., [36], [46]). Technical complexity and complicated setups also discouraged participation, especially among individuals who lacked technical expertise or access to reliable equipment. Additionally, real-time feedback and assessment posed challenges for learning due to technological issues (e.g., [31]). This issue becomes critical because students without real-time assessment and feedback may struggle to apply the theoretical concepts they have learned. Furthermore, some studies highlighted design-related issues (e.g., [32]), such as the lack of reliable design, limited customization, and failure to include design principles in the configuration. To address these issues, different solutions and strategies were proposed and implemented, such as including universal design principles (e.g., [40]), incorporating realistic simulations (e.g., [31]), and integrating different technologies and frameworks for realistic feedback and compatibility issues (e.g., [32], [37], [47]). Although advanced technological solutions are still required, these proposed solutions and strategies have the potential to mitigate the identified accessibility barriers.

Table 2:
Themes of Identified barriers

Identified Barriers	Studies
1. Technological	[31], [33], [34], [35], [36], [41], [46], [49], [51]
2. Infrustractural	[36], [37], [38], [39], [42], [44], [47], [48], [50]
3. Pedagogical	[32], [36], [37], [39], [40], [45], [46], [47]
4. Cultural	[32], [48]

More than one-third of the studies ([36], [37], [38], [39], [42], [44], [47], [48], [50]) identified limited funding for laboratory development as an infrastructural challenge. According to their findings, this limitation results in outdated and less effective VL environments that negatively impact student learning due to the unavailability of the latest technology and equipment. Additionally, the lack of high-specification servers with massive processing capabilities to host all the virtual machines (e.g., [39]) results in slow performance and response delays due to limited internet connectivity and bandwidth (e.g., [47], [48]). To address these issues, some studies (e.g., [31], [38], [39], [46]) proposed offering VL that do not require expensive hardware or infrastructure and increasing the number of physical laboratory spaces available as the best solution.

Pedagogically, a lack of well-specified pedagogical approaches and principles (e.g., [40]) was identified as a hindrance to the learning process when teaching complex concepts. Similarly, the reliance on mathematical models (e.g., [36]) and a long learning curve (e.g., [47]) were key issues found. These challenges restrict students from opportunities for exploration and experimentation and make it difficult to assess their performance. To solve the issues primary studies proposed a variety of solutions, for instance, integrating VL experiences into existing courses and curricula (e.g., [49]).

While most studies focused on three main themes, some also identified cultural barriers (e.g., [32], [48]) related to misconceptions and trust issues with laboratory platforms. To address these issues, studies proposed promoting the benefits of VL and encouraging experimentation with technology. Although these studies showed encouraging results in mitigating barriers, most were unable to evaluate the long-term effectiveness of the proposed solutions or their impact on students' overall educational experiences. Therefore, further research is needed to assess the usability features of developed tools and evaluate the long-term effectiveness of these strategies. Overall, our review highlights the importance of addressing accessibility barriers in VL to ensure that all students have access to educational opportunities.

4. Conclusion and Future work

The way in which students learn about and interact with technology has the potential to be completely transformed by VL. However, accessibility barriers make it difficult to fully utilize these services. Our paper identifies several accessibility barriers and proposed remedy to VL in four themes, including technological, infrastructural, pedagogical, and cultural themes. The study's results have significant contributions to various stakeholders, such as educators, researchers, and educational institutions. They can use these findings to develop strategies, laboratory frameworks, tools that are accessible to educators. By addressing these barriers, the VL becomes more accessible, enable all students to engage and learn from these important resources. This research has broader implications for promoting accessible learning opportunities for students, not only in computing disciplines but also in other fields. The study acknowledges that there is still work to be done to make VL fully accessible, and suggests future work to explore existing virtual platforms and their usability features to further address accessibility barriers.

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