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Utilizing "Interactive Labs" Technology Resources in Science Learning: A Literature Review

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Science education is widely recognized as crucial for equipping students with the necessary skills to navigate the complexities of the modern world. In response to the changing educational landscape, the integration of Interactive Labs technology resources has emerged as a promising strategy to enhance science learning experiences. This literature review aims to provide insights into the benefits, challenges, and emerging trends associated with the use of Interactive Labs in science education. Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology, this review systematically identified 35 relevant studies from the SCOPUS database. The findings highlight the transformative potential of Interactive Labs in promoting active learning, addressing accessibility issues, and catering to diverse learning styles and paces. Specifically, Interactive Labs have been found to improve students' understanding of complex scientific concepts, increase their engagement in the learning process, and provide personalized learning experiences tailored to individual needs. However, despite these advantages, challenges persist, including concerns about the authenticity of the learning experience, technical issues, and the need for sufficient teacher training. To advance the field of technology-enhanced science education, future research should consider expanding search criteria, utilizing mixed-methods approaches for comprehensive analysis, conducting longitudinal studies to track long-term impacts, and ensuring equal access to Interactive Labs for all students. By addressing these recommendations, stakeholders can collaborate to maximize the benefits of Interactive Labs, ultimately advancing science education to be more engaging, accessible, and effective for all students.

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INTRODUCTION

Science education is widely recognized as a crucial component in preparing students for the demands of the modern world. In today's digital age, characterized by rapid technological advancements, it is more important than ever to equip students with the skills and knowledge they need to comprehend, appreciate, and contribute to scientific progress. One promising avenue for achieving these educational objectives is the integration of Interactive Labs technology resources into science learning (Ali et al., 2022). The need for a more interactive and engaging approach to science education is evident (Abouhashem et al., 2021). Traditional lecture-style teaching, where students passively absorb information, often fails to inspire them and results in a shallow understanding of scientific concepts. Interactive Labs, which fall under the umbrella of Educational Technology, leverage technology's power to address these shortcomings (Verawati et al., 2023). They offer students hands-on, immersive experiences that foster critical thinking, problem-solving skills, and a genuine passion for science. By creating a dynamic, interactive environment, these resources have the potential to transform science education into a more stimulating and effective endeavor.

Interactive Labs encompass a wide range of digital tools, including virtual experiments, simulations, interactive software, and online platforms (Elmoazen et al., 2023). These resources can be utilized in various educational settings, from primary and secondary schools to higher education and professional development. Their adaptability makes them valuable assets for educators and learners of different age groups and levels of expertise. However, fully harnessing the potential of Interactive Labs requires a nuanced understanding of their strengths and limitations (Ali & Ullah, 2020). Consequently, conducting a literature review is crucial to navigate the complex landscape of Interactive Lab usage in science education. Such a review aims to illuminate the benefits, challenges, and emerging trends associated with this innovative approach, providing a comprehensive overview of the current state of research in the field.

Interactive Labs in Science Learning

Numerous studies have highlighted the benefits of incorporating Interactive Labs into science learning. One major advantage is that students gain a better understanding of complex scientific concepts (Toth et al., 2014). By engaging in hands-on experiences, students are more likely to grasp abstract ideas and connect theoretical knowledge with real-world applications. Additionally, Interactive Labs promote active learning, encouraging students to explore, experiment, and collaborate. This shift from passive to active learning allows students to take ownership of their education, leading to improved retention, critical thinking skills, and scientific literacy (Lestari et al., 2023).

Moreover, incorporating Interactive Labs can address the issue of accessibility in science education (Potkonjak et al., 2016). Students in underserved communities often lack access to well-equipped laboratories and materials. Virtual experiments and simulations can level the playing field, providing students from all backgrounds with the opportunity to engage with scientific phenomena. This democratization of science education aligns with the principles of equity and inclusivity, which are increasingly emphasized in educational policies worldwide.

Another advantage of Interactive Labs is their ability to adapt to individual learning styles and paces (Haleem et al., 2022). Each student is unique, and their learning journeys should reflect this diversity. Interactive Labs offer the flexibility for students to explore scientific concepts at their own pace, reinforcing their strengths and addressing their weaknesses. Furthermore, adaptive technology can provide personalized feedback and support, maximizing learning outcomes for every student (Ghergulescu et al., 2020; Lavidas et al., 2022). The engagement factor of Interactive Labs should not be underestimated, particularly in an era marked by short attention spans and information overload. Educators face the challenge of maintaining students' interest, but Interactive Labs help address this issue by infusing novelty and interactivity into the learning process (Hossain et al., 2018). By tapping into students' innate curiosity, these resources make science exciting and relevant, fostering a lifelong interest in the subject and inspiring the next generation of scientists, engineers, and innovators.

In addition to enhancing students' learning experiences, Interactive Labs also offer benefits for educators. They provide valuable data on students' progress, enabling teachers to track performance and customize instruction accordingly. Furthermore, Interactive Labs can reduce the time and resources required to set up and maintain physical laboratories, offering cost-effective solutions for institutions with limited budgets (Hossain et al., 2018). This streamlines the teaching process and facilitates efficient educational practices.

However, despite the significant benefits of Interactive Labs, several challenges need to be addressed to maximize their effectiveness. One major concern is the authenticity of the learning experience. While Interactive Labs can simulate real-world scenarios, they may not fully capture the complexity and unpredictability of actual laboratory work (Haleem et al., 2022). This can result in gaps in students' practical skills, which are essential for their scientific education. Another persistent issue is the potential for technical glitches that can disrupt the learning process and cause frustration among both students and instructors. Additionally, the successful integration of these advanced technological tools into educational settings relies on the availability of adequately trained teachers. It is crucial to provide comprehensive training programs that equip educators with the necessary skills and knowledge to effectively utilize these resources (Stahre Wästberg et al., 2019). By addressing these challenges, Interactive Labs can fully support and enhance science education, creating a robust and engaging learning environment that prepares students for the demands of the scientific community and beyond.

Previous Research

Interactive laboratories, both in physical and virtual forms, have become a focal point of educational research due to their engaging approaches to science learning. These labs offer diverse tools, data collection techniques, models, and theoretical frameworks that are crucial for a well-rounded scientific education (de Jong et al., 2013). The effectiveness of virtual laboratories in biology education has been extensively studied, with a focus on the topics covered and the resulting learning outcomes (Byukusenge et al., 2022). The integration of virtual labs into the biology curriculum is increasingly recognized as a valuable strategy for deepening students' understanding of abstract concepts and improving their practical laboratory skills, resulting in a more engaging and effective learning experience (Udin et al., 2020).

Research consistently emphasizes the important role of inquiry-centered laboratories in enhancing science education. Studies, such as those conducted by Gupta and Sharma (2017), demonstrate how these environments not only improve students' conceptual understanding and constructive learning but also enrich their perception of the nature of science. Laboratory activities are considered essential for providing meaningful and lasting learning experiences, enabling students to grasp and internalize complex scientific concepts (Harman et al., 2016). Additionally, the integration of practical laboratory work has been shown to contribute significantly to comprehensive learning outcomes, addressing cognitive, affective, and practical aspects of education (Hofstein & Mamlok-Naaman, 2007). Recent findings by Susanti et al. (2023) suggest that the strategic use of laboratories can greatly enhance the overall quality of science learning, highlighting their critical role in educational settings. The literature stresses the importance of monitoring students' opinions and perceptions of science laboratory learning to inform and guide reform efforts effectively (Nicol et al., 2022). Science educators have long recognized the substantial educational benefits that engaging students in laboratory activities can have, such as enhancing learning, promoting hands-on experience, and applying theoretical knowledge (Hofstein & Lunetta, 2004). Comprehensive reviews of the history, objectives, and research findings related to the use of the laboratory as an instructional medium have provided valuable insights. These reviews have contributed to an evolving understanding of how laboratories contribute to the educational process and have informed effective science education strategies for educators and policymakers (Hofstein, 2004).

Research on interactive laboratories in science learning has increasingly focused on the benefits of incorporating virtual laboratories alongside traditional physical labs. The Physics Education Technology (PhET) Project offers interactive computer simulations that have proven valuable for teaching various scientific disciplines (Scalise et al., 2011). These simulations provide students with dynamic and interactive experiences, allowing them to engage with scientific concepts effectively. Studies have shown that virtual laboratories, such as those offered by the PhET Project, can significantly enhance students' learning outcomes in terms of conceptual knowledge, procedural skills, self-efficacy, and overall perceptions of science (Susanti et al., 2023).The integration of virtual laboratories in science education is increasingly recognized as an effective way to enhance practical scientific skills, problem-solving abilities, and scientific habits of mind among students (Gunawan et al., 2018). These labs not only support the development of essential scientific skills but also play a crucial role in boosting motivation, interest, and positive attitudes towards science learning (Sypsas et al., 2020).

Virtual labs provide a dynamic platform where students can conduct experiments, gather data, and develop new understandings within a controlled virtual environment, offering a unique and engaging opportunity for exploration and learning. This immersive experience allows students to experiment in ways that may not be possible in traditional labs due to cost, safety, or resource constraints, opening up new possibilities for inquiry and discovery in scientific education. In addition to virtual labs, physical laboratories remain essential in science education, allowing students to directly engage with materials and equipment. The Science Laboratory Environment Inventory (SLEI) and Questionnaire on Teacher Interaction (QTI) have been instrumental in assessing students' perceptions of their learning environments and interactions with teachers in laboratory settings (Gupta & Sharma, 2017). These assessments help understand the impact of the laboratory environment on students' attitudes and academic performance.

Overall, the literature highlights the critical role of interactive laboratories in science education, particularly in deepening comprehension of scientific concepts, improving practical skills, and cultivating positive attitudes towards science. Combining virtual laboratories with traditional lab settings offers a holistic approach to science education that accommodates diverse learning styles and preferences. However, utilizing interactive laboratories effectively requires a nuanced understanding of their advantages and limitations, as pointed out by Ali and Ullah (2020).

Research Gap

The field of science education is constantly evolving due to technological advancements, changes in educational policies, and the evolving needs of students and society. Interactive Labs have emerged as a dynamic force in this transformation, offering a promising avenue for a more engaging, accessible, and effective science education. Previous research on Interactive Labs in science education has predominantly highlighted their potential to enhance learning outcomes and student engagement. These studies often emphasize the benefits of these technologies, such as improved understanding of complex scientific concepts, increased student interest, and the ability to personalize learning experiences. However, there is a noticeable gap in the existing literature concerning the challenges, obstacles, and limitations associated with the implementation and effective use of Interactive Labs. While the advantages are well-documented, less attention has been given to the practical difficulties faced by educators and institutions, including the technical reliability of these tools, the need for extensive educator training, and the integration of these technologies into existing curricula.

This research gap presents a critical opportunity for the present study to contribute significantly to the field by conducting a systematic literature review focused on identifying and analyzing these underexplored areas. By synthesizing studies that also address the limitations and challenges of Interactive Labs, the review aims to provide a more balanced and comprehensive understanding of the current state of their usage in science education. This approach not only enriches the academic discussion by addressing the identified gaps but also assists educational stakeholders—ranging from policymakers to practitioners—in making informed decisions regarding the adoption and optimization of these technologies.

Study Objectives

The purpose of this study is to examine the use of "Interactive Labs" in science education. This literature review builds upon previous research and specifically looks at how Interactive Labs are integrated and their impact in different educational settings, ranging from primary schools to higher education. The analysis focuses on identifying and summarizing the main advantages and challenges associated with the use of these tools in creating a more engaging and effective learning environment. By reviewing the current research in this field and offering a detailed perspective on the benefits and challenges of Interactive Labs, this study aims to contribute to the ongoing discussion about the future of science education.

METHODS

A comprehensive investigation was conducted to review the literature on "Interactive Labs in Science Learning." The literature review utilized the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)" methodology, recommended by Page et al. (2021). This method was chosen for its numerous advantages, particularly its ability to synthesize relevant findings related to the focus of the current study and identify areas for future research. Additionally, it serves as a valuable tool for identifying shortcomings in previous research efforts and guiding improvements in future studies. The PRISMA methodology typically involves four stages: identification, screening, eligibility, and inclusion (Moher, 2009; Tülübaş et al., 2023). For this study, the PRISMA approach utilized the keyword "Interactive Labs in Science Learning," as shown in Figure 1. PRISMA relies on SCOPUS as its primary database source. SCOPUS is widely recognized for providing precise and reliable indexation data. It offers comprehensive tools and features that allow users to explore article quality based on various criteria such as author, title, publication year, publisher, citations, and other important metrics.

On April 1, 2024, we conducted data analysis using the SCOPUS database. We used the keywords "interactive labs in science learning" in the TITLE-ABS-KEY field and identified a total of 368 documents of all types. We then screened these documents to ensure they were closely related to our research theme. In the first round of screening, we considered documents published from 2013 to 2023, resulting in 230 documents. We further screened these documents based on type, selecting 204 journal articles and conference papers. From these, we refined our selection to 100 documents that were relevant to the field of social science. Finally, we manually selected 35 documents based on their relevance to science learning areas such as physics, chemistry, and biology for inclusion in our study review.

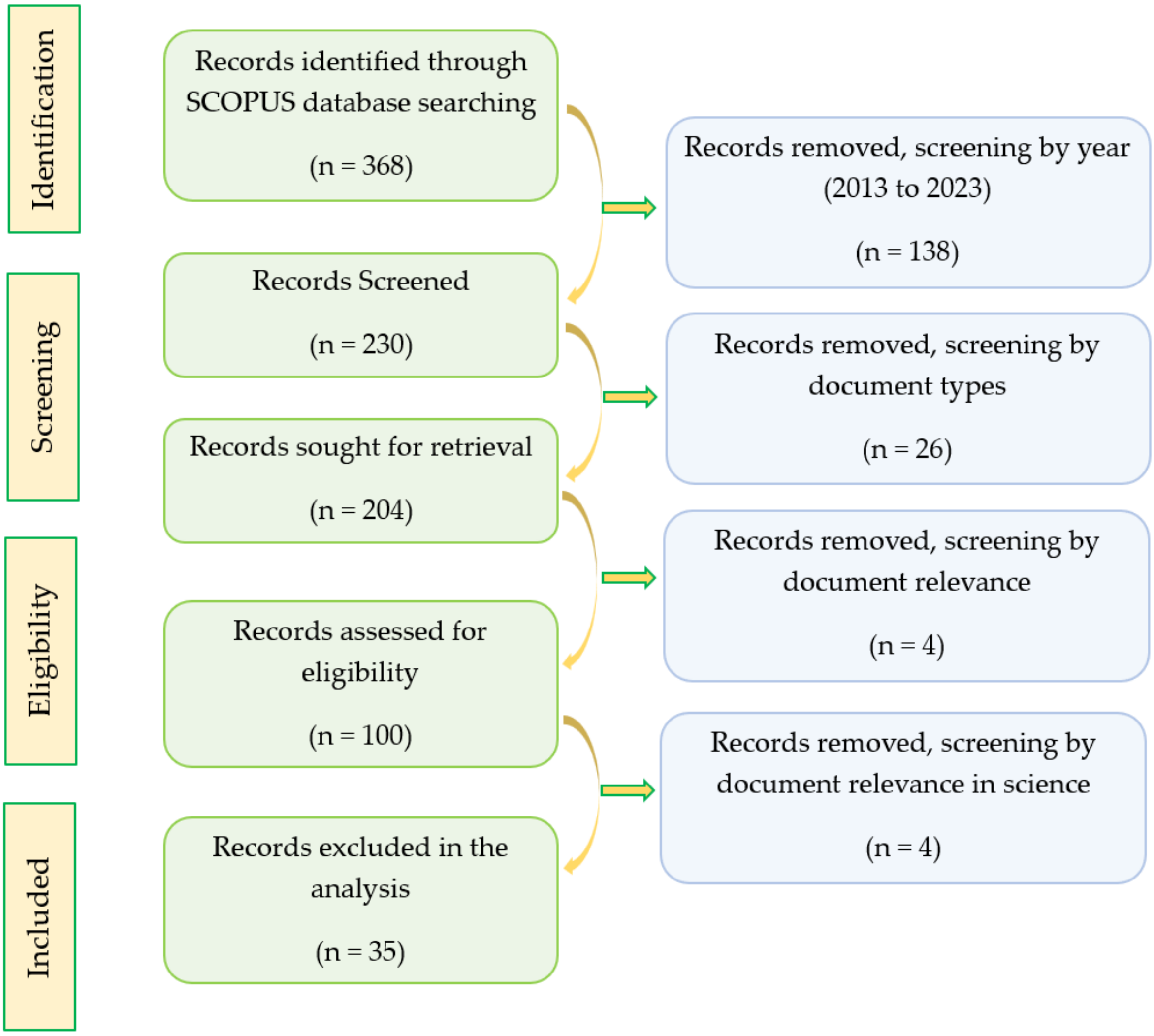
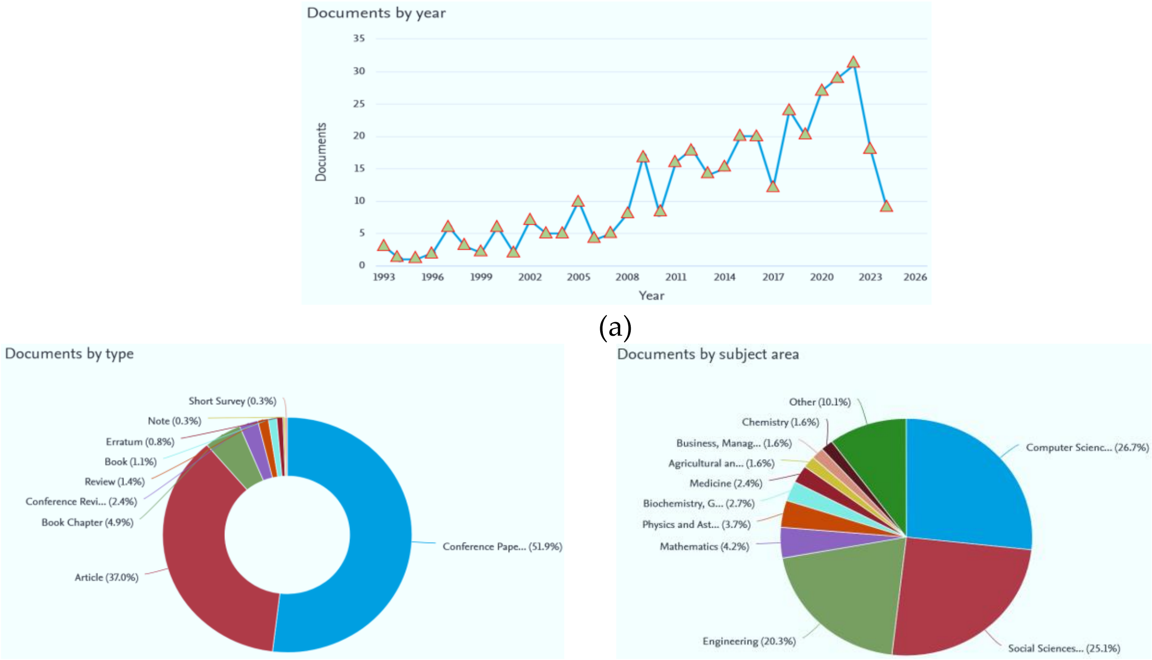


Figure 1. The PRISMA approach is employed to examine literature reviews concerning the subject of "Interactive Labs in Science Learning."

Using the PRISMA method, we conducted bibliometric analysis, following systematic documentation practices. Each document was carefully analyzed and recorded. We compiled the findings into (.ris)/(.csv) files for organized record-keeping and took screenshots from the SCOPUS database to visually represent the data. This comprehensive literature review provides valuable insights and establishes a solid foundation for exploring the theme of "Interactive Labs in Science Learning." By comparing our findings with other relevant literature, we enhance the robustness of our research and gain a compelling starting point to understand the contribution of Interactive Labs to science education.

RESULTS AND DISCUSSION

The results of retrieving documents from the SCOPUS database using the search term "Interactive Labs in Science Learning" [TITLE-ABS-KEY (interactive AND labs AND in AND science AND learning)] are shown in Figure 2. It is important to mention that no restrictions were applied to the selection criteria for these documents, such as publication year, subject domain, document format, publication status, source title, keywords, source category, and other relevant factors.

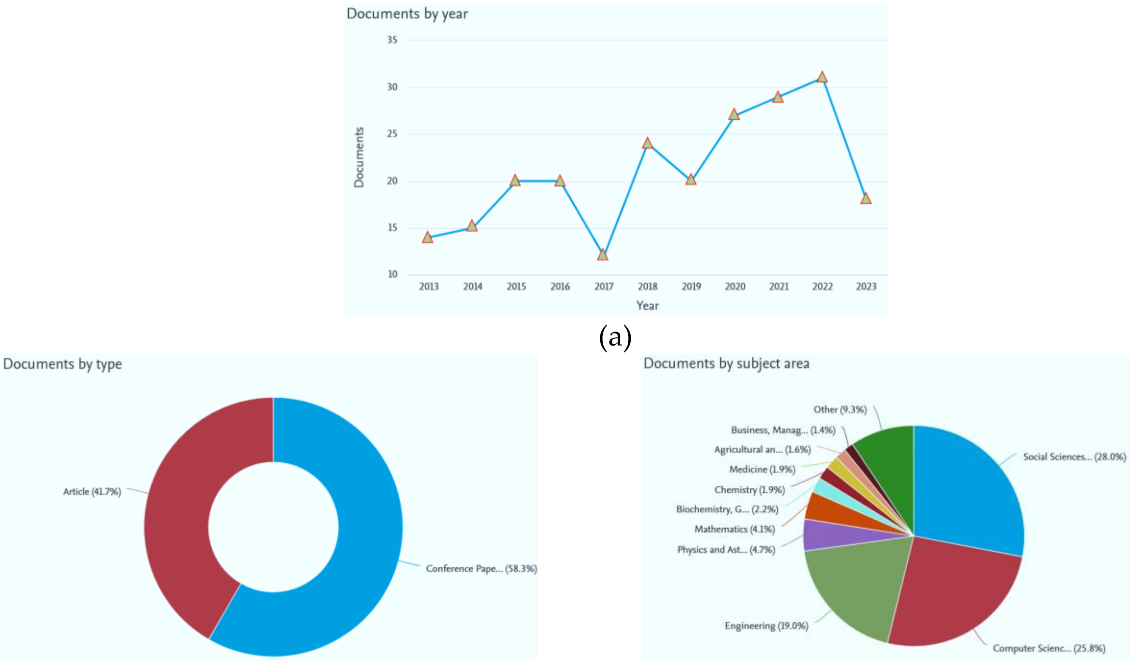


(a)

(b) (c)

Figure 2. Document identification results based on (a) all year, (b) all type, and (c) all subject area.

The data shown in Figure 2 reveals that a total of 368 documents were found through keyword-based searches from 1993 to 2024. These documents can be categorized into different types, with articles making up 37%, conference papers comprising 51.9%, book chapters accounting for 4.9%, conference reviews making up 2.4%, and miscellaneous categories such as reviews, books, erratum, notes, and short survey. In terms of subject areas, the identified documents cover a wide range of disciplines, with 25.1% in social science, 26.7% in computer science, 20.3% in engineering, 4.2% in mathematics, and the rest from various other fields.



(a)

(b) (c)

Figure 3. Document screening results based on: (a) last 10 years (2013-2023), (b) type (article and conference paper), and (c) all subject areas.

Following that, a screening protocol is implemented, which establishes criteria based on the publication year and type of the documents. This step ensures that the materials used for scrutiny or as reference sources in this investigation are from recent research within the past decade. Furthermore, in line with the study's objectives, the eligible document types primarily include journal articles and conference papers that closely relate to the central theme of the study. Figure 3 visually represents the distribution of documents, taking into account the restrictions on publication year and document type.

The initial screening focused on documents published between 2013 and 2023 and resulted in 230 findings. A second screening was then conducted to identify document types, yielding 204 documents, including articles (41.7%) and conference papers (58.3%). Subsequently, a further review was carried out to ensure the relevance of these 204 documents to the study's theme. From this review, 100 documents were selected, comprising both journal articles and conference papers, specifically related to various fields of science.

The final phase involved a manual selection process based on keywords within the domains of science learning, specifically physics, chemistry, and biology. After a thorough review, 35 documents were chosen as the materials for this study, marking the completion of the document selection process following the PRISMA method. Table 1 provides details of the articles that form the source material for this review.

Table 1. Documents from the selection of articles used as review material

No	Author(s)	Title	Study highlights
1	(Aleman et al., 2023)	Immersive, interactive virtual learning environments increase accessibility in soil science.	This study presents the efficacy of immersive virtual learning environments (VLEs) in soil science education, specifically in improving accessibility. VLEs provide a cost-effective and replicable alternative to conventional field labs by enabling students to explore virtual field settings regardless of time or physical limitations. The study highlights a soil science-based VLE set in the Laramie Range Mountains, which demonstrates comparable learning outcomes to traditional field trips, but with heightened student engagement and comprehension. As online learning continues to evolve, this technology holds great promise in delivering high-quality and accessible content in natural science education.
2	(Sánchez-Zurano et al., 2023)	Virtual labs for the study of enzymatic stirred tank bioreactors.	This study describes the creation of a virtual laboratory on the Easy JavaScript Simulation platform. The focus is on simulating the behavior of an enzymatic stirred-tank bioreactor

No	Author(s)	Title	Study highlights
			using a dynamic model. The simulation is able to replicate the continuous operation of the bioreactor, even under nonideal flow conditions. It includes interactive features that allow students to customize parameters and engage in practical learning, which is especially beneficial during the COVID-19 pandemic.
3	(Asudhani et al., 2023)	Aug-Labs: Redefining Scientific Education with Smartphone-Integrated Augmented Laboratories.	The paper presents Aug-Labs, a cutting-edge augmented reality (AR) platform that seamlessly integrates with smartphones to revolutionize science education. Aug-Labs provides an immersive learning experience by offering virtual experiments accompanied by digital markers and 3D models. By analyzing student feedback, we have found that Aug-Labs not only enhances comprehension but also increases enjoyment when compared to traditional laboratory settings. This study demonstrates the potential of AR in improving educational outcomes.
4	(Uysalel et al., 2023)	Developing Virtual Laboratory Modules for Broadening Experiential Learning in Engineering Education.	In this ongoing project, engineering educators are using virtual laboratory modules to enhance students' learning experiences by connecting theoretical concepts with practical applications. The modules include different characterization and testing methods such as Rockwell hardness measurement and fatigue cycle analysis, and they have a Python-based interface for user interaction. By conducting simulated hands-on experiments, students can investigate material properties, mechanical behavior, and design considerations. This approach supplements traditional laboratory practices, while also being cost-effective and accessible.

No	Author(s)	Title	Study highlights
5	(Brown et al., 2023)	Teaching roles and communication strategies in interactive web broadcasts for practical lab and field work at a distance.	This study investigates teaching roles and communication strategies in interactive web broadcasts for distance practical lab and field work. By analyzing transcripts and chat logs from 14 sessions across five undergraduate modules, the study reveals that affective communication is dominant, promoting student engagement and satisfaction. This has significant implications for institutions, both distance and campus-based, that prioritize practical science and technology education.
6	(Bose & Humphreys, 2022)	The 5I's of Virtual Technologies in Laboratory Teaching for Faculties of Higher Education in Kerala.	This study evaluates the effectiveness of virtual technologies in training faculty members for laboratory teaching in higher education institutions in Kerala. It introduces the 5I framework (innovative, interactive, involvement, informative, and influential) to measure effectiveness and identifies substantial improvements in understanding, execution time, and accuracy among individuals trained virtually, as compared to the control group. These findings suggest a positive transfer of skills from virtual training to real laboratory settings.
7	(Senapati, 2022)	Peeking into the Sophisticated World of Interactive Science Simulations.	The study examines the growing field of virtual science labs, specifically in relation to the COVID-19 pandemic, with a specific focus on how India has embraced remote learning. It presents three emerging platforms—Beyond Labz, Labster, and Praxilabs—describing their features, experimental functionalities, and the advantages and disadvantages they bring to undergraduate science education.
8	(Lee et al., 2022)	Open-Source Virtual Labs with Failure-Mode-Inspired	This study investigates the efficacy of open-source virtual labs that incorporate physics and optics

No	Author(s)	Title	Study highlights
		Physics and Optics Experiments.	experiments based on failure modes. The primary objective is to improve students' engagement and comprehension of theoretical concepts by providing interactive simulations. These simulations serve as a valuable substitute for conventional lab settings, particularly in situations where remote learning is necessary. Extensive research has consistently shown the educational advantages of virtual labs, as they enhance students' ability to make predictions and grasp concepts, surpassing the outcomes achieved through traditional methods.
9	(Francis et al., 2022)	The virtual flow cytometer: A new learning experience and environment for undergraduate teaching.	The study presents a new interactive simulation, called the virtual flow cytometer, that aims to improve undergraduate teaching in biosciences. This simulation allows students to participate in experimental design and data interpretation, which offers a more realistic evaluation compared to traditional methods. Although the simulation was generally well-received, there were technical difficulties during the initial implementation. This highlights the importance of providing additional hands-on experiences in conjunction with simulations to ensure comprehensive skill development.
10	(Schuman et al., 2022)	Ocean Data Visualization on a Touchtable Demonstrates Group Content Learning, Science Practices Use, and Potential Embodied Cognition.	This study examines how ocean data visualization on touch-based technology can enhance group learning and engagement in scientific practice. By conducting a think-aloud procedure with adult-child groups, the research reveals evidence of meaningful learning, including discussions about scientific concepts, pattern recognition, and idea refinement. The findings indicate

No	Author(s)	Title	Study highlights
			that interactive visualizations of this kind can promote embodied cognition and facilitate a deeper understanding of complex systems, such as Earth's oceans. These findings have important implications for educational design.
11	(Hughes et al., 2022)	Teaching Quantum Computing to High School Students.	This study presents a groundbreaking quantum computing course specifically designed for high school students aged 15-18. The course's objective is to simplify intricate concepts through interactive problem sets and simulation-based labs. By bridging the divide between popular science and advanced textbooks, it offers accessible education and is made available under a Creative Commons license.
12	(Chan et al., 2022)	DIVE: Make Online Learning Diversified, Interactive, Versatile, and Engaging.	The study introduces DIVE, a comprehensive solution for online learning in computer science during the pandemic. DIVE provides a versatile virtual environment featuring interactive tools such as notebooks, Docker, and Git. This enables students to recreate setups, collaborate on projects, and receive prompt feedback and guidance from instructors.
13	(Loddo & Kanawati, 2022)	Mariotel: A web-based virtual remote computer science lab.	The paper presents Mariotel, a web-based virtual remote computer science lab that was developed during the Covid-19 pandemic. Its main focus is on simplicity, allowing users to easily access it through web browsers. Mariotel has been widely adopted, with 42 teachers conducting a total of 9989 lab sessions at USPN since 2020, with an average duration of three hours each.
14	(Paxinou et al., 2022)	A Distance Learning VR Technology Tool for Science Labs.	This study presents a novel solution to the problem of distance teaching in laboratory courses, which have traditionally required physical

No	Author(s)	Title	Study highlights
			presence. By utilizing desktop immersive virtual reality (VR) technology, specifically through the use of a photonic microscope, it offers an innovative approach. The accompanying analytics platform allows instructors to analyze students' interactions, providing valuable insights for improving instructional methods. This VR tool not only increases engagement in laboratory courses, but also provides flexibility for different classroom settings, whether during a pandemic or in normal circumstances.
15	(Sung et al., 2021)	Enhancing distance learning of science—Impacts of remote labs 2.0 on students' behavioural and cognitive engagement.	This study aims to assess the effectiveness of a decentralized remote lab called Telelab in improving students' cognitive and behavioral engagement in online science education. A mixed-methods approach was used to analyze the engagement levels of high school students participating in virtual chemistry classes. Clickstream logs and timestamps were used to measure engagement. The findings suggest a positive correlation between engagement and conceptual learning, highlighting the value of Telelab in facilitating real-time interactions between students and instructors. The study also utilized behavioral engagement patterns to inform timely instruction, indicating the potential of Telelab to transform remote inquiry-based learning.
16	(Roman et al., 2021)	Socrative, a powerful digital tool for enriching the teaching–learning process and promoting interactive learning in Chemistry and Chemical Engineering studies.	The study examines the effectiveness of mobile learning in Science and Engineering Higher Education, specifically in a Polymer Technology course. By using the "Socrative" platform for formative assessment through quizzes, the findings demonstrate a substantial positive influence on students' grades and

No	Author(s)	Title	Study highlights
			engagement. Additionally, there is an observed increase in motivation and a more enjoyable learning atmosphere.
17	(Mamani et al., 2021)	A systematic mapping about simulators and remote laboratories using hardware in the loop and robotic: Developing STEM/STEAM skills in pre-university education.	This systematic mapping study aims to examine the effects of simulators, remote laboratories, and robotics on the development of STEM/STEAM skills in pre-university education. Specifically, it focuses on how these technologies have addressed the challenges brought about by the COVID-19 pandemic. By analyzing data from prominent electronic databases such as ACM, IEEE, Scopus, and Web of Science, this study identifies significant trends, popular tools, and emerging concerns in educational technology from its inception up until 2020. The findings of this study provide valuable insights into the future directions of this field.
18	(Thompson, 2021)	Work-in-progress-LIVE: Model for learning in interactive and immersive virtual environments.	This study presents Work-in-progress-LIVE, an innovative model that combines immersive environments and intelligent tutoring to enhance learning. Developed based on affordance principles and informed by embodied interaction ideals, this model provides adaptive pedagogical methods and social support for tutor-to-student and peer-to-peer instruction in inquiry-based activities, such as science labs.
19	(Seibert et al., 2021)	Multitouch experiment instructions to promote self-regulation in inquiry-based learning in school laboratories.	The study examines the effectiveness of Multitouch Experiment Instructions (MEIs) in facilitating self-regulated learning in inquiry-based laboratory settings. MEIs are interactive eBooks that provide digital tools for personalized learning. Specifically, the experiment investigated the impact of MEIs on self-regulation in "Analysis of Cola"

No	Author(s)	Title	Study highlights
			experiments, comparing the outcomes of two groups: one using MEIs alone (control group) and another receiving integrated self-regulation training along with MEIs (experimental group). The results revealed a significant increase in self-regulation in both groups, suggesting that MEIs have the potential to promote self-regulated learning to a similar extent as explicit self-regulation training.
20	(Alvarez, 2021)	Using virtual simulations in online laboratory instruction and active learning exercises as a response to instructional challenges during COVID-19.	Amidst the challenges posed by the COVID-19 pandemic, instructors have been searching for alternatives to traditional wet lab experiments. This study investigates the use of virtual simulations in online laboratory instruction and active learning exercises. Platforms such as Labster, McGraw Hill Connect Virtual Labs, and others provide affordable and secure solutions. These platforms are aligned with specific student learning outcomes in biology courses, such as microbiology, genetics, and cell biology. By incorporating virtual simulations, educators can ensure the continuity of education during these unprecedented times.
21	(Broyer et al., 2021)	Using Virtual Reality to Demonstrate Glove Hygiene in Introductory Chemistry Laboratories.	Recent advancements in immersive technology, such as virtual reality (VR), augmented reality (AR), and extended reality (XR), have revolutionized educational methods, specifically in the field of chemistry education. Although virtual lab simulations are widely available, there is a noticeable lack of products that address chemical transfer and glove hygiene. This study aims to investigate the integration of VR technology for teaching proper glove hygiene, with a focus on promoting collaboration between different

No	Author(s)	Title	Study highlights
			disciplines and improving safety education, particularly in environments where access to physical laboratories is limited. Despite some initial obstacles, this project highlights the promising potential of VR in instructing laboratory safety.
22	(Oveissi & Ebrahimi Ghadi, 2022)	Preparing Chemical Engineers for Industry 4.0: An Interactive Education Approach.	This study focuses on the need to provide future chemical engineers with the necessary skills for Industry 4.0. It aims to achieve this by offering a master-level course that integrates digital technologies like digital twins and deep learning. The course incorporates practical exercises, such as constructing predictive control systems and applying deep learning to chemical processes. These activities promote the development of problem-solving abilities and industry-specific skills that are crucial in the ever-changing field of chemical engineering.
23	(Iordache, 2021)	Educational value of a virtual reality laboratory – focus group with students.	The study examines the educational effectiveness of virtual reality (VR) laboratories, with a specific focus on student feedback. VR applications provide innovative three-dimensional visualization that improves understanding of abstract concepts. The results demonstrate that VR labs, such as HoloLAB Champions, enhance the learning experience in chemistry, promoting the development of crucial skills and motivation, despite any limitations in technical aspects and interaction.
24	(Kadir et al., 2021)	The Effectiveness of a STEM-Based Physics Interactive Laboratory (I-LAB) Module for Form Four Physics Students.	The study assesses the effectiveness of a STEM-based Physics Interactive Laboratory (I-LAB) Module for Form Four physics students. The module incorporates STEM elements, Problem Based Learning (PBL), and feedback mechanisms. By comparing traditional lab settings with I-LAB

No	Author(s)	Title	Study highlights
			variants, the results show a substantial improvement in student achievement. This suggests that the I-LAB Module is a suitable tool for enhancing Physics education.
25	(Wan et al., 2020)	Characterizing science graduate teaching assistants' instructional practices in reformed laboratories and tutorials.	This study examines the instructional practices of graduate teaching assistants (GTAs) in reformed laboratories and tutorials at a research-intensive university in the southeastern USA. The study focuses on 11 chemistry GTAs and 11 physics GTAs and identifies three instructional styles within each group. The results show a correlation between interactive GTA styles and student engagement, suggesting potential advantages of reformed instructional environments. Therefore, it is essential to prioritize effective GTA professional development to enhance student learning experiences in these settings.
26	(Mrani et al., 2020)	Effects of the integration of PhET simulations in the teaching and learning of the physical sciences of common core.	This study aims to examine the effects of integrating PhET simulations, particularly the "Buoyancy" simulation, in the teaching of common core physical sciences. The research was conducted within the Moroccan educational system and seeks to compare the effectiveness of these simulations with traditional hands-on experiences. The results highlight that PhET simulations greatly enhance comprehension and learning outcomes, showing similar efficacy to real experiments. Additionally, they also contribute to increased motivation, engagement, and interaction among learners.
27	(Hamed & Aljanazrah, 2020)	The Effectiveness of Using Virtual Experiments on Students' Learning in the General Physics Lab.	This study investigates the effectiveness of virtual experiments in the general physics lab. The objective is to enhance students'

No	Author(s)	Title	Study highlights
			learning and practical skills while understanding their perspectives on virtual lab usage. The results indicate that substituting face-to-face lab preparation with virtual experiments is equally, if not more, effective in deepening students' understanding of physics concepts and preparing them for real experiments. These findings support the integration of virtual experiments into physics education, especially in challenging times such as the COVID-19 pandemic. This integration provides flexible learning solutions and potential cost savings for universities and students. Recommendations include incorporating interactive multimedia into virtual experiments and further research into expanding virtual lab applications in physics and science education.
28	(Correia et al., 2019)	The application of PhET simulation to teach gas behavior on the submicroscopic level: secondary school students' perceptions.	The study used a Computer-Assisted Scaffolding system that integrated PhET simulation to teach secondary school students about gas behavior at the submicroscopic level. The results indicate that this approach had a positive impact on students' understanding, especially when it came to manipulating variables, using visualization aids, and understanding system design. These findings show promise for improving chemistry education.
29	(Pedersen et al., 2016)	Virtual learning environment for interactive engagement with advanced quantum mechanics.	This study presents "StudentResearcher," a virtual learning environment created to enhance engagement with advanced quantum mechanics. Drawing on insights gained from Quantum Moves workshops, it incorporates simulations, quizzes, video lectures, and gamification. During a trial conducted at Aarhus University, participants who actively used the

No	Author(s)	Title	Study highlights
			platform showed improved learning outcomes, regardless of their initial performance levels.
30	(Potkonjak et al., 2016)	Virtual laboratories for education in science, technology, and engineering: A review.	This review examines the development of virtual laboratories in science, technology, and engineering education. Although there are challenges in providing hands-on experiences online, advancements in technologies such as computer graphics and augmented reality show promise in addressing these issues. The focus of this review is on robotics, emphasizing its multidisciplinary nature and its potential to enhance learning in different engineering disciplines.
31	(Gryczka et al., 2016)	Interactive online physics labs increase high school students' interest.	The integration of a web-based circuit application in high school physics classrooms, supported by college mentors and teachers, greatly enhances students' understanding of and interest in circuits. This interactive module not only boosts learning but also offers valuable teaching opportunities for mentors and extra support for teachers, creating a collaborative and enriched learning environment.
32	(Diwakar et al., 2015)	Role of ICT-enabled virtual laboratories in biotechnology education: Case studies on blended and remote learning.	The study examines the effectiveness of ICT-enabled virtual laboratories in biotechnology education, with a specific focus on India. Virtual labs incorporate various features like animations, simulations, and remote-triggered experiments, providing an interactive environment for active learning. Feedback from students and teachers suggests that using virtual labs has led to better academic performance compared to traditional methods. This emphasizes the versatility and user-friendly nature of these virtual resources, making them valuable for the future of

No	Author(s)	Title	Study highlights
			education, especially in remote and blended learning contexts. Additionally, virtual labs help overcome challenges such as limited access to equipment and economic constraints in traditional classrooms.
33	(Chiu et al., 2015)	The effects of augmented virtual science laboratories on middle school students' understanding of gas properties.	This study examines how the use of augmented virtual science laboratories affects the understanding of gas properties among middle school students. Through the use of the Frame, a sensor-augmented virtual lab that integrates physical and virtual experiences, students were able to explore and explain gas behavior at the molecular level. The findings indicate notable improvement in students' grasp of fundamental concepts related to gases, providing valuable insights for enhancing science education in accordance with the Next Generation Science Standards (NGSS).
34	(Moore et al., 2014)	PhET interactive simulations: Transformative tools for teaching chemistry.	PhET interactive simulations provide valuable support for teaching chemistry by enhancing understanding of symbolic, macroscopic, and particulate representations. Created by the University of Colorado Boulder, these simulations offer dynamic access to various representations, promote inquiry-based learning, and captivate students and educators alike. With a wide range of over 30 simulations available online, including Molecule Polarity and Beer's Law Lab, PhET simulations are suitable for different teaching approaches and environments, bringing interactivity, accessibility, and enjoyment to the learning of chemistry.
35	(Osman & Lee, 2014)	Impact of Interactive Multimedia Module with	The study investigates the effectiveness of an Interactive

No	Author(s)	Title	Study highlights
		Pedagogical Agents on Students' Understanding and Motivation in the Learning of Electrochemistry.	Multimedia Module with Pedagogical Agents (IMMPA) known as the Electrochemistry Lab (EC Lab) in enhancing students' understanding and motivation in learning Electrochemistry. Through a non-equivalent pretest-posttest control group design involving 127 Form Four students from two secondary schools in Malaysia, the research demonstrates significant improvements in students' grasp of Electrochemistry concepts when they were exposed to the IMMPA EC Lab, as opposed to the control groups.

Interactive labs, which use advanced technology, have become powerful tools for enhancing science learning experiences. This is evident in the variety of studies listed in Table 1. This review aims to provide a comprehensive overview of the literature on the effectiveness of interactive labs in different scientific disciplines. It offers unique insights into how these labs impact student engagement, comprehension, and practical skills development. For example, Aleman et al. (2023) and Sánchez-Zurano et al. (2023) demonstrate the effectiveness of immersive virtual learning environments (VLEs) in soil science education and enzymatic bioreactors. These studies show how simulated field settings and dynamic models can enhance engagement and understanding. Asudhani et al. (2023) introduce Aug-Labs, a smartphone-integrated augmented reality (AR) platform that revolutionizes science education. It offers immersive learning experiences with virtual experiments and 3D models. Uysalel et al. (2023) focus on engineering education and showcase the development of virtual laboratory modules. These modules bridge theoretical concepts with practical applications, making them accessible and complementing traditional laboratory practices.

Another study by Brown et al. (2023) explores teaching roles and communication strategies in interactive web broadcasts. It highlights the importance of these strategies in supporting student engagement and satisfaction. Bose and Humphreys (2022) assess the efficacy of virtual technologies in training faculty for laboratory teaching. They find significant improvements in understanding and execution. Senapati (2022) delves into the emerging field of virtual science labs and highlights platforms like Beyond Labz and Labster. Lee et al. (2022) examine open-source virtual labs that feature physics and optics experiments. These labs offer an interesting alternative to traditional lab settings. Finally, Francis et al. (2022) introduce the virtual flow cytometer, an interactive simulation designed to enhance undergraduate teaching in biosciences. It promotes embodied cognition and deeper understanding of complex systems, such as Earth's oceans. Frequently, utilities are discussed in the past tense. Hughes et al. (2022) introduced a quantum computing course specifically for high school students. The course aimed to demystify complex concepts through interactive problem sets and simulation-based labs. Chan et al. (2022), on the other hand, presented DIVE, a virtual environment that offers interactive tools like notebooks and Git.

Paxinou et al. (2022) introduced a groundbreaking solution to distance teaching in laboratory courses. They leveraged desktop immersive virtual reality (VR) technology to enhance engagement and flexibility. Moving on, Alvarez (2021) explored the integration of virtual simulations into online laboratory instruction, ensuring educational continuity during the COVID-19 pandemic. Broyer et al. (2021) utilized virtual reality (VR) to demonstrate proper glove hygiene in chemistry laboratories. Their focus was on safety education and collaboration across disciplines. Iordache (2021) examined the educational efficacy of virtual reality (VR) laboratories, highlighting their contribution to the comprehension of abstract knowledge.

Kadir et al. (2021) evaluated the effectiveness of a STEM-based Physics Interactive Laboratory (I-LAB) Module for enhancing Physics education. They emphasized the development of practical skills. Moving on, Wan et al. (2020) investigated the instructional practices of science graduate teaching assistants in reformed laboratories and tutorials. They found correlations between interactive teaching styles and student engagement.

Mrani et al. (2020) explored the impact of integrating PhET simulations in teaching common core physical sciences. Their findings indicated improvements in understanding, motivation, and engagement. Hamed and Aljanazrah (2020) examined the effectiveness of virtual experiments in the general physics lab. They demonstrated how virtual experiments deepened students' understanding of physics concepts.

Correia et al. (2019) used PhET simulations to teach gas behavior at the submicroscopic level to secondary school students. Their approach positively impacted students' understanding. Pedersen et al. (2016) introduced "StudentResearcher," a virtual learning environment designed to enhance engagement with advanced quantum mechanics. Active platform users experienced increased learning outcomes. Lastly, Potkonjak et al. (2016) reviewed the evolution of virtual laboratories in science, technology, and engineering education. They highlighted advancements in technologies such as computer graphics and augmented reality. Frequently, studies have indicated the effectiveness of interactive online physics labs in increasing high school students' interest and conceptual grasp in circuits (Gryczka et al., 2016). Diwakar et al. (2015) found that ICT-enabled virtual laboratories in biotechnology education can improve academic performance compared to traditional methods. Chiu et al. (2015) discovered that augmented virtual science laboratories can significantly enhance middle school students' comprehension of gas properties. Additionally, Moore et al. (2014) emphasize the transformative role of PhET interactive simulations in teaching chemistry by fostering fluency across multiple representations.

Osman and Lee (2014) advocate for integrating virtual experiments into physics education, based on their examination of the impact of virtual experiments on students' learning in general physics labs. Overall, these studies highlight the potential of interactive labs in science education, offering immersive learning experiences, increased engagement and comprehension, and addressing challenges posed by traditional instructional methods and external factors such as the COVID-19 pandemic.

Table 1 presents a comprehensive literature review that guides educators, researchers, policymakers, and those interested in the intersection of technology and science education. Each study in Table 1 offers a unique perspective on the benefits and challenges of interactive labs, contributing to a deeper understanding of their effectiveness in enhancing science learning experiences. The studies included in Table 1 provide educators with evidence-based practices and innovative approaches for integrating interactive labs into their teaching. By exploring the wide range of interactive lab technologies and their applications in various scientific disciplines, educators can find inspiration and practical strategies for creating engaging and effective learning experiences. These insights can also inform curriculum development efforts to meet the needs of 21st-century learners. Researchers can benefit from the literature review by identifying gaps in existing research and areas for further investigation. By synthesizing findings from multiple studies, they can gain a nuanced understanding of the factors affecting the effectiveness of interactive labs and develop hypotheses for future research. The literature review also serves as a foundation for theoretical frameworks and conceptual models in technology-enhanced science education.

Policy makers can use the insights from Table 1 to inform their decision-making processes regarding educational policy and funding priorities. Recognizing the potential of interactive labs to improve student engagement, comprehension, and practical skills development, policymakers can advocate for investments in technology infrastructure, professional development initiatives for educators, and research programs that advance the field of technology-enhanced science education. They can also shape policies that promote equitable access to interactive lab technologies for all students, regardless of socioeconomic background or geographic location.

For those interested in the intersection of technology and science education, the literature review in Table 1 offers a glimpse into the transformative power of interactive labs in revolutionizing teaching and learning practices. It highlights the diverse applications of interactive lab technologies, such as virtual reality simulations and smartphone-integrated augmented reality platforms, showcasing their versatility and adaptability in addressing the challenges of science education. Additionally, the literature review prompts a critical dialogue on best practices and ethical considerations in the design and implementation of technology-enhanced learning environments. The literature review in Table 1 is a valuable resource for educators, researchers, policymakers, and anyone interested in the intersection of technology and science education. It synthesizes findings from various studies, providing a comprehensive overview of the current research in the field. The review offers insights into the benefits and challenges of interactive labs, inspiring future innovation and inquiry.

CONCLUSION

The integration of Interactive Labs technology resources in science education shows great promise for enhancing student engagement, comprehension, and practical skills development. This literature review provides valuable insights into the benefits, challenges, and emerging trends associated with the use of Interactive Labs in science learning. Through a thorough exploration of relevant research, this review emphasizes the transformative potential of Interactive Labs in promoting active learning, addressing accessibility issues, and catering to individual learning styles and paces.

The findings presented in this review highlight the various applications of Interactive Labs, ranging from immersive virtual environments to augmented reality platforms, and their significant impact on student engagement and comprehension. By synthesizing evidence from a wide range of studies, this review offers a nuanced understanding of the factors that affect the effectiveness of Interactive Labs and provides practical strategies for educators to incorporate these technologies into their teaching methods. Additionally, this review identifies key areas for future research, including the authenticity of the learning experience, technical considerations, and the need for teacher training. By addressing these challenges, researchers can further advance the field of technology-enhanced science education and contribute to the ongoing transformation of science learning practices.

Overall, this literature review serves as a comprehensive guide for educators, researchers, policymakers, and anyone interested in the intersection of technology and science education. By highlighting the transformative potential of Interactive Labs and providing insights into their benefits and challenges, this review aims to inspire innovation and inquiry in the pursuit of more engaging, accessible, and effective science education.

LIMITATION

One limitation of this literature review is the potential for selection bias in the search and screening process. Despite our efforts to use a systematic approach with the PRISMA methodology, there is a possibility that we unintentionally excluded some relevant studies. This could be due to limitations in our search terms, database coverage, or the criteria we used to screen the studies. Additionally, our review mainly focused on English-language studies from the SCOPUS database, which means we may have missed valuable contributions from non-English-speaking researchers or those using different academic platforms. As a result, our findings may not fully represent the breadth of research on Interactive Labs in science education, which limits the generalizability of our conclusions.

RECOMMENDATION

To overcome the limitations found in this literature review and improve the quality and scope of future research in the field of technology-enhanced science education, several recommendations are proposed. First, researchers should broaden their search criteria to include studies published in languages other than English and accessible through diverse databases. This inclusive approach will help capture a wider range of perspectives and insights, leading to a more comprehensive understanding of the topic. In addition, future studies could benefit from using a mixed-methods approach that combines quantitative and qualitative analyses to gain a more nuanced understanding of the effectiveness of Interactive Labs. By triangulating findings from different methodological approaches, researchers can enhance the validity and reliability of their conclusions. Furthermore, conducting longitudinal studies to track the impact of Interactive Labs over extended periods could provide valuable insights into their long-term effectiveness and sustainability. By monitoring student outcomes and engagement over time, researchers can identify factors contributing to success or challenges that may arise with prolonged use of Interactive Labs. Lastly, efforts should be made to ensure equal access to Interactive Labs for all students, particularly those from underserved communities. Policymakers and educational institutions should prioritize investments in infrastructure and resources to bridge the digital divide and ensure that Interactive Labs are accessible to students regardless of socioeconomic status or geographic location. Additionally, professional development initiatives should be implemented to equip educators with the knowledge and skills necessary to effectively integrate Interactive Labs into their teaching practices. By addressing these recommendations, researchers, educators, and policymakers can collaboratively overcome challenges and maximize the benefits of integrating Interactive Labs into science education. Ultimately, this will foster more engaging, accessible, and effective learning experiences for all students.

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