JURNAL PENDIDIKAN SAINS DAN MATEMATIK MALAYSIA
VOL 14 NO 1 2024 / ISSN 2232-0393 / eISSN 2600-9307

Integration of Virtual Labs in Science Education: A Systematic Literature Review

Pengintegrasian Makmal Maya dalam Pendidikan Sains: Satu Kajian Literatur Bersistematik

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Published: 30 April 2024

To cite this article (APA): Rosli, R., & Ishak, N. A. (2024). Integration of Virtual Labs in Science Education: A Systematic Literature Review. *Jurnal Pendidikan Sains Dan Matematik Malaysia*, *14*(1), 81–103. https://doi.org/10.37134/jpsmm.vol14.1.8.2024

To link to this article: https://doi.org/10.37134/jpsmm.vol14.1.8.2024

ABSTRACT

Real experiments can be demonstrated to students through virtual labs, which will greatly facilitate their learning. Virtual labs allow students to conduct experiments independently, offering the ability to integrate theoretical and practical aspects. This study conducted a systematic literature review on virtual labs in science education over the past five years. In addition, this study used multiple research designs, and the review was based on the publication standard, PRISMA Statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses). The articles were selected using Scopus, a leading database, and Google Scholar, a supporting database. This review features two main themes based on the thematic analysis, namely (1) educational settings practicing virtual labs in Science Education and (2) learning outcomes measured by implementation of virtual labs. Seven sub-themes have emerged from the two main themes. The findings revealed (1) the potential of virtual labs to improve the teaching and learning process, (2) the utilization of an effective virtual lab for scientific learning, and (3) the adoption of virtual labs will enhance students' competencies in practical experiences and improve learning outcomes in science education.

Keywords: Educational Settings, Learning Outcomes, Science Education, Systematic Literature Review, Virtual Labs

ABSTRAK

Eksperimen sebenar dapat ditunjukkan kepada murid melalui makmal maya bagi memudahkan pembelajaran mereka. Melalui makmal maya, murid dapat melaksanakan eksperimen secara kendiri dan berupaya untuk mengintegrasikan aspek teori dan praktikal. Kajian ini menjalankan kajian literatur bersistematik mengenai makmal maya dalam pendidikan sains sejak lima tahun yang lalu. Di samping itu, ulasan dalam kajian ini adalah berdasarkan PRISMA Statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses). *Artikel-artikel dipilih menggunakan pangkatan data utama iaitu* Scopus *dan* Google Scholar *sebagai pangkalan data sokongan. Kajian ini mempunyai dua tema utama berdasarkan analisis tematik, iaitu (1) institusi pendidikan yang mengintegrasikan makmal maya dalam pendidikan sains dan (2) hasil pembelajaran yang diukur dengan pelaksanaan makmal maya. Tujuh sub-tema telah muncul daripada dua tema utama. Hasil dapatan menunjukkan (1) potensi makmal maya untuk meningkatkan proses pengajaran dan pembelajaran, (2) penggunaan makmal maya yang berkesan untuk pembelajaran saintifik, dan (3) penggunaan makmal maya akan meningkatkan kecekapan murid dalam melaksanakan eksperimen dan meningkatkan hasil pembelajaran dalam pendidikan sains*.

***Kata Kunci**: Institusi Pendidikan, Hasil Pembelajaran, Pendidikan Sains, Kajian Literatur Bersistematik, Makmal Maya*

INTRODUCTION

Laboratory activities are essential in science education for facilitating students' learning (Abd Rahman et al., 2021; Purwaningtyas et al. 2022). They engage in hands-on practice that enables students to achieve a deep understanding of grasping theories and principles, resulting in meaningful learning experiences (De Jong et al., 2013; Lim & Kamin, 2023; Ratamun, 2018; Sutarno et al., 2019). Pedaste et al. (2020) indicated that relevant scientific experiments can stimulate students' learning, especially for abstract and difficult concepts. Moreover, this activity also equips students with the skills needed to become proficient and highly capable in science for future learning (Arifin et al., 2020; De Jong et al., 2013). Real experiments can be demonstrated to students through technology, which will greatly facilitate their learning and improve their knowledge (Ng & Chua, 2023; Kolil et al., 2020). Virtual laboratories, often known as virtual labs, are simulated versions of traditional laboratories that emphasize a learner-centered approach (Alkhaldi et al., 2016; Lestari et al., 2023; Rosli & Ishak, 2022). The two main components of virtual labs are simulation and animation (Singhai, 2019), which allow the learner to freely explore and also assist the learner in integrating theoretical and practical elements (Jain & Kaur, 2022; Manikowati & Iskandar, 2018). Virtual labs range in complexity from simple two-dimensional (2D) to interactive three-dimensional (3D) simulations and immersive virtual reality (VR) in creating a more engaging learning environment (Chan et al., 2021).

Virtual labs can be defined in a variety of ways. Generally, virtual labs are defined as software that enables students to conduct scientific investigations in a virtual setting (Bogusevschi et al., 2020; De Jong et al., 2013). Students are able to conduct virtual experiments and visualize similar to real experimental results through virtual labs (Bogusevschi et al., 2020). Singhai (2019) described virtual labs as an electronic system that can be utilized to support learning environments without the usage of a physical laboratory. Virtual labs, as defined by Jones (2018), provide a platform for the simulation and remote initiation of laboratory investigations, enabling students to visualize and perform the scientific concepts governing the experiment. Virtual labs are described as a digital-based medium for conducting practicum that can be operated using mobile or laptops to achieve a set of given goals without the need for real apparatus and chemicals (Solikhin et al., 2022). Regardless of the differences in terminology, the concepts of virtual labs are similar, which is to facilitate learning among students in science education.

The utilization of virtual labs in educational settings offers numerous advantages. The learning approach through virtual labs emphasizes the use of contextual, simulation, and animation with concepts that are expected to develop students' creativity and critical thinking (Singhai, 2019; Tatli & Ayas, 2013). Therefore, students are free to share scientific ideas and observations among themselves, which will help them to improve their academic performance (Raman et al., 2020). Teachers may enhance the quality of teaching as virtual labs provide a visual and immersive experience that helps students learn difficult concepts much better (Smetana & Bell, 2012). Therefore, it improves the quality of class teaching and makes learning interactive, enjoyable, and effective (Akpinar, 2014; Ng & Chua, 2023). Virtual experiments can be effective as the learning materials involve multimedia representations, such as text, pictures, and animations based on real scenarios (Muhamad et al., 2012; Yuliati et al., 2018). Furthermore, students require less time to set up the apparatus, which can offer immediate results from extended study and can be performed repeatedly (Byukusenge et al., 2022). In addition, with virtual labs, students can determine their own pace of learning at anytime and anywhere (Abdullah et al., 2017; Byukusenge et al., 2022; Potkonjak et al., 2016).

However, despite their advantages, virtual labs have several drawbacks. It has been reported that the implementation of virtual labs may affect students' responsibility, awareness, or health issues (Potkonjak et al., 2016; Akinola & Oladejo, 2020). Moreover, virtual labs are not effective in acquiring laboratory skills as the training is often through actual hands-on experience (Bonser, 2013). The current study attempted to bring to light fresh knowledge and current practices regarding the experience of teaching and learning in science subjects via virtual labs.

METHODOLOGY

This section addresses five key issues: 1) the review protocol, 2) formulation of research questions, 3) systematic searching strategies, 4) quality appraisal and 4) data extraction and analysis.

The review protocol – PRISMA

The present study used the PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) as a guide, which is commonly used across various fields, including education (Shaffril et al., 2019). The PRISMA statements offer three advantages: precisely define research questions to enable a systematic study, identify inclusion and exclusion criteria, and evaluate a large database of scientific literature within a specific time limit (Sierra-Correa & Cantera Kintz, 2015). It allows a thorough search for virtual lab-related terms and can be employed for monitoring the implementation of virtual labs, particularly in science subjects.

The authors began the review by formulating research questions in accordance with the review process. Then, the authors outlined the systematic search strategy, which involved three primary steps: 1) identification, 2) screening, and 3) eligibility. Following that, the authors appraised the quality of the selected articles, explaining the approaches taken to ensure that the reviewed articles met the quality standards. Finally, the authors reported how the data for the review were abstracted, analyzed, and validated.

Formulation of research questions

A systematic literature review requires a comprehensive research question (Sulaiman et al., 2023). The research questions for this study were formulated based on the PICo framework. It is a tool that is based on three fundamental concepts: Population or Problem (P), Interest (I), and Context (Co). By employing the concepts outlined in Table 1, the authors were able to develop two research questions: 1) In which educational settings that virtual labs are commonly practice in Science Education and 2) What are the learning outcomes measured by the implementation of virtual labs?

Table 1: Three Concepts of PICo

Concept	Definition	In This Study
Population (P)	What are the characteristics of the population?	Science students in Chemistry, Biology, Physics, and Science subjects.
Interest (I)	What are the phenomena of interest? A defined event, activity, experience, or process?	Learning outcomes measured by the implementation of virtual labs.
Context (Co)	The particular settings or areas of the population	Type of educational settings that practicing virtual labs in Science Education.

Systematic searching strategies

The systematic search strategy, which involved three primary steps: 1) identification, 2) screening, and 3) eligibility as can be seen in Figure 1.

The identification stage of the searching process involves finding synonyms, related terms, and variations for the main keywords of the study, such as virtual labs and educational settings. The idea is to give the database more choices for searching additional related articles. Two primary search techniques were employed: advanced searching in the chosen database (by creating a comprehensive search string) and manual searching (handpicking). The keywords were generated from the study using a combination of online thesauri, previous research, keyword suggestions from Scopus, and expert guidance (Okoili, 2015).

The authors refined the existing keywords and developed a full search string (utilizing Boolean operators, phrase searching, truncation, wild cards, and field code functions) on the leading database, Scopus as follows:

TITLE-ABS-KEY(("virtual lab*" OR "remote* lab*") AND ("secondary school" OR "elementar* school*" OR "universit*" OR "high school*" OR "primary school*" OR "college*")).

The selection of Scopus as a leading database is because it provides powerful search capabilities, extensive coverage of over 5,000 publishers, rigorous quality control measures for articles, and its interdisciplinary approach, which includes research linked to virtual labs (Gusenbauer & Haddaway, 2019; Martin-Martin et al., 2018). Google Scholar was selected with manual searching and handpicking applied (Kamaruddin et al., 2022). Due to its usefulness as a supplementary resource in systematic review procedures (Boeker et al., 2013), Google Scholar was selected as a supporting database. Additionally, Google Scholar is accessible to anyone (Jensenius et al., 2018) and offers extensive results of documents (Gusenbauer, 2019), journal articles (Orduña-Malea et al., 2017), and excellent retrieval of known scholarly items (Loan & Sheikh, 2018). Relevant keyword combinations, such as "virtual lab," "virtual laboratory," and "science education," were used with phrase searching and Boolean operators (OR, AND). The search process in both Scopus and Google Scholar databases yielded a total of 2,125 articles, with 2,106 articles retrieved from database searching and 19 articles selected through manual techniques.

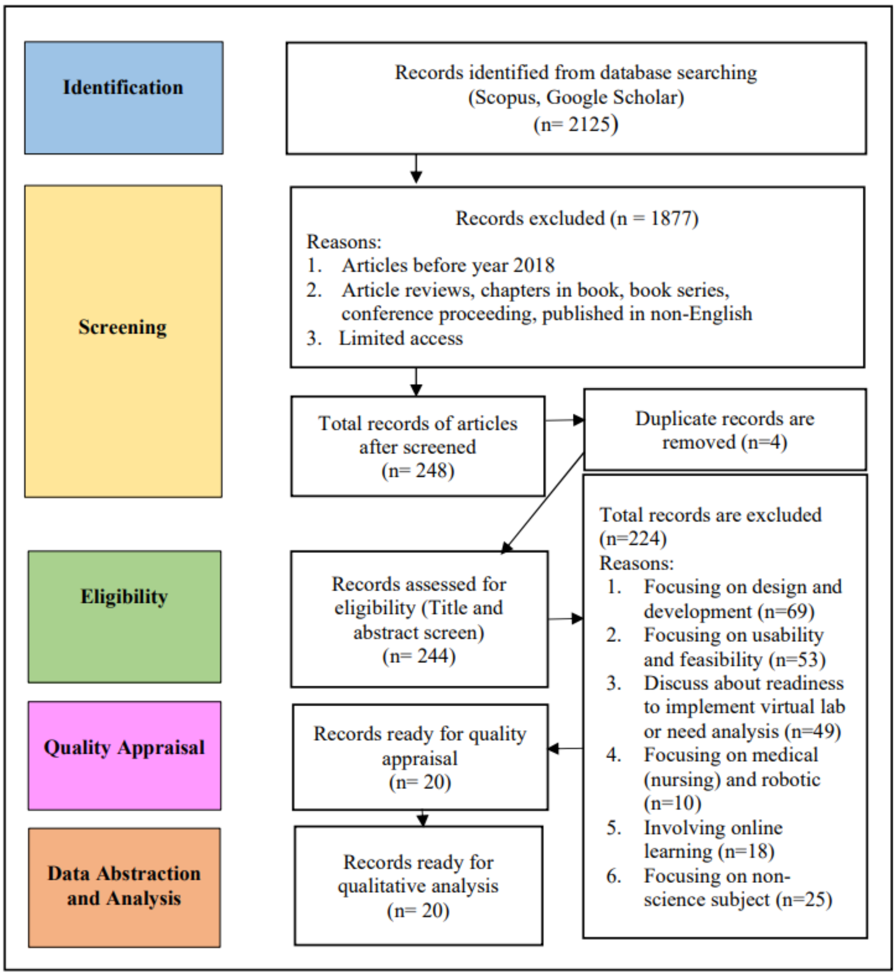

Figure 1 Flow diagram of the searching process (Adapted by Shaffril et al. (2021))

The authors implemented specific criteria for inclusion and exclusion in the screening process, as outlined in Table 2.

Table 2: Inclusion and exclusion criteria

Inclusion	Exclusion
Articles focus on the effectiveness of virtual labs	Articles discussed on: • Design and development of virtual labs • Usability and feasibility of virtual labs • Virtual labs in medical and engineering fields
Virtual labs in science subjects: Physics, Chemistry, Biology, and Science	Virtual labs in non-science subjects
Journal articles	Non-journal articles
Articles published in English	Articles not published in English

All 2,125 articles were automatically screened by the database using the sorting function based on the article selection criteria proposed by Kitchenham et al. (2009). As it would take a very long time to read through all previously published articles, the authors set a time limit for their review as suggested by Okoli (2015). Higgins and Green (2011) stated that the publishing time-limit should be applied only if it is known that these studies were reported during that time.

The number of articles regarding the use of virtual labs started to increase rapidly in 2010, according to the results of the database search. Given the maturity of these studies, articles published between 2018 and 2022 were selected. The search was limited to 2022 because the search process began in March 2023, and the year had not yet ended. Thus, one of the inclusion criteria was the timeline between 2018 and 2022. To assure the quality of the review, only research with empirical data and journal publications were considered for inclusion. Furthermore, only publications published in English were taken into account for the assessment. Articles that were duplicated were also excluded.

For eligibility, the authors reviewed the retrieved articles in the third step to ensure the remaining articles met the requirements. This phase involved reading article titles and abstracts. The process resulted in the exclusion of 224 articles because those were published before 2018; were in the form of review articles, book chapters, book series, and conference proceedings; were published in languages other than English; or having limited access. In total, only 20 articles were selected for further review.

Then, for quality appraisal, two reviewers were involved in assessing each selected article using the Mixed-Methods Appraisal Tool (MMAT) by Hong et al. (2018). In this study, the MMAT guided the reviewers to appraise quantitative non-randomized studies and mixed-methods studies. Before proceeding to the quality assessment, two screening questions were conducted: 1) clear research questions and 2) data collection to address the research questions. The selected articles were evaluated using five key criteria set by Hong et al. (2018). The reviewers had three options for delivering the answers: "Yes," "No," and "Can't Tell." The articles were included in the review of those that met at least three criteria (Hong et al. 2018). In all, 16 articles met all criteria and four articles managed to satisfy four of the criteria (see Table 3).

Table 3: Results of quality appraisal

Study	Research Designs	QA1	QA2	QA3	QA4	QA5	Number of Criteria Fulfilled	Inclusion in the Review
Aldosari et al. (2022)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Manyilizu (2022)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Suyanta et al. (2022)	MX	✓	✓	✓	✓	X	4/5	✓
Amin and Ikhsan (2021)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Gambari et al. (2018)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Ratamun and Osman (2018)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Peechapol (2021)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Hamed and Aljanazrah (2020)	MX	✓	✓	✓	✓	✓	5/5	✓
Paxinou et al. (2020)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Makransky and Petersen (2019)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Sari et al. (2019)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Ting-Ling et al. (2021)	MX	X	✓	✓	✓	✓	4/5	✓
Puspitaningtyas et al. (2021)	MX	✓	✓	X	✓	✓	4/5	✓
Gunawan et al. (2019)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Arista and Kuswanto (2018)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Gunawan et al. (2018)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Rasheed et al. (2021)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Putri et al. (2021)	QN (NR)	✓	✓	✓	✓	✓	5/5	✓
Yildirim (2021)	MX	✓	✓	X	✓	✓	4/5	✓
Ambusaidi et al. (2018)	MX	✓	✓	✓	✓	✓	5/5	✓

Note. "QA" indicates quality assessment, "QN (NR)" indicates quantitative non-randomized and "MX" indicates mixed-methods

RESULTS

Background of The Selected Articles

The review yielded in two themes and four sub-themes related to implementation of virtual labs. Thematic analysis revealed that the main themes are educational settings (one sub-theme) and learning outcomes measured by implementation of virtual labs (three sub-themes). The studies were conducted in various countries such as seven articles focused in Indonesia (Amin & Ikhsan, 2021; Arista & Kuswanto, 2018; Gunawan et al., 2019; Gunawan et al., 2018; Puspitaningtyas, 2021; Putri et al., 2021; Suyanta et al., 2022) and two articles in Turkey (Sari et al., 2019; Yildirim, 2021). Meanwhile, each research study also focused in Saudi Arabia (Aldosari et al., 2022), Nigeria (Gambari et al., 2018), Palestine (Hamed & Aljanazrah, 2020), Oman (Ambusaidi et al., 2018), Malaysia (Ratamun & Osman, 2018), Taiwan (Ting-Ling et al., 2021), Denmark (Makransky & Petersen; 2019), Greece (Paxinou et al., 2020), Tanzania (Manyilizu, 2022), Pakistan (Rasheed et al., 2021) and Thailand (Peechapol, 2021) (see Figure 2).

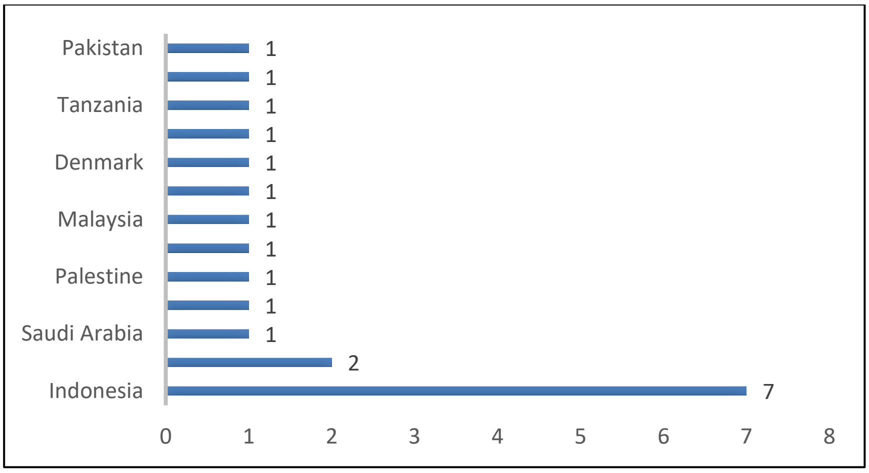

Figure 2 Countries in which the selected studies were conducted

Moreover, the results provided comprehensive analysis of the present implementation of virtual labs in subjects namely Chemistry (Aldosari et al., 2022; Amin & Ikhsan, 2021; Gambari et al., 2018; Manyilizu, 2022; Ratamun & Osman, 2018; Peechapol, 2021), Biology (Makransky & Petersen; 2019; Paxinou et al., 2020), Physics (Arista & Kuswanto, 2018; Gunawan et al., 2018; Gunawan et al., 2019; Hamed & Aljanazrah, 2020; Puspitaningtyas, 2021; Putri et al., 2021; Rasheed et al., 2021; Sari et al., 2019) and Science (Ambusaidi et al., 2018; Ting-Ling et al., 2021; Suyanta et al., 2022; Yildirim, 2021) (see Figure 3).

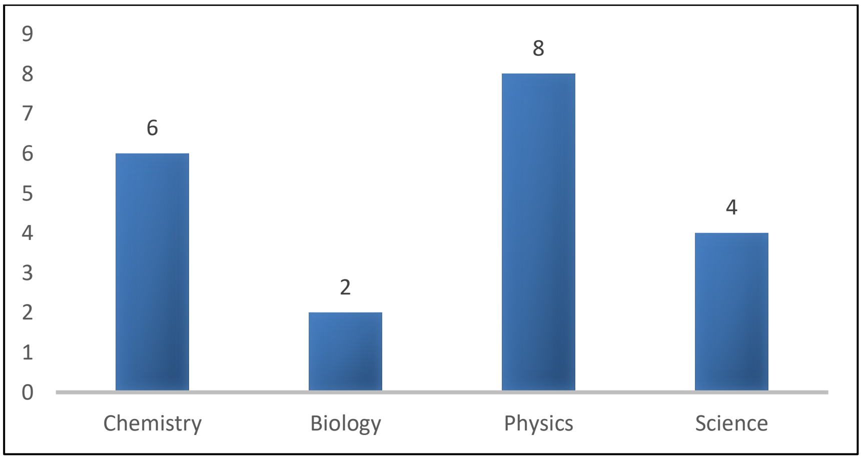

Figure 3 Subjects of selected studies

It was recorded that 14 studies focused on quantitative analyses (Aldosari et al., 2022; Amin & Ikhsan, 2021; Arista & Kuswanto, 2018; Gambari et al., 2018; Gunawan et al., 2018; Gunawan et al., 2019; Makransky & Petersen; 2019; Manyilizu, 2022; Ratamun & Osman, 2018; Paxinou et al., 2020; Peechapol, 2021; Putri et al., 2021; Rasheed et al., 2021; Sari et al., 2019) and the remaining studies employed mixed-method approach (Ambusaidi et al., 2018; Hamed & Aljanazrah, 2020; Puspitaningtyas, 2021; Suyanta et al., 2022; Ting-Ling et al., 2021 Yildirim, 2021) (see Figure 4).

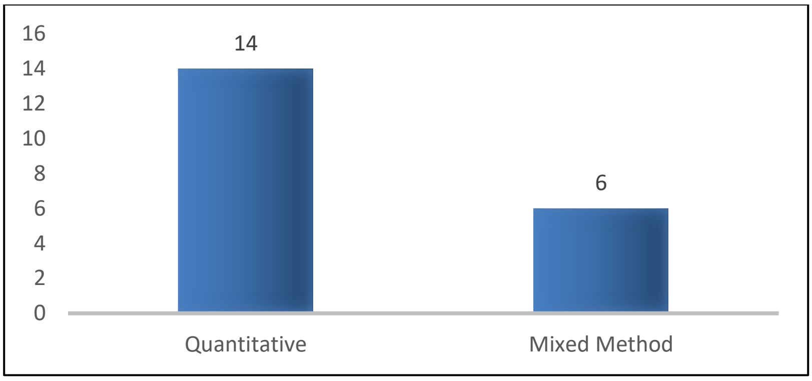

Figure 4 Research design of selected studies

Regarding the year of publication, five articles were published in 2018 (Ambusaidi et al., 2018; Arista & Kuswanto, 2018, Gambari et al., 2018; Gunawan et al., 2018; Ratamun & Osman, 2018), three articles were published in 2019 (Gunawan et al., 2019; Makransky & Petersen; 2019; Sari et al., 2019), two articles were published in 2020 (Hamed & Aljanazrah, 2020; Paxinou et al., 2020), seven articles were published in 2021 (Amin & Ikhsan, 2021; Peechapol, 2021; Puspitaningtyas, 2021; Putri et al., 2021; Rasheed et al., 2021; Ting-Ling et al., 2021; Yildirim, 2021) and three articles were published in 2022 (Aldosari et al., 2022; Manyilizu, 2022; Suyanta et al., 2022) (see Figure 5).

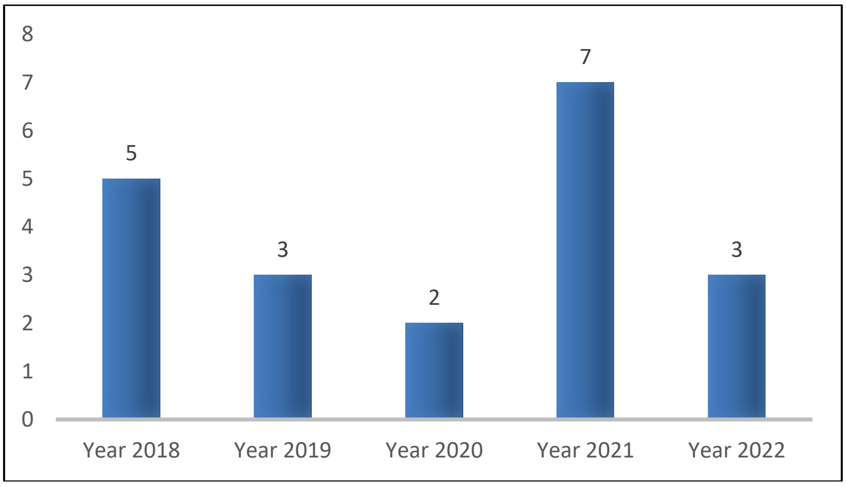

Figure 5 Publication years of selected studies

Themes and The Sub-Themes

The review yielded two themes and four sub-themes related to the implementation of virtual labs. The main themes were educational settings practicing virtual labs in Science Education (one sub-theme) and learning outcomes measured by the implementation of virtual labs (three sub-themes).

Educational Settings Practicing Virtual Labs in Science Education

The first theme in this study is the educational settings practicing virtual labs for a successful teaching and learning (T&L) process in Science Education (see Figure 6).

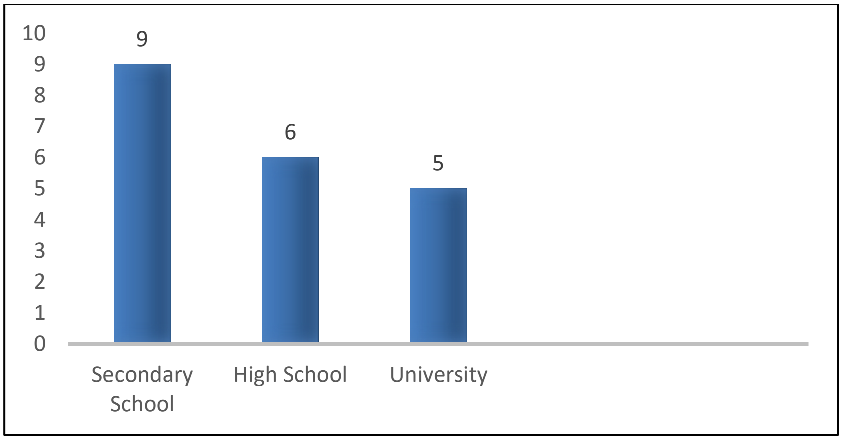

Figure 6 Type of educational settings that practise virtual labs

Based on Figure 2, the majority of the studies (n = 9, 45%) focused on the implementation of virtual labs in secondary schools (Aldosari et al., 2022; Ambusaidi et al., 2018; Amin & Ikhsan, 2021; Gambari et al., 2020; Manyilizu, 2022; Rasheed et al., 2021; Ratamun & Osman, 2018; Suyanta et al., 2022; Yildirim, 2021). A total of six studies focused on the implementation of virtual labs in high schools (n = 6, 30%) (Arista & Kuswanto, 2019; Gunawan et al., 2019; Gunawan et al., 2018; Putri et al., 2021; Puspitaningtyas, 2021; Ting-Ling et al., 2021) and five studies in universities (n =5, 25%) (Hamed & Aljanazrah, 2020; Makransky & Petersen; 2019; Paxinou et al., 2020; Peechapol, 2021; Sari et al., 2019).

A sub-theme was identified under this theme, which is the rationale for the implementation of virtual labs in educational settings. This sub-theme was further grouped into four categories, namely 1) teaching constraints, 2) abstract concepts, 3) teaching methods, and 4) technology advancement. The majority of the articles indicate that the rationale for incorporating virtual labs into the T&L process is the presence of teaching constraints, including time allocation, high costs, safety concerns, and inadequate infrastructure. Students gain essential practical skills through frequent hands-on lab experiences. However, due to time limitations in conducting the experiment, students were less competent to attain better results (Amin & Ikhsan, 2021), and practical skills acquisition is often inadequately developed (Gunawan et al., 2019). Furthermore, virtual experiments have been conducted as a result of limited laboratory facilities and insufficient funding for expensive equipment (Aldosari et al., 2022; Gambari et al., 2018; Manyilizu, 2022; Rasheed et al., 2021). The use of virtual labs appears as a solution to these problems, with the potential to significantly improve educational outcomes (Amin & Ikhsan, 2021; Gunawan et al., 2019). According to Aldosari et al. (2022), virtual labs can be utilized to allow students to apply correct practical skills and to provide many other benefits without cost limits. Additionally, virtual labs provide an effective solution concerning student safety, as some experiments could pose a danger if conducted in a physical laboratory (Ambusaidi et al., 2018; Paxinou et al. 2020; Rasheed et al., 2021).

The articles reviewed indicate that students frequently encounter challenges when learning science disciplines, primarily attributed to the abstractness of many concepts. Using virtual labs in Chemistry can help students better understand chemical reactions, orbital concepts, and atomic structures (Aldosari et al., 2022), (Aldosari et al., 2022; Peechapol, 2021) and qualitative salt analysis (Ratamun & Osman, 2018). In Physics, virtual labs allow students to concretely observe light wave phenomena (Puspitaningty, 2021), accurately draw diagrams of free forces causing rotation, interpret data, and comprehend the concept of rolling motion (Arista & Kuswanto, 2018) and visualize light and optic concepts (Putri et al., 2021). Such abstract concepts are often challenging for teachers to visualize and explain verbally (Gunawan et al., 2018). Yildirim (2021) found that integrating virtual labs into science learning assists students in analyzing factors that affect the pressure of solids liquids, and gases, which are typically abstract concepts.

Several articles highlighted that virtual labs can enhance the quality of teaching methods, particularly in conducting experiments. Traditional teaching approaches in chemistry laboratories struggle to effectively promote students' understanding of scientific principles, as they lack interaction with real-world results (Aldosari et al., 2022; Amin & Ikhsan, 2021). However, this method may not be as effective as anticipated. Students might only use prescribed procedures to confirm textbook conclusions (Ting-Ling et al., 2020) and memorize scientific concepts and principles (Paxinou et al. 2020). Virtual labs motivate teachers to design and develop mobile learning applications for science education (Suyanta et al., 2022). Studies suggest that the most effective approach is inquiry-based learning or inquiry instruction, where students actively participate in planning experiments, observing, collecting data, formulating hypotheses, analyzing results, and making predictions (Hamed & Aljanazrah, 2020).

The integration of multimedia in teaching activities has become essential due to the rapid advancement of technology. To ensure that classroom environments keep pace with technology, Yildirim (2021) developed a virtual lab for the topic of Pressure. Similarly, Sari et al. (2019) employed a virtual lab to enhance students' learning on the topic of the Law of Motion. Students' learning is enhanced by VR and interactive simulations. This potential has been recognized by Makransky and Peterson (2019), who used VR to enhance learning among the students in Genetics.

Learning Outcomes Measured in The Reviewed Articles

The second theme of the study focused on learning outcomes measured in the reviewed articles (see Table 4). These outcomes were categorized into three sub-themes: 1) cognitive, 2) psychomotor, and 3) affective domains. The cognitive domain pertains to the cognitive abilities of individuals encompassing their achievement, knowledge, and conceptual understanding (Ay & Yilmaz, 2015; Al Hassan, 2016; Udin et al., 2020). The psychomotor domain relates to practical skills, such as scientific skills (Chan et al., 2021; Padilla, 1990). The affective domain refers to the participant's own reaction, which comprises attitude, self-efficacy, motivation, and interest (Bandura, 1977; Byukusenge et al., 2022; Chan et al., 2021; Chan & Abdullah, 2018). In several cases, the reviewed articles included assessments of multiple learning outcomes.

In the present study, a total of 20 articles were subjected to analysis. Among them, nine articles specifically focused on investigating the effects of virtual labs in relation to improving students' achievement (Aldosari et al., 2022; Ambusaidi et al., 2018; Amin & Ikhsan, 2021; Gambari et al., 2018; Gunawan et al., 2018; Hamed & Aljanazrah, 2020; Peechapol, 2021; Putri et al., 2021; Yildirim, 2021). Most studies found post-test scores to be significantly different between the experimental and control groups. In a study comparing students' understanding of oil-and-water mixtures and salt hydrolysis, Aldosari et al. (2022) found that those who learned about the concepts using a combination of theoretical and gesture-based virtual simulation performed better. Incorporating gesture-based technology led to more engaging interactions and more realistic simulations, both of which contributed to students' greater understanding of molecular structures and chemical theories (Aldosari et al., 2022). According to study by Gunawan et al. (2018), females outperformed males on both numerical and figural aspects of creativity after participating in Physics virtual labs. However, both male and female results were similar in terms of numerical aspects.

The achievement of higher-order thinking skills was significantly different between the experimental and control groups, as discovered by Amin and Ikhsan (2021). The study divided samples into a control group (CG) that worked in a traditional lab setting, an experimental group 1 (EG-1) that conducted their practical using a virtual lab called Second Life (s-SL), and a third (EG-2) that used a hybrid approach that drew on both traditional and s-SL-based virtual lab. The results of the post-test indicated that EG-2 achieved better higher-order thinking skills in observing changes at the sub-microscopic level, which were not visible during practical work in a real laboratory compared to CG and EG-1.

Also, Gambari et al. (2018) found that employing a Chemistry Virtual Laboratory (CVL) in a collaborative method led to significantly higher achievement scores for both homogeneous and heterogeneous groups. The results of their research showed that students who were taught biology using CVL-cooperative approaches outperformed those who were taught the same concepts using traditional methods or individually.

Peechapol (2021) conducted a study involving 95 students who were enrolled in a general chemistry course. The results of the study demonstrated that students who were exposed to a combination of traditional lectures and virtual labs exhibited a greater achievement as compared to those who solely participated in traditional lectures. Students can use chemistry simulations to practice lab skills in a realistic setting and gain a better grasp of abstract subjects through visualization and intrinsic motivation. As shown by an increase in the N-gain score (0.441), Putri et al. (2021) revealed that the use of virtual labs had an effective impact on students' scientific literacy achievement. Based on these results, it appears that a combination of an inquiry-based approach and virtual labs, namely Ray Optics simulation and the Lens and Mirror Labs, can be a useful supplement to students' online science education.

Yildirim (2021) discovered that students in the experimental group performed better on tests after using virtual labs. Furthermore, it has been demonstrated that virtual lab applications enrich students' learning by facilitating the visual representation of theoretical concepts. The attractive and engaging aspect of these applications also had a beneficial effect on students' interest, excitement, and motivation in science classes. Similarly, Ambusaidi et al. (2018) revealed a statistical difference in the post-test between the control and experimental groups ($t = 0.03 < 0.05$). The evidence suggested that Crocodile Virtual Lab effectively enhanced students' learning in science.

Table 4: The findings

Studies	**Year**	**Research Question 1: Educational Settings**	**Purpose of using Virtual Labs**				**Research Question 2: Learning Outcomes**							
							Cognitive			**Psychomotor**	**Affective**			
			TC	AS	TM	TA	AC	KN	CU	SS	SE	MO	IN	AT
Aldosari et al.	2022	Secondary school	✓	✓	✓		✓		✓					
Manyilizu	2022	Secondary school	✓					✓						✓
Suyanta et al.	2022	Secondary school			✓							✓		
Amin and Ikhsan	2021	Secondary school	✓		✓		✓							
Gambari et al.	2018	Secondary school	✓				✓							
Rasheed et al.	2021	Secondary school	✓							✓			✓	
Ratamun and Osman	2018	Secondary school		✓						✓				
Ambusaidi et al.	2018	Secondary school	✓				✓							✓
Yildirim	2021	Secondary school		✓		✓	✓						✓	
Gunawan et al.	2018	High school		✓			✓							
Putri et al.	2021	High school		✓			✓							
Ting-Ling et al.	2021	High school			✓			✓				✓		
Puspitaningtyas et al.	2021	High school		✓					✓					
Gunawan et al	2019	High school	✓							✓				
Arista and Kuswanto	2018	High school		✓					✓					
Peechapol	2021	University		✓			✓				✓			
Hamed and Aljanazrah	2020	University			✓		✓			✓				✓
Paxinou et al.	2020	University	✓		✓					✓				
Makransky and Petersen	2019	University				✓		✓			✓			
Sari et al.	2019	University				✓				✓		✓		✓

Note. Purpose of using virtual labs: TC=Teaching constraints; AS= Abstract concept; TM= Teaching Methods; TA=Technology advancement, Cognitive: AC= Achievement; KN= Knowledge; CU =Conceptual understanding, Psychomotor: SS=Scientific skills, Affective: SE=Self-efficacy; MO= Motivation; AT = Attitude; IN=Interest

However, Hamed and Aljanazrah (2020) found that virtual labs had the same effect as traditional labs on students' achievement in Physics. By using a mixed research methodology, 90 samples were divided equally into two groups: experimental and control groups. The findings of the independent sample t-test indicated that the mean score for the control group was 3.42, whereas the mean score for the experimental group was 3.07. With a significance level of 0.17, it was concluded that there was no statistically significant difference between the two groups in achievements. This finding implies that the impact of virtual labs on students' achievements has the same effect as traditional labs.

Several reviewed articles found that virtual labs improved students' knowledge (Makransky & Peterson, 2019; Manyilizu, 2022; Ting-Ling et al., 2021). The findings of both studies by Makransky and Peterson (2019) and Ting-Ling et al. (2021) provide corroborating evidence about the role of VR in enhancing the understanding of Genetics and Electrochemical Cells, respectively. Ting-Ling et al. (2021) conducted a study about oxidation-reduction reaction concepts using Scientific Investigation VR Lab (VR SIVRLAB). In the study, 66 grade nine students were divided into three groups: 1) immersive VR, in which students used Head mounted-display (HMD) immersive VR; 2) PC VR, in which students used desktop computer VR; and 3) VR observation, in which students observed one student using VR. The findings of the study indicated that the level of knowledge in the PC VR group was significantly greater compared to the other groups. Students had to review oxidation-reduction reaction ideas and construct a voltaic cell to save a robot; thus, it can be assured that VR SIVRLAB provides complete learning resources within a guided problem-solving framework. Makransky and Peterson (2019) discovered that the attributes of VR technology had a positive influence on students' thoughts regarding the utility of the simulation. Moreover, the ease of use of VR technology was found to enhance students' evaluations of the virtual world, ultimately leading to an improvement in their understanding of genetics concepts. Meanwhile, in the study conducted by Manyilizu (2022), 79 students were placed in order whereby real experiment was conducted in the first, second, or third order in comparison to paper-based practical and virtual lab experiments. Having students start with virtual labs, then move on to paper-based practical, and finally real (hands-on) experiments is a great way to increase their knowledge and prepare them for the real thing.

Virtual labs have been shown to improve students' conceptual knowledge, especially for concepts that are difficult to observe directly in a classroom setting (Aldosari et al., 2022; Arista & Kuswanto, 2018; Puspitaningtyas et al. 2021). Aldosari et al. (2022) indicated that students gained a better understanding of chemistry lessons using virtual labs compared to those who received only theoretical instruction without hands-on experiments. Virtual labs enable students to conduct experiments at any time and place, assisting them in exam preparation by reviewing information and identifying weaknesses. The proposed system is also well-suited to e-learning due to its capacity to manage difficulties like lab availability, missing materials, and hazardous substances. According to Puspitaningtyas et al. (2021), the utilization of structured inquiry learning, along with the implementation of a virtual lab called PhET, showed a positive impact on students' comprehension in the domain of light wave theory. Through PhET, students were able to visualize double-slit interference and single-slit diffraction. Interview responses revealed that students found it easier to distinguish the characteristics of multiple-slit interference patterns, single-slit diffraction, and diffraction grating, as they could directly observe the patterns in each situation. Meanwhile, Arista and Kuswanto (2018) discovered that the integration of ViPhyLab improved students' conceptual understanding of rotational dynamics in three aspects: translation, interpretation, and extrapolation. The learning materials were effectively developed with contextual examples, encouraged students to participate actively, provided opportunities to define ideas, and allowed students to assess concepts (Arista & Kuswanto, 2018).

Six of the twenty reviewed articles revealed that virtual labs can assess students' scientific skills, mainly manipulative skills and science process skills (Hamed & Aljanazrah, 2020; Gunawan et al., 2019; Ratamun & Osman, 2018; Paxinou et al., 2020; Rasheed et al., 2021; Sari et al., 2019). The integration of virtual labs has been found to enhance students' proficiency in manipulating physical laboratory apparatus (Hamed & Aljanazrah, 2020; Paxinou et al., 2020). According to Hamed and Aljanazrah (2020), despite several mistakes, 45 students in the experimental group who trained with the virtual lab were able to set up equipment and devices with minimum assistance from the teacher during the real lab session. The students acquired better manipulative skills through virtual labs in a flexible learning environment (Hamed & Aljanazrah, 2020).

Paxinou et al. (2020) found that compared to students who observed a live presentation of a microscopy experiment, those who conducted the experiment themselves in a VR biology lab (specifically Onlabs) were twice as likely to ask for help from the instructor. The one-hour intervention utilizing simulations in Onlabs improved the students' understanding of practical skills, allowing them to use the skills during the real lab. Meanwhile, Gunawan et al. (2019) divided the samples into two groups: 1) an experimental group in which students learn through the integration of a guided inquiry model and virtual lab, and 2) a control group in which cooperative learning was taught. The results of the post-test revealed that the experimental group showed a significant effect on making hypothesis, practicing, and communicating compared to the control group. Rasheed et al. (2021) conducted a study involving four different schools. Each school's samples were divided into control (CG) and experimental (EG) groups. The EG used virtual labs to help students learn, while the CG did the tasks without any technology. The findings demonstrated that the students' practical skills using desktop-based virtual labs in the EG were higher than in the CG. Students' skill development was aided by the virtual lab's accessibility, simplicity, and instructional support.

However, two reviewed articles demonstrated that using a physical lab improves students' science process skills (Ratamun & Osman, 2018; Sari et al., 2019). Based on the findings of the Science Process Skills Test, Ratamun and Osman (2018) showed that the average score of the CG (i.e., physical labs) was higher than that of the EG. Although the virtual lab can increase the students' science process skills in confirmations of anion and cation experiments, this improvement is not as good as the use of a physical lab. Meanwhile, Sari et al. (2019) conducted a study to compare the effects of virtual laboratory (VL) application and computer-based real laboratory (CBL) on students' graphic skills in seven experiments on Law of Motion concepts. The results revealed that CBL applications were more effective than VL applications in helping students to create, comprehend, and analyze visual representations. Students are able to assess data faster, get immediate feedback, and visualize images in real time from the exhibited data using the CBL system that employs an air rail set connected to a device called Sensor-Cassy (Sari et al., 2019).

In this study, the reviewed studies reported that virtual labs show positive changes in students' self-efficacy (Makransky & Peterson, 2019; Peechapol, 2021), motivation (Sari et al., 2019; Suyanta et al., 2022; Ting-Ling et al., 2021) interest (Rasheed et al., 2021; Yildirim 2021), and attitudes (Ambusaidi et al., 2018; Hamed & Aljanazrah, 2020; Sari et al., 2019). Peechapol (2021) found a significant difference in the post-test self-efficacy levels between EG and CG using an independent t-test. The post-test results for the experimental and control groups were 4.03 and 3.70, respectively. Peechapol (2021) concluded that interactive 3D simulation, gamification, storytelling, a quiz question with immediate feedback, and theoretical knowledge were all components of virtual labs that influence changes in self-efficacy among students in Chemistry. Meanwhile, Makransky and Peterson (2019) found that realism in the VR environment is linked to changes in self-efficacy for genetics.

Suyanta et al. (2021) developed a mobile virtual lab named Amazing Science to increase students' motivation in learning. The sample paired t-test showed that students' motivation increased significantly after using Amazing Science as compared to before. Amazing Science was pointed out as evidence of quality in the good category. Virtual labs presented via mobile apps have been shown to increase students' motivation in difficult concepts like electrical conductivity (Suyanta et al., 2021). In the study conducted by Ting-Ling et al. (2012), students engaged in inquiry learning benefit from the VR's sensation of presence. As a result, the I-VR group was more enthusiastic than the PC-VR group in conducting galvanic cell experiments independently (Ting-Ling et al., 2021). The post-test results of Sari et al. (2019) showed substantial differences in communication, cooperative working, and engagement motivation areas in favor of the CG. The collaborative approach in CBL applications motivates students more than VL applications for communication, cooperation, and involvement.

Rasheed et al. (2021) found that students in the EG were more interested in performing physics labs compared to those in the CG. The students were eager to test out new technologies for studying physics experiments because they were inspired and drawn to the characteristics of virtual labs including the design, colors, interfaces, and navigation to simply drag and drop virtual objects. Yildirim (2021) proposed a study to determine the effectiveness of virtual labs in enhancing students' interest in science lessons. According to the interview, the majority of the students stated that the virtual lab provides effective ways to study solid, liquid, and gas pressure in an engaging and enjoyable atmosphere. Hence, it can be concluded that the developed virtual lab was fascinating, allowing the students to learn better. Furthermore, based on observations, the students were excited before the class began and looked forward to the start of the lesson as soon as possible. The students also concentrated on the computers to visualize the changes in variables and recorded the results before they drew the conclusion.

According to Ambusaidi et al. (2018), the implementation of the Crocodile virtual lab showed positive attitudes among students. Based on the interviews, the animations utilized in the virtual lab helped students to better understand and recall the content. Moreover, the students enjoyed performing experiments like the real labs, such as setting up experiment materials and tools, executing specified tasks, capturing their observations, and drawing conclusions without dependence on the teacher. Hamed and Aljanazrah (2020) found that the students were positive about three Physics experiments: measuring gravity (g), the half-life of a draining water column, and RC circuit via virtual labs. Virtual labs helped students grasp physics concepts and prepare for experiments while saving time in the lab, pacing learning, and establishing a flexible and interesting learning environment. Meanwhile, Sari et al. (2019) discovered that both CBL and VL applications used in the study groups had a positive influence on students' attitudes toward difficult-to-learn notions of motion in Physics. Computer-based real laboratory applications allow students to transform data into real-time data in a computer environment and interpret them in a short time in a graphical form, while VL applications provide active learning, data collection, graphical demonstration, simplify learning activities, and make concepts visual and understandable (Sari et al. 2019). Manyilizu (2022) found that virtual labs improved students' attitudes in Chemistry. The students' positive views towards virtual labs enabled for self-learning and enjoyment.

DISCUSSIONS

According to the study's findings for the first theme, the authors concluded that virtual labs have been widely practiced in secondary schools, universities, as well as high schools. This implies that practical work at schools and universities, integrated with virtual labs, is required for students to gain expertise and skills in laboratory-based subjects, such as Biology, Chemistry, Physics, and Science (Udin et al., 2020). Moreover, students can use virtual labs to easily execute repeated experiments and investigate the impact of various parameters (Nkemakolam et al., 2018; Puspitaningtyas et al. 2021; Toth, 2016). Virtual labs provide students with a range of opportunities, such as enhancing their educational experiences, conducting experiments in a setting similar to physical laboratories, and cultivating skills relevant to experimentation.

Most of the evaluated articles suggested that the usage of virtual labs was motivated by teaching constraints (Aldosari et al., 2022; Gambari et al., 2018; Manyilizu, 2022; Rasheed et al., 2021). Teaching science requires a substantial financial investment in resources like labs, chemicals, and other facilities (George & Kalobe, 2014; Raman et al., 2020). Thus, many schools that teach science courses lack laboratory space, equipment, consumable supplies, and educated science teachers, which puts additional demand on them. As a result, students' abilities for scientific skills have diminished (Kinyota, 2020). To address this issue, virtual labs serve as a valuable alternative or supplementary learning environment to traditional laboratories (Aljuhani et al., 2018; Çelik, 2022; Diwakar et al., 2019). Virtual labs may circumvent resource constraints by offering students with flexible learning environment, rapid feedback, and experiment repetition (Potkunjak et al., 2016; Vasiliadou, 2020). Moreover, the implementation of virtual labs provides advantageous opportunities for students to engage in high-cost, hazardous, and high-complexity experiments that are difficult to carry out (Akçayr et al., 2016; Shambare & Samuja, 2022). As a consequence, students' practical skills such as manipulating materials and equipment, gathering data, testing, and reporting may be done successfully without resource constraints.

Another common rationale for using virtual labs is the abstract nature of the subjects. Misconceptions arise because the concepts are difficult to understand (Akpinar, 2014; Cimer, 2012). It is essential to provide effective teaching materials that relate concepts to previous learning and help students to comprehend how they are created in order to eradicate these misconceptions and ensure effective learning of these concepts and new concepts. Akpinar (2014) suggested that virtual labs are excellent methods of learning abstract topics. It has been proven that visualization offered by virtual labs facilitates successful learning by simplifying and concretizing complicated and abstract principles of virtual experiments (Özdemir, 2019, Sriadhi et al., 2022; Tatli & Ayas, 2013). For example, Gupta et al. (2012) developed a module integrated virtual lab namely LabVIEW to give visualizations and simulations for comprehending different electromagnetics and microwave concepts that are considered difficult. This invention may give visual representations of physical processes to students, allowing them to create relationships between scientific theory and facts (Akinola & Oladejo, 2020).

For the second theme, learning outcomes related to cognitive domain, it has been reported that achievement is the most learning outcome measured when using virtual labs. The enhanced interactions and realistic simulations given by the integration of virtual labs that allow students to visualize concepts and conduct experiments similar to a real lab setting contributed to students' achievement (Aldosari et al., 2022; Amin & Ikhsan, 2021; Peechapol, 2021). For example, Rizki et al. (2018) found that 3D visualization helps students' imaginations for the process of chemical equilibrium, which improves their grasp of the subject at the sub-microscopic level. Similarly, Al Hassan (2016) showed that different representations of colors, sounds, and animation while the learner interacts with virtual labs help students learn better. Another factor contributing to success is the instructional strategy used in virtual labs (Lee et al., 2021). An inquiry-based approach offers an alternative tool for enhancing students' learning experience using virtual labs (Putri et al., 2021). Gambari et al. (2018) also verified that the collaborative approach improved achievement among the students in Chemistry. Instructional approaches such as feedback, scaffolding, and modality are integrated into the virtual lab experience to enable meaningful learning (Chan et al., 2021; Beichumila et al., 2022a; Lee et al., 2021). Valdehita et al. (2019) agreed that the integration of virtual labs into an online learning environment offers a more advantageous foundation for fostering meaningful learning, allowing students to participate collaboratively. Their research found that integrating visualization with an instructional approach throughout the implementation of virtual labs increased students' achievement.

Furthermore, most of the reviewed articles also demonstrate the usefulness of virtual labs in fostering conceptual understanding (Aldosari et al., 2022; Arista & Kuswanto, 2018; Puspitaningtyas et al. 2021). Virtual experiments are thought to aid in the acquisition of conceptual knowledge as they generate accurate data. The study conducted by Faour and Ayoubi (2018) found that the utilization of PhET simulations resulted in an enhanced conceptual understanding of direct current electric circuits among 10th grade secondary students. Akpinar (2014) discovered that students exhibited a greater emphasis on the conceptual aspects of experiments while utilizing interactive animations of electricity. This can be attributed to the enhanced efficiency in manipulating the materials included in the experiments facilitated by these animations. Sypsas et al. (2019) discovered that integrating virtual labs with physical labs helps students gain a deeper understanding and comprehension of science concepts, as students can conduct virtual experiments to investigate indistinct phenomena that are not found in physical investigation. In addition, the use of multimedia elements like animation and simulation significantly improved students' conceptual understanding, leading to enhanced learning (Bhatti et al., 2017; Sriadhi et al.2022).

For psychomotor aspects, virtual labs are commonly seen as a viable substitute for physical labs in terms of improving students' practical skills during the learning process. Students using the virtual lab were able to prepare equipment and instruments with minimal teacher assistance (Hamed & Aljanazrah, 2021; Paxinou et al., 2020). Advanced virtual learning systems with interaction, animations, and simulations provide students with high-quality hands-on experiment-based learning (Beichumila et al., 2022a; Raman et al., 2020). Students can exhibit a variety of abilities and skills via practical practice in classrooms (Ahmed et al., 2023; Demircioglu & Yadigaroglu, 2011; Ramadhan & Irwanto, 2017). For example, using the virtual lab, students may virtually adjust the variables in the experiment and see the experimental results in visual representations, such as changes in solution color, mass, and temperature (Bactol et al., 2017). Furthermore, Sutarno et al. (2019) and Akinola and Oladejo (2020) believed that students acquire practical skills through virtual labs, such as formulating questions and hypotheses; experimenting, measuring, analyzing, and interpreting data; explanations; drawing conclusions; and communicating. According to Paxinou et al. (2020), a combination of a virtual lab namely Olabs, and a physical lab allows students to efficiently perform microscopy experiments. Similarly, the implementation of online learning assisted by Olabs improved science process skills in alkaline acid matter (Azma et al., 2021). Makransky et al. (2016) also found that a combination of a virtual lab namely vLAB and a physical lab improved laboratory skills in Microbiology. Owing to that reason, virtual labs may be a beneficial tool for students to acquaint themselves with the laboratory environment prior to their laboratory sessions (Sriadhi et al., 2022).

Studies have provided more evidence that virtual labs have significantly increased students' affective domain, specifically in terms of motivation (Sari et al., 2019; Suyanta et al., 2021; Ting-Ling et al., 2021; Yang et al., 2021) and attitude (Ambusaidi et al., 2018; Hamed & Aljanazrah, 2020; Manyilizu, 2022; Sari et al., 2019) toward the learning process. Virtual labs facilitate students' engagement in self-paced and independent learning (Campos et al., 2020; Zhang et al., 2014). Furthermore, students may apply learning theory to practice by just visiting a virtual lab via a computer rather than physically being in a lab (Duman & Avcı 2016; Al Hassan, 2016; Potkunjak et al., 2016). For instance, Sriadi et al. (2022) discovered that the virtual lab module application satisfied students' needs in terms of feasibility, learnability, and interactive interfaces, which enhanced students' learning motivation in science education. Enhancing both intrinsic and extrinsic motivation in students fosters a heightened interest in studying science (Leong et al., 2018). Virtual labs have been found to improve students' attitudes toward scientific learning in the reviewed articles (Ambusaidi et al., 2018; Hamed & Aljanazrah, 2020; Sari et al., 2019). Similarly, Samosa (2021) revealed that the learners' attitudes toward science had improved and were significantly changed as mobile virtual labs were used in learning Chemistry. Furthermore, students' attitudes in virtual labs were influenced by the inquiry and enjoyment learning environment (Urdanivia Alarcon et al., 2022). Aşıksoy and Islek (2017) implied that a positive attitude may result from the utilization of simulations to make abstract concepts more tangible and the opportunity for students to engage in self-paced experimentation, as proposed by Hamed & Aljanazrah (2020), Manyilizu (2022), and Sari et al. (2019).

CONCLUSIONS

This study found that virtual labs can greatly improve Biology, Chemistry, Physics, and Science instruction. The findings of the study can be utilized to develop an effective virtual lab for scientific learning. Furthermore, virtual labs provide a platform for solving obstacles that arise while doing experiments in real labs, allowing students to see how information is used in the real world. Virtual labs allow students to study phenomena, link abstract concepts to prior knowledge, emphasize crucial information, and execute numerous experiments quickly. Adoption of this innovative T&L practice has the potential to raise students' competencies via practical experiences and improve students' learning outcomes cognitively, psychomotor, and affectively.

Several important implications for future research and practice are provided by the study. The findings explained 1) the potential of virtual labs to improve the T&L process, 2) the utilization of an effective virtual lab for scientific learning, and 3) the adoption of virtual labs will enhance students' competencies in practical experiences and improve learning outcomes. Two research gaps were highlighted in the study. First, most of the articles reviewed were carried out in Indonesia. The gap can be narrowed if other nations, particularly those in Asia, propose more studies related to the implementation of virtual labs in science education. Secondly, the current state focuses on the quantitative research approach. Future analysis of methodologies can be carried out using mixed-methods techniques in which quantitative and qualitative data are triangulated (Beichumilla et al., 2022b). According to Creswell and Plano Clark (2018), qualitative results serve as secondary data to quantitative research findings, providing greater depth to the findings and making conclusions.

On the other hand, the authors propose that future study evaluates the technology utilized to develop virtual labs in science education. According to Chan et al. (2021), the technology utilized to create virtual labs includes 2D Desktop, 3D Desktop, immersive VR, and Natural User Interaction (NUI). Furthermore, the integration of learning theories is regarded as essential for meaningful learning in science education. To that extent, the authors conclude that future research should focus more on underlying learning theories in the implementation of virtual labs.

ACKNOWLEDGEMENTS

Full appreciation is given to the Ministry of Education (MOE) Malaysia for the sponsorship of Hadiah Latihan Persekutuan (HLP) to enable this study to be implemented successfully.

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