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Research Trends of Virtual Laboratory in Science Learning to Improve Affective Domain: a Systematic Literature Review

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Abstract. A virtual laboratory is a simulated environment that enables users to conduct various experiments anytime and anywhere without the need for a physical laboratory. Its main goal is to identify trends (such as publication year, education level, publication journal, keywords used, and academic disciplines) and map the platforms and affective domains related to virtual laboratories in science education. This systematic review utilizes 41 articles found in the scopus database from 2013 to 2023 using pre-determined criteria. The method applied is a systematic literature review following PRISMA guidelines. The results show that publication trends have fluctuated over time, with a significant increase in the last four years. Most studies were conducted at the higher education level, with the journal of chemical education being the most dominant publication outlet. Chemistry emerged as the most frequently explored discipline, and "virtual laboratory" appeared as a commonly used keyword. Various virtual laboratory platforms were employed in these studies, and most of the reported affective domains related to positive attitudes towards the learning process.
Keywords: Virtual laboratory; Science learning; Affective domain; Research trends; Systematic literature review

Introduction

Science topics are often considered among the most difficult for students to understand, while traditional teaching methods frequently fail to convey a deep comprehension of scientific theories and concepts. As a result, students often struggle in class and tend to memorize concepts rather than truly understanding them (Achuthan et al., 2018). One of the important aspects of science learning is the existence of laboratory practices and direct student exercises to support theoretical lectures carried out in the classroom (Estriegana et al., 2019). Teaching science topics requires laboratory exercises to provide students with effective skills gain and hands-on experience (Potkonjak et al., 2016). In other words, the laboratory is a place where students gain experience through various practicum activities (Hensen et al., 2020).

Laboratory practicums often do not run optimally due to time constraints, so students do not have the opportunity to repeat the experiment. Limited time in the laboratory causes students to focus only on procedural tasks to obtain results, rather than actively participating and being involved in the process they are doing. As a result, students may not fully understand the principles and theories behind the practicum (Moozeh et al., 2020). The implementation of practicum in the laboratory cannot run optimally because various challenges are found including requiring a lot of reagents and expensive costs, taking a long time, lack of laboratory space and adequate tools and materials (Widarti et al., 2021; Widarti et al., 2022; Manyilizu, 2023).

Based on these problems, a media is needed that can support practicum activities. Nowadays, technology is developing very rapidly and has succeeded in transforming every aspect of modern life, including education (Putri et al., 2022). The use of monotonous media and other conventional methods is the main cause of students getting bored easily and lacking motivation in learning science in the classroom. The characteristics of science are closely related to practical activities in the laboratory which are very dependent on the quality of the learning process (Sasmito et al., 2022). The development of android-based learning media is one of the ways technology can improve the learning process to be more effective and efficient. Research conducted by (An et al., 2019) stated that android is a perfect and easy-to-use platform for learning in the form of an application. One of the android-based learning media that needs to be applied in practicum is a virtual laboratory.

Virtual laboratories are believed to be a valuable tool for educators and prove to be beneficial if applied in the learning process, as well as considered as part of new technological advancements in science teaching (Amanio et al., 2022; Shambare et al., 2022; Widarti et al., 2022). Virtual laboratory is a simulation that can visualize objects that are small or cannot be displayed in a macro manner (Gao et al., 2020; Rokhim et al., 2020; Widarti et al., 2021; Widarti et al., 2022). Virtual labs offer a variety of benefits such as providing the desired combination for face-to-face teaching, offering an alternative to physical labs, and improving the quality of experiments by allowing for repetition and clarification of doubts (Nirmala et al., 2021).

According to another study, the use of virtual laboratories for practicum activities only takes a small amount of time when compared to conducting practicum directly in the laboratory (Hensen et al., 2020), offering flexibility as it can be used independently in any location without the need for time constraints, easier to operate (Gao et al., 2020), thus allowing students to access and repeat experiments at their own pace (Rokhim et al., 2020), this has an impact on encouraging active learning and improving performance (Miyamoto et al., 2019; Trúchly et al., 2019). Virtual laboratories have also been proven to reduce costs, and are safer so that they have greater potential to educate and attract students (Winkelmann et al., 2017).

The affective domain in learning includes emotions, attitudes, and values that affect the learning process (Lax, 2014). It is considered an important aspect of education, but it is often overlooked and only concerned with the cognitive and psychomotor realms (Casey et al., 2019; Berg-Carramusa et al., 2023). The affective domain is considered a learning access point, and its positive outcomes are essential for success in the cognitive domain (Scrutton, 2020). In addition, affective domains are interconnected with cognitive and psychomotor domains, and there is a significant correlation between these domains (Sönmez, 2017). It has been emphasized that learning in the affective realm takes time to develop, and its development is very important to achieve the desired learning outcomes (Casey et al., 2015).

The use of virtual laboratories in improving the affective domain in science learning has become a broad research goal and has received considerable attention because it has been proven to have a positive impact on science learning. Affective aspects can include motivation and interest in learning, attitudes towards chemistry subjects, and students' perceptions of the learning process (Minata et al., 2022). Motivation is a person's personal internal and external encouragement to make a change. The existence of learning motivation is one of the keys to success in the learning process for students in teaching and learning activities (Widarti et al., 2024; Widarti et al., 2024).

The integration of virtual laboratories in educational settings has attracted attention due to its potential not only in cognitive understanding but also in students' affective domains, which include motivation, interest, and attitude towards science. This systematic literature review aims to bridge the existing gap in research by focusing on how virtual laboratories impact the affective domain, an area that is less explored compared to the cognitive domain. Research shows that virtual laboratories foster interactive and engaging learning environments, which significantly increase students' motivation and interest in science subjects (Mphafudi et al., 2020). Virtual laboratories can significantly improve students' motivation and attitude towards science (Ratamun et al., 2018; Byukusenge et al., 2022; Alhashem et al., 2023; Safaryan, 2023; Spencer et al., 2024). This study aims to provide an overview of research trends on the use of virtual laboratories in science learning related to students' affective domain.

Methods

This study uses the systematic literature review (SLR) by adopting guidelines preferred reporting items for systematic review and meta-analysis (Prisma). SLR is a comprehensive method used to collect, analyze, and synthesize relevant research on a particular topic (rushiana et al., 2023). Preferred reporting items for systematic review and meta-analysis used to improve quality SLR and meta-analysis by encouraging transparency and standardizing the completeness of reporting, and is usually presented in the form of a flowchart to ensure that important information is included in that type of publication (Page et al., 2021). In the context of data collection for SLR, the PRISMA-P guidelines emphasize the importance of a comprehensive and reproducible systematic search strategy. This involves establishing clear eligibility criteria, conducting searches across multiple databases, and carefully documenting the search process (Hu et al., 2022). A systematic approach not only helps minimize bias but also increases the reliability of findings (Satalkina et al., 2020). Article search is carried out by browsing the scopus database with article publication criteria from 2013 to 2023 and assigning certain keywords. Scopus is commonly used for literature mapping due to its strict inclusion criteria and comprehensive indexing procedures, which facilitate the identification of high-quality publications (Abdullah, 2022). The article search was conducted from October 2023.

The keywords used include "the impact of virtual laboratory or vlab in science learning", "virtual laboratory or vlab and attitude", "virtual lab and affective or attitudes or interest", "virtual laboratory in science learning and senior high school", and "virtual laboratory in science learning and bachelor or undergraduate". Furthermore, the selection of articles is carried out based on the predetermined eligibility criteria to select the most qualified research studies in particular.

SLR determination of inclusion and exclusion criteria is a fundamental thing used to ensure that the literature is systematically searched (Lin et al., 2018). Article selection was guided by pre-defined inclusion and exclusion criteria, which helped simplify the process of screening relevant studies and ensured that the selected articles met the required standards for quality and relevance (Van Tam, 2021). This method was supported by a SLR framework, which emphasized the importance of defining clear criteria for article selection (Kulenović et al., 2021).

Inclusion criteria specify which studies will be part of the review, while exclusion criteria determine which articles will not be included (Achimugu et al., 2014). The inclusion criteria used include (i) research results published in verified scientific journals in the last 10 years (2013-2023), (ii) studies conducted on science learning, (iii) articles describing the combination of virtual laboratories in science learning and their results related to the affective domain, (iv) articles describing technology or software in virtual laboratories. As for the exclusion criteria, they include (i) studies other than science learning, (ii) articles review, systematic review, and Meta Analysis, (iii) studies that do not have a focus on the use of virtual laboratories in science learning, (iv) studies that do not evaluate or do not involve aspects of the affective domain, and (v) do not mention the technology or software used in the virtual laboratory. Overall, the selection process of articles using Prisma can be seen in Figure 1.

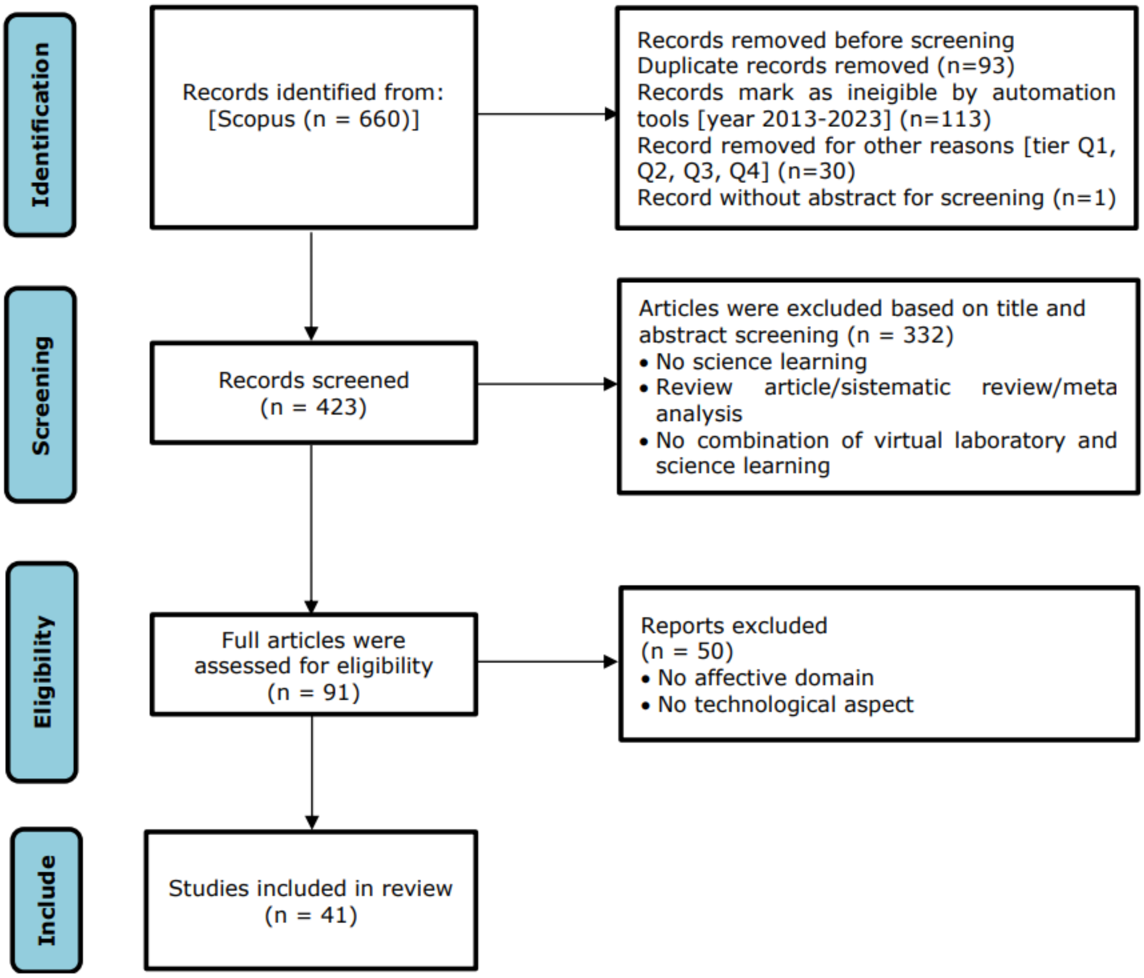

Figure 1. Article selection process using a prisma

After searching for articles using keywords that have been set from the scopus database, the number of articles obtained is 660 (identification stage). Of the 660 articles, 93 articles were deleted because duplicates were detected, 113 were deleted because they did not meet the requirements in 2013-2023, 30 articles were deleted because they did not meet the criteria (Q1, Q2, Q3, Q4), and 1 article without an abstract was deleted, so that the remaining and can be continued at the screening stage are 423 articles. A total of 332 articles were deleted because they did not meet the criteria and there are 91 articles left that will be assessed for feasibility. At the eligibility stage, 50 articles were deleted so that 41 articles were obtained to be further analyzed for the SLR.

Bibliometric analysis serves as a valuable tool for data analysis in systematic reviews. It involves the quantitative analysis of academic literature to identify patterns, trends, and impact in a particular field (Passas, 2024). This method can be particularly useful in assessing the volume of research output, citation patterns, and influence of a particular study or journal (Srivastava et al., 2022). Advanced bibliometric software, such as VOSviewer facilitates the visualization and interpretation of bibliometric data, allowing researchers to gain meaningful insights from large datasets (Ragazou et al., 2022), and to identify dominant research patterns, recent trends, and gaps in the literature by leveraging databases such as scopus. Integration of bibliometric techniques into systematic reviews can enhance understanding of the research landscape and inform future research directions (Rethlefsen et al., 2021). In addition, the use of bibliometric tools can aid in visualizing data and identifying patterns, which improves the interpretability of results.

After obtaining 41 articles that met the criteria, the analysis was conducted by studying and synthesizing the relevant research results. To support the bibliometric analysis, software such as VOSviewer was used. VOSviewer can be used to map the network of relationships between authors, articles, and keywords. This helps in visualizing research trends and understanding the interrelationships between various existing studies. The results of the analysis were then synthesized to identify key themes, trends, and potential gaps in existing research. This synthesis aims to provide deeper insights into the effectiveness of using virtual laboratories in science learning and its impact on students' affective domains.

Results and Discussion

The emergence of learning media is closely related to technological developments, especially in the field of education. Educational technology has become a focal point in recent years, with an increasing emphasis on technology-based learning and new learning environments (Widarti et al., 2022). This trend is further supported by increasing international recognition of conferences focused on educational technology and related topics. As the field of educational research evolves, there are clear indications of a global shift towards the integration of technology into various aspects of education, including curriculum and instruction, learner needs, and instructional design.

The role of technology in education is not limited to a specific field but covers a wide range of subjects. This development reflects an increasing awareness of the potential of technology to improve the learning experience and quality of education in Indonesia (Widarti et al., 2022), as well as meeting the needs of students in the 21st century. The integration of technology in education is not only about improving traditional teaching methods but also about adapting to the evolving needs of a global society and enabling teaching and learning to overcome physical barriers and take place in diverse environments.

Technological advances have had a significant impact on the creation and application of ICT-based learning media, leading to the evolution of traditional teaching methods. ICT-based learning media is a means of delivering material that can be accessed online, making it easier for students to acquire various knowledge independently, as well as making the learning process more effective and efficient (Tanwir et al., 2018). In the world of education, it has an influence on the creation of a media that can be applied in practicum activities, namely virtual laboratories (Rokhim et al., 2020).

Virtual laboratory is defined as an interactive environment that demonstrates experiments in detail to prove a concept that is difficult to implement directly in the laboratory. The environment allows for dangerous practicums, and depicts reactions that cannot be seen in real life (Widarti et al., 2021). A virtual laboratory can be interpreted as a computer-based practicum simulation place that can visualize abstract concepts into more concrete (Reny et al., 2018), which allows users to learn an experimental procedure, access and move freely from one position to another, select various chemicals and equipment, and take the number of materials to be used as if doing a practicum in a real lab (Ullah et al., 2016). The virtual laboratory is designed by combining text, images, animations, and sounds so that students can do practicum as if they are facing a phenomenon or a set of real laboratory equipment without being present in the laboratory room or real lab. Additionally, virtual laboratories present several advantages, such as cost-effectiveness, security, and the ability to overcome time and space constraints, involving expensive instrumentation, making them valuable educational tools and potentially more informative and engaging for students (Winkelmann et al., 2017).

Research has shown the positive impact of virtual laboratories on learning outcomes, supporting their application as an alternative to conducting practical work in educational procedures (Kharki et al., 2021). Virtual labs have also proven to be effective at modeling abstract concepts, making them valuable for improving students' understanding of complex scientific principles (Tseng et al., 2023). In addition, the use of in-person and virtual hands-on labs in sequence has been shown to provide better results in the acquisition of students' knowledge and inquiry skills (Kapici et al., 2019). The following are the results of research on the trend of using virtual laboratories in science learning to improve students' affective domains.

Trends by Year of Publication

The results of the search for articles that discuss the use of virtual laboratories for improving the affective domain in science learning through the scopus database are 41 research articles that are considered relevant and meet the desired search criteria so they are included in this review. All articles published in the last ten years, from 2013 to 2023, are documented in Figure 2. In 2013, there was no study reviewing the use of virtual laboratories in science learning to improve the affective domain. Based on the data from Figure 2, it can be concluded that out of a total of 41 articles studied, the distribution occurred in 2014 (1 article), 2015 (3 articles), 2016 (3 publications), 2017 (2 articles), 2018 (2 articles), 2019 (1 article), 2020 (5 articles), 2021 (5 articles), 2022 (9 articles), and 2023 (10 articles). This phenomenon illustrates that 2023 shows the highest achievement in the number of published articles.

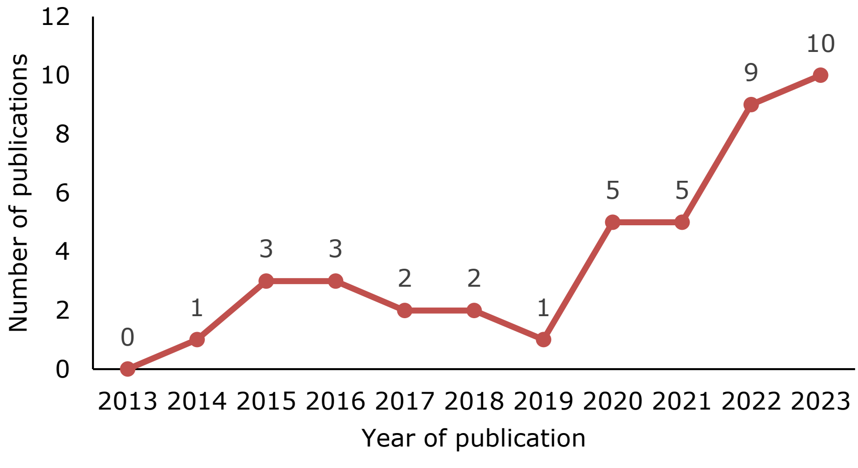

Figure 2. Trends by year of publication

The graph shows a growth trend for the first three years, remaining stable in 2016, before declining for two consecutive years in 2017 and 2018. After this period, there was a significant increase from 2019 to 2023. This suggests an increased interest in the topic of the article, likely driven by the global shift to online education necessitated by the COVID-19 pandemic. The pandemic catalyzed the adoption of virtual laboratories as a critical tool for maintaining educational continuity, leading to an increase in the volume of research and publications in this area (Gamage et al., 2020; Antrakusuma et al., 2021). This trend suggests that researchers are increasingly recognizing the importance of the affective domain—which encompasses aspects such as motivation, attitudes, and self-efficacy—in the context of science education. The affective domain plays a critical role in shaping students' engagement and success in learning, as it influences their emotional responses and attitudes toward science subjects (Adolphus et al., 2022; Quirós et al., 2023).

Another possibility is that the number of researchers working on this topic will increase, and it is also possible that more journals and conferences will be willing to publish articles on this topic, enriching the academic landscape with diverse perspectives and findings (Alhashem et al., 2023). This growing interest will likely result in more journals and conferences focusing on this topic, further enriching the academic discourse around virtual laboratories in science education (Rigue, 2022). As educators and researchers continue to investigate the efficacy of virtual laboratories, it is anticipated that more evidence will emerge regarding their impact on the affective domain, particularly in terms of enhancing student motivation, engagement, and overall learning experience (Wen et al., 2022; Agbo et al., 2023).

This trend can be attributed to several factors, including technological advances that facilitate the creation and implementation of virtual laboratories, as well as the growing recognition of their potential to enhance student engagement and learning outcomes. Virtual laboratories have been shown to increase student motivation and engagement, thereby enhancing their overall learning experience (Sugiharti et al., 2021). The ability of virtual laboratories to provide an interactive and immersive learning environment allows students to engage more deeply with scientific concepts, which can lead to improved attitudes toward science and increased self-efficacy (Alhashem et al., 2023). Additionally, the flexibility and accessibility of virtual laboratories allow students to engage with learning materials at their own pace, which can enhance motivation and self-efficacy (Peechapol, 2021).

Trends by Education Level

The study on the use of virtual laboratories in science learning for the improvement of the affective domain reviewed has populations of various levels of education can be seen in Figure 3.

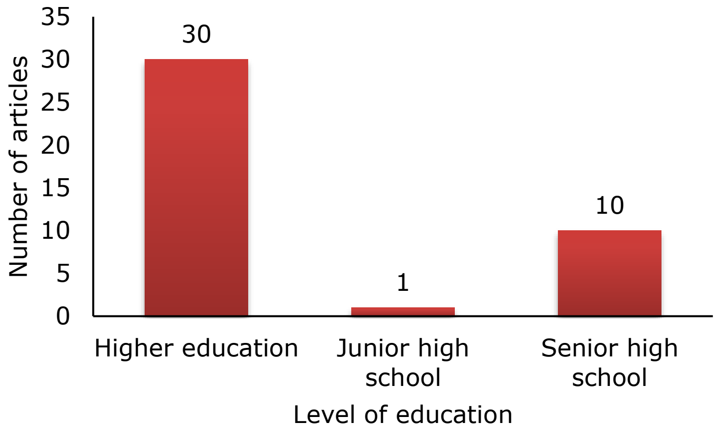

Figure 3. Trends by education level

Further analysis of the level of education in the use of virtual laboratories in science learning for the improvement of the affective domain shows a wide range of subjects or participants targeted. The results of the literature review show that the most dominant studies are carried out at the higher education level of 73% (n = 30), of which 14 are in the field of chemistry, 8 are in the field of physics, 7 focus on the field of biology, and 1 study focuses on the field of science. These findings suggest that the effectiveness of virtual laboratories in fostering affective domains such as motivation, attitudes, and engagement tends to be more pronounced in higher education, where students are often more independent and able to utilize these technologies for deeper learning (Rohim, 2020).

Furthermore, the senior high school level is 24% (n = 10) which each focuses on 3 studies in chemistry, 2 studies in biology, and 5 studies in physics. The limited use of virtual laboratories in high schools can be attributed to a variety of factors, including resource constraints and lack of familiarity with technology among educators. The gap in virtual laboratory adoption between senior high schools and higher education underscores the need for targeted interventions to promote technology integration in secondary education (Asgari et al., 2021).

Only 3% (n = 1) of studies conducted at the junior high school level focused on the field of science. This suggests higher educational attainment is more common than lower levels of education. There is a significant gap between the percentage of virtual laboratory use in senior high school and in higher education. The percentage of students who are highly educated is three times the percentage of students in senior high school. The percentage of students with junior high school education is the lowest among the three levels of education shown. This disparity suggests that while higher education institutions are embracing technological advances to enhance the learning experience, there are still critical gaps in the adoption of such technologies in senior high school and junior high school. Overall, the level of use of virtual laboratories is likely to increase as education levels are higher. This reflects efforts to enhance the learning experience by utilizing advanced technology, especially at higher levels of education. Nonetheless, it should be noted that the adoption of this technology still needs to be increased at the senior high school and junior high school education levels to achieve a more equitable level of use at all levels of education.

Trends by Journal Publication

Of the 41 articles that have been collected from the scopus database, the researcher counted the number of articles to see the journal's bibliographic pairs, then sorted them based on the number of articles. The seven articles with the highest number are presented in Figure 4.

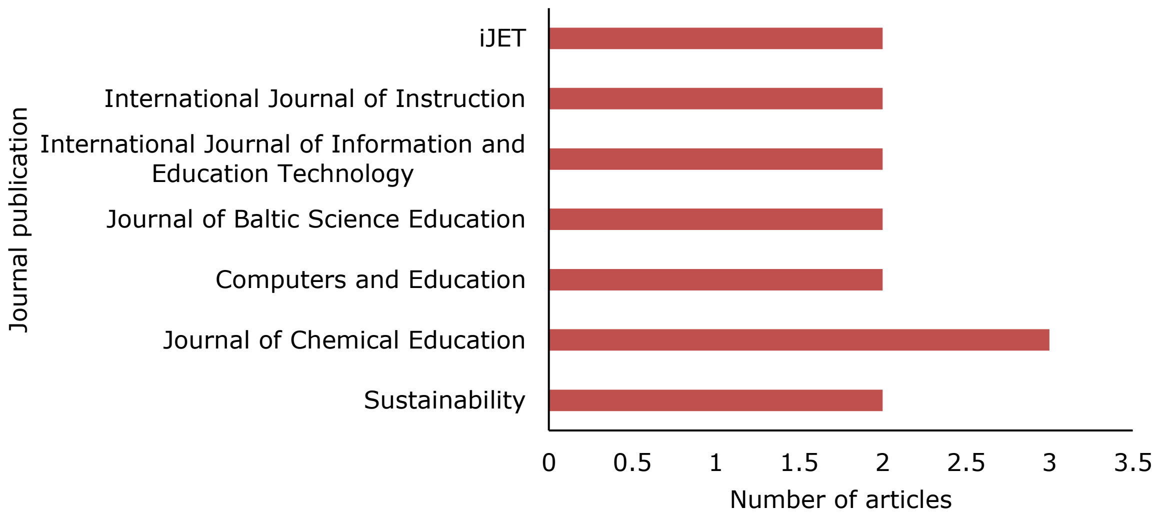

Figure 4. Trends by journal publication

From the figure above, it shows the trend of journals with the number of publications regarding the use of virtual laboratories in science learning for the most affective domain improvement. Journal of chemical education is at the top with 3 articles, followed by iJET, sustainability, computers and education, journal of baltic science education, international journal of information and education technology, and international journal of instruction which have the same number of 2 articles.

Trends Based on Keywords Used

Figure 5 shows the virtual laboratory-related keyword network provided by VOSviewer software for the scopus database. Keywords that are not related to the research are removed manually. VOSviewer can effectively map collaborations between authors across countries, providing insight into the landscape of scientific collaboration (Lam et al., 2023). VOSviewer can be used to illustrate international collaborations and research trends through keyword mapping, underscoring its usefulness in visualizing the evolution of a research field (Sun et al., 2020). This visualization helps researchers recognize influential works and authors, which is important for understanding the trajectory of a particular research area.

VOSviewer's ability to visualize research trends is particularly useful for planning future studies as researchers can identify areas that are still under-researched or under-explored and potential directions for future investigation (Chen et al., 2022). The software's overlay visualization feature allows for a two-dimensional representation of nodes, where color and distance indicate relationships and temporal aspects of research topics, further enhancing understanding of research developments. VOSviewer's ability to generate cluster maps allows researchers to intuitively analyze the current status of a field and identify research foci and frontiers (Lu et al., 2023).

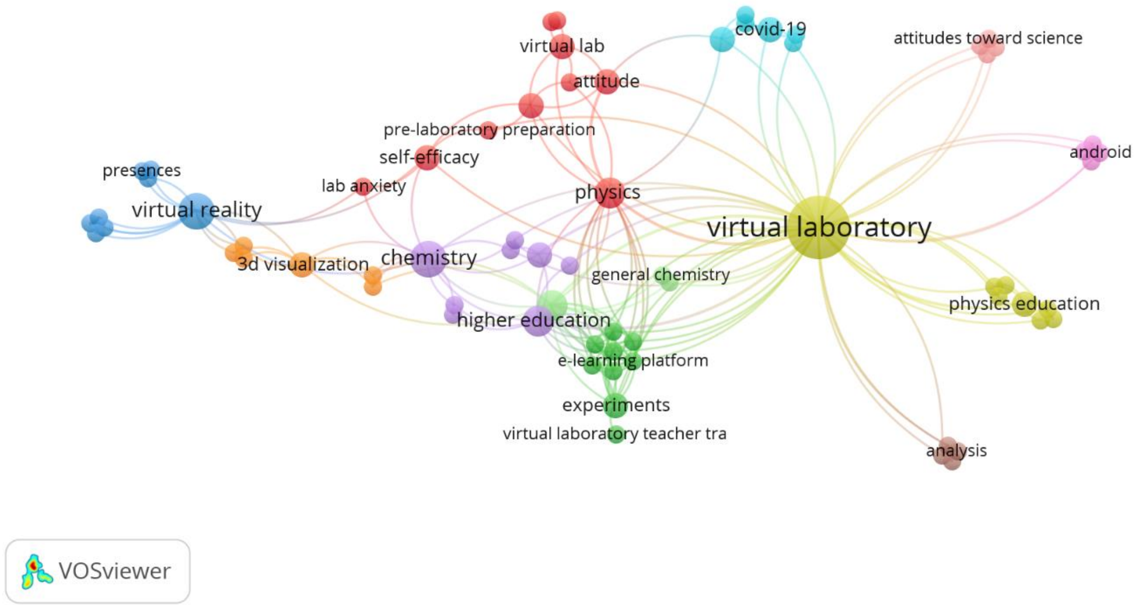

Figure 5. Trends based on keywords used

The results of the network visualization in the figure above show that there are 11 clusters with a total of 70 items regarding virtual laboratories in science learning for the improvement of the affective domain. However, what is discussed in this study is only up to cluster 5, with a minimum of 2 times of shared use. In cluster 1, physics is the main node and occurs 3 times which is marked in red. As the main node in cluster 2, the experiment occurs 2 times, marked in green. In cluster 3, in blue, the main node is virtual reality with 4 events. In cluster 4, the main node is yellow and the main node is virtual laboratory with 12 occurrences; and in cluster 5, in purple, the main node is chemistry with

4 occurrences. From the figure above, it shows the network visualization of the use of shared keywords (minimum 2). The keyword "virtual laboratory" is the most commonly found, which is as many as 12 shared uses, this can be seen from the large circle size compared to the others. The larger the circle, indicating that the keyword has been widely used and in demand by researchers related to the use of virtual laboratory in science learning. Followed by chemistry and virtual reality which were both used for 4 events. another keyword that is included in the most common events is physics.

Trends by Discipline

The focus of learning in literature studies is identified through research objectives, research questions, and research results. The main focus in this research includes the disciplines of physics, chemistry, biology, and science.

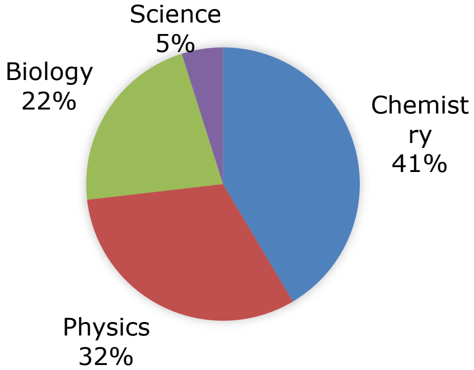

Figure 6. Trends by discipline

The studies reviewed had populations from different fields of science. From the image above, the chemistry virtual laboratory is very popular and is the most widely used and developed in supporting the affective domain of learning. The majority of the studies in the articles reviewed, n = 17 articles (42%) investigated in the field of chemistry, n = 13 articles (32%) in the field of physics, n = 9 articles (22%) in the field of biology, and only n = 2 articles (5%) in the field of science. In this context, information was obtained that the field of science is rarely studied further. These results are in accordance with the research (Jagodziński et al., 2015) which states that virtual laboratories have been developed in the field of chemistry compared to other fields of science. The flexibility of virtual laboratories has been known to improve the understanding of abstract concepts in chemistry.

Today, more and more research is supporting the need for virtual laboratories in chemistry, a solution in response to the ever-evolving educational landscape and the need for flexible, accessible, and effective learning environments. Shift towards platform Virtual laboratories have been accelerated by the covid-19 pandemic, prompting the need for innovative approaches to engage students in chemistry education (Soong et al., 2021). The addition of virtual labs can reportedly improve students' understanding of chemistry and increase their motivation to study the subject (Hale-Hanes, 2015; Trindade et al., 2022). In addition, the development of virtual laboratories has been recognized as a means to address the challenges of implementing chemistry practices in secondary schools, emphasizing its potential to improve accessibility and inclusivity in science education (Aliyu et al., 2019).

The use of virtual laboratories in chemistry learning can help students gain an in-depth understanding and overcome conceptual errors. Students involved in such learning show a strong interest, thus virtual laboratories can be implemented to facilitate the teaching of chemistry. Virtual laboratories are also a practical option to optimize resources and a good substitute for laboratory experiments in the event of a pandemic, lockdown, or an interest in testing the impact of hazardous conditions to ensure the sustainability of learning outcomes from related experiments (Elkhatat et al., 2023). Research (Tatenov et al., 2023) also shows the same thing, namely there is an increase in conceptual understanding, scientific process skills, working with laboratory tools, logical thinking, creativity, motivation, interest, perception and learning outcomes. Most students argue that virtual labs help them understand complex concepts and acquire practical skills.

Research on the use of virtual laboratories in chemistry shows that most students are able to write hypotheses, test their accuracy and report test findings correctly; Students have fun during the implementation which also provides effective learning (Avcı, 2022). In addition, it has also been shown to be effective in enhancing students' learning experience, being able to stimulate their engagement with course content but also optimizing their preparation for actual laboratory work (Alhashem et al., 2023).

Virtual Lab Platform

The authors of the reviewed articles use various virtual lab development platforms. Amrita virtual labs and amrita technology enabling center (TEC) and go-lab are used in the field of science. The chemistry virtual lab is accessible on several platforms, such as 3dvista, blender and unity, aspen plus (APSAT), praxilabs, unreal engine 4 and oculus quest™, PhET, unity 3d, javascript, telelab, blackboard collaborate, amrita, virtual general chemistry laboratory (VCL), labview, SL viewer, and thinglink. In the field of biology, the platforms photolab, labster, blender and unity, javascript, hyper text, and unity, learn.genetics, praxilabs and learn.genetics, and adobe premiere pro v 14.3. Various fields of physics utilize different virtual laboratory platforms, such as SL viewer platform, PhET, vue.js, virtools, schematic editor, javascript, adobe flash cs 6 and actionscript 3.0, glx, facelab and applied science laboratories (ASL) mobileeye, and circuit lab.

From the above findings, it shows that the use of these platforms provides variation in learning experiences, allowing students to engage in more immersive and dynamic activities. Each platform has different advantages, and by understanding this, the teaching approach can be tailored to meet the learning needs and maximize its impact on the affective domain of students.

Some studies highlight that students' affective responses can be affected by the type of platform used, using simulations PhET in teaching chemistry has the potential to increase students' enthusiasm (Moore et al., 2014). This supports the claim that PhET providing a more immersive and dramatized experience, potentially influencing students' affective responses positively. Furthermore, it was found that the simulation PhET has an overall positive impact on students' attitudes and perceptions of learning, improves conceptual understanding and facilitates the learning of abstract concepts (Salame et al., 2021). Virtual simulation integration PhET with LMS platform Improving students' reasoning skills in modern physics courses (Verawati et al., 2022). Moreover PhET useful in helping students to visualize abstract concepts (Avcı, 2022).

Simulation using the labster platform allow students to learn at their own pace and plan and repeat content whenever needed. The use of the APSAT platform in learning has been studied and shown that the platform can stimulate deep understanding and overcome conceptual errors. Students showed quite high interest so that this platform can be a practical choice to optimize resources and a good substitute for laboratory experiments in the event of a pandemic/lockdown (Elkhatat et al., 2023).

Another platform, thinglink can produce unique virtual laboratory resources because it is able to display image and video augmentation to create interactive visual learning experiences for users to utilize. One of the greatest potential strengths of the thinglink platform compared to other means of producing virtual laboratories is its simplicity and flexibility. The platform requires minimal training to use, and the only raw materials needed for content creation are images or videos that can be combined with audio files, all of which can be generated at minimal cost. Additionally, thinglink is a browser-based platform and does not have major requirements in terms of hardware (an internet connection is required) (Jeffery et al., 2022).

Affective Domain

These findings suggest that the use of virtual laboratories has a positive impact on students' affective domains in a variety of science subjects, including physics, chemistry, biology, and science in general. Various studies have reported improvements in affective domains such as self-efficacy, attitudes towards learning, motivation to learn, interest in learning, scientific attitudes, and student confidence. Assessing and evaluating the affective domain presents challenges, as it relates to the feelings, interests, and values inherent in the subject matter (Abdulfatai et al., 2014). Affective domain assessment can be carried out with various methods and instruments, including observation, questionnaires and surveys, interviews, portfolios, performance measurement, peer observation, parent reviews, and formative approaches. The combination of several methods can provide a more complete picture of the student's affective realm (Williyanto, 2020).

Questionnaires and surveys are widely used instruments to assess students' attitudes, interests, and motivation towards learning, covering aspects such as confidence, motivation to learn, and perception of subject matter (Galloway et al., 2015). Interviews can provide a deeper understanding of students' feelings and attitudes towards learning. By asking open-ended questions that encourage students to talk about their emotional experiences, educators can gain valuable qualitative data regarding students' affective domains. Interviews allow for a personal and in-depth exploration of students' emotional aspects and attitudes in the learning process. Observation is a fundamental method to measure students' affective realm. By observing students' behavior during learning, educators can record their facial expressions, postures, and social interactions, which can provide insight into their emotional states and attitudes towards learning.

Constructivist theory states that students' motivation to learn can begin with students having to put in the effort to learn, and in turn will try to be motivated to learn in a meaningful way, and it is necessary as a whole in the learning process. Motivation and engagement are critical aspects to support effective learning (Rahayu et al., 2011). The success of this student's learning is highly dependent on his or her motivation. The higher the learning motivation that students have, the higher the learning goals will be achieved. The existence of high learning motivation in students can be characterized by the emergence of perseverance, tenacity, independence, not easily wavering and happy to solve or solve a problem. On the other hand, when students have low motivation to learn, the attitude that arises is not confident and feels stupid, does not have clear goals (Widarti et al., 2024).

In general, student motivation can be identified into two, namely intrinsic and extrinsic motivation (Putri et al., 2022). Intrinsic motivation is related to the love of learning and interest in mastering a subject. While extrinsic motivation is related to motivations that come from outside the self, such as values, parental pressure, work or school, friends, and so on (Álvarez-Herrero et al., 2021). Increased self-efficacy and expectation of outcomes can increase intrinsic motivation and lead to further progress while learning (Rahayu et al., 2011).

Findings regarding the improvement of students' affective domains are reported consistently in the literature reflecting a strong consensus in the study. This shows that the use of virtual laboratories in science learning has a consistent positive impact on affective aspects. The implication is that this approach has the potential to stimulate interest, increase learning motivation, and create a more positive learning experience in the context of science learning.

Conclusion

This study provides a detailed analysis of publication trends in scopus-indexed journals on the use of virtual laboratories in science learning that fluctuated, peaking in 2023 with 10 articles published, most of which came from higher education (30 articles). The journal of chemical education dominated with 3 articles, while other journals such as iJET and sustainability each contributed 2 articles. The most frequently appearing keyword was "virtual laboratory", with chemistry as the most widely studied subject, and the affective domain commonly reported was positive attitudes towards learning. This study noted variations in the use of various digital platforms which led to fragmentation of perspectives, making it difficult to draw consistent generalizations. In other words, because the main findings come from specific contexts and platforms, generalizations are difficult to apply to different cases or use other platforms.

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