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RESEARCH TRENDS ON VIRTUAL LABORATORY IN SCIENCE EDUCATION OF THE LAST DECADE: INTEGRATION OF BIBLIOMETRIC AND CONTENT ANALYSIS

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Abstract

Virtual labs (VL) and simulations are attractive for their broad applicability across academic disciplines, spanning STEM, healthcare, and social sciences. They bridge theory and practice, offer cost-effective and scalable solutions, and provide secure learning environments. The COVID-19 pandemic has further emphasized their importance in education. However, how was the development of VL in science education and post-Covid, is it still interesting? This article presents a bibliometric and content analysis of research trends in the field of Science Education from 2014 to 2023, with a specific focus on the integration of virtual labs in learning. The analysis employs VOSviewer application and encompasses the titles and abstracts of scientific articles from international journals indexed by Scopus over the recent decade. This research review and bibliometric analysis of virtual laboratories (VL) in education reveals several critical insights. A highly cited article, "Virtual laboratories for education in science, technology, and engineering: A review," serves as a cornerstone in the VL literature, while Krishnashree Achuthan stands out as a prolific researcher in India, actively contributing to virtual labs and educational innovation. Co-occurrence analysis spotlights the significance of keywords like "student," "education," "e-learning," and "virtual reality," underscoring their relevance within the realm of VL in education. The presence of "COVID-19" highlights the pandemic's impact on the increased utilization of virtual labs for remote learning. Across various subject areas, virtual laboratories find broad applicability, especially in the social sciences, computer science, medicine, and mathematics. Furthermore, the prevalence of VL themes in fields like Chemistry, Physics, and Biology showcases their suitability for experiments, controlled environments, and increasing accessibility. In summary, virtual labs offer enhanced learning experiences, interactivity, scalability, and cost-efficiency, bridging the gap between theory and practice and supporting diverse disciplines despite persistent challenges in terms of user-friendly interfaces.

Keywords: Bibliometrics, Virtual Laboratory, Science Education.

1. INTRODUCTION

The adoption of Virtual labs (VL) and simulations extends beyond specific educational levels or subject areas and encompasses a wide array of disciplines, spanning from science, technology, engineering, mathematics (STEM), healthcare, to social sciences, and more (Achuthan, Kolil, and Jyothy 2023; August et al. 2016). Digital technologies, including virtual tools, have revolutionized education by bridging the gap between theory and practice, promoting in-depth comprehension and skill development among students. These technologies not only aim to reduce pollution and waste while boosting production and efficiency but also have significantly impacted the education sector, with the COVID-19 pandemic further cementing their role.(Mohsin, Arfin, and Sarwar 2022) This digital transformation in education offers cost-effective and scalability solutions (Kogan et al. 2014), replacing the need for physical models or field trips with virtual environments accessible to multiple students simultaneously. Additionally, it ensures a secure and regulated learning environment, particularly when dealing with intricate machinery or dangerous materials.. (Haleem et al. 2022; Marougkas et al. 2023)

Each year, the quality and quantity of publications related to digital in educational settings show a notable increase, attracting growing interest from researchers in the field of education (Gutiérrez and Mora 2017). With the introduction of these virtual tools, educators have gained the capability to bridge the divide between theoretical knowledge and practical application, facilitating a deeper comprehension and the cultivation of skills among students.

Bibliometric analysis is a method that condenses extensive bibliometric data to provide an overview of the intellectual structure and emerging research trends within a specific research topic or field. (Donthu et al. 2021).Bibliometrics is described as the "utilization of mathematical and statistical techniques for the examination of literature and other modes of communication" (Pritchard, 1969) (Glänzel 2003). It encompasses the categorization of research items in a particular scientific field, contingent upon bibliographic particulars, encompassing citations, keywords, subjects, institutions, nations, authors, sources, and titles. Through the application of advanced bibliographic analysis techniques, scholars can generate bibliographic visualizations, navigate these maps for exploration, scrutinize bibliometric associations, construct bibliographic couplings, and gauge the robustness of these couplings. Bibliographic maps are produced, visually represented, and explored using sophisticated methodologies, with elements such as authors, publications, or terms as the foundational components. The ties between pairs of elements illustrate affiliations or associations, with the intensity of these links signified by numerical values, where higher values denote more robust associations between elements. In the context of bibliographic couplings, the link strength underscores the number of referenced sources shared by two elements, while for co-occurrence connections, link strength signifies the recurrence of instances where two terms emerge concurrently. These elements and connections collectively compose a bibliographic network. (Glänzel 2003)(Muhammad et al. 2022) (Newman, 2004; Perianes-Rodriguez, Waltman, & Van Eck, 2016; Waltman, Van Eck, & Noyons, 2010; Waltman & Van Eck, 2013; Van Eck & Waltman, 2009; Van Eck, Waltman, Dekker, & Van den Berg, 2010).

Content analysis is valuable for categorizing the substantive focus of published research and providing a parsimonious perspective on a topic and insight into what is viewed as important to the field (Eby et al. 2005)

In Content Analysis We selected 30 articles bibliometric database that related to Virtual laboratory science education. This research harnessed the extensive Scopus database as the primary source for the identification of substantial publications concerning Virtual Simulation and Virtual Laboratory in the realm of education. Employing both descriptive and evaluative bibliographic analysis methodologies, the research team retrieved and scrutinized data from these databases. As technology continues to progress, VL introducing new possibilities and addressing the ever-changing demands of education and research. This article will delve into recent advancements in the utilization of these technologies, exploring their profound influence on teaching, learning, and research across diverse fields of study.

This study aims to provide a comprehensive overview of the evolution of this transformative educational technology. Through bibliometric analysis, we seek to unravel the key themes, influential authors, top journals, and emerging research directions that have shaped the landscape of virtual lab and simulation integration in learning. Drawing upon an extensive analysis of articles indexed in the Scopus

database, So this article of bibliometric and content analys are intend to explores the trends and developments in the utilization of virtual labs and simulations in education, spanning the years from 2014 to 2023.

To enhance the depth of a bibliometric article, we conducted content analysis with the aim of identifying current research trends and extrapolating potential future research directions. This analytical approach allows us to gain insights into the evolving landscape of research in our field, helping us better understand where it is headed and how we can contribute to its ongoing development.(Bhandari 2022). In our comprehensive study on the utilization of Virtual Laboratories (VL) in education, we aim to unveil a multifaceted understanding of this innovative approach. We explore the extensive realm of VL literature and investigate the most prolific authors and countries actively engaged in this field, shedding light on their collaborative networks. Additionally, we delve into the predominant subject areas explored within VL literature, discerning the key domains of focus. Furthermore, we scrutinize the abstracts of VL in education to unearth the most popular keywords and terms, which provide valuable insights into the core themes of this research area. Finally, we track the evolving research trends related to Virtual Laboratories in education, thus contributing to a comprehensive picture of the field's development over time."

2. METHOD

Data Collection:

This bibliometric analysis focuses on research trends in the field of Education, specifically the integration of virtual labs and simulations in learning, spanning the period from 2014 to 2023. The dataset for this analysis was sourced from international journals indexed by Scopus. To narrow down the focus, the keyword "virtual lab in science education" was employed to retrieve relevant scientific articles.

Data Source:

The primary source of data for this study is the titles and abstracts of scientific articles from Scopus-indexed journals. The selection criteria included articles published within the specified timeframe and related to the integration of virtual labs and simulations in the context of education, with a particular emphasis on science education.

Data Analysis:

The methodological approach adopted for this bibliometric analysis involves the utilization of the VOSviewer application. VOSviewer is a widely-used tool for bibliometric visualization and analysis, allowing for the exploration of co-occurrence networks and the identification of research trends, influential authors, and thematic clusters within the dataset.

Keyword Search:

The initial search was conducted using the keyword "virtual lab in science education" to extract a relevant subset of articles. This keyword was chosen to ensure a specific focus on the integration of virtual labs and simulations within the field of science education.

Visualization and Network Analysis:

The analysis involves the visualization of bibliometric data to uncover trends, connections, and areas of research concentration. The VOSviewer application is instrumental in creating visual representations that illustrate the network, overlay, and density of research topics and their interrelationships.

Identification of Research Trends:

Through the analysis of co-occurrence networks, thematic clusters, and influential authors, this study aims to identify key research trends in the integration of virtual labs and simulations in learning, with a particular emphasis on the field of science education.

Content Analysis:

The results of this bibliometric analysis will provide insights into how virtual labs have been integrated into learning environments, particularly within the context of Science education. It will also shed light on the potential for innovation at various educational levels.

In Content Analysis We selected 30 articles bibliometric database that related to Virtual laboratory science education

In summary, the materials and methods employed in this study involve the systematic collection of relevant scientific articles from Scopus-indexed journals, keyword-based data retrieval, the application of the VOSviewer tool for visualization and network analysis, and a comprehensive examination of research trends in the integration of virtual labs and simulations in education, with a specific focus on science education.

Table 1: Publication Records and Percentages by Publication Years

Publication Years	Publication Records	% of 572
2023*	154*	14.0
2022	196	17.9
2021	160	14.6
2020	144	13.1
2019	89	8.1
2018	88	8.0
2017	81	7.4
2016	76	6.9
2015	59	5.4
2014	59	5.4

* **The publication year 2023 is still ongoing, data taken until Oktober 2023**

Physics, neurosciences, urology, nephrology, dentistry, archaeology, chemistry, architecture, applied psychology, mechanical engineering, general medicine, geosciences, environmental sciences, applied mathematics, and oncology). Among the Scopus database categories, only the categories of social Science Education were selected, and the search results were refined. When search results were refined, there were 572 publications.

Search virtual AND laboratory AND Science Education

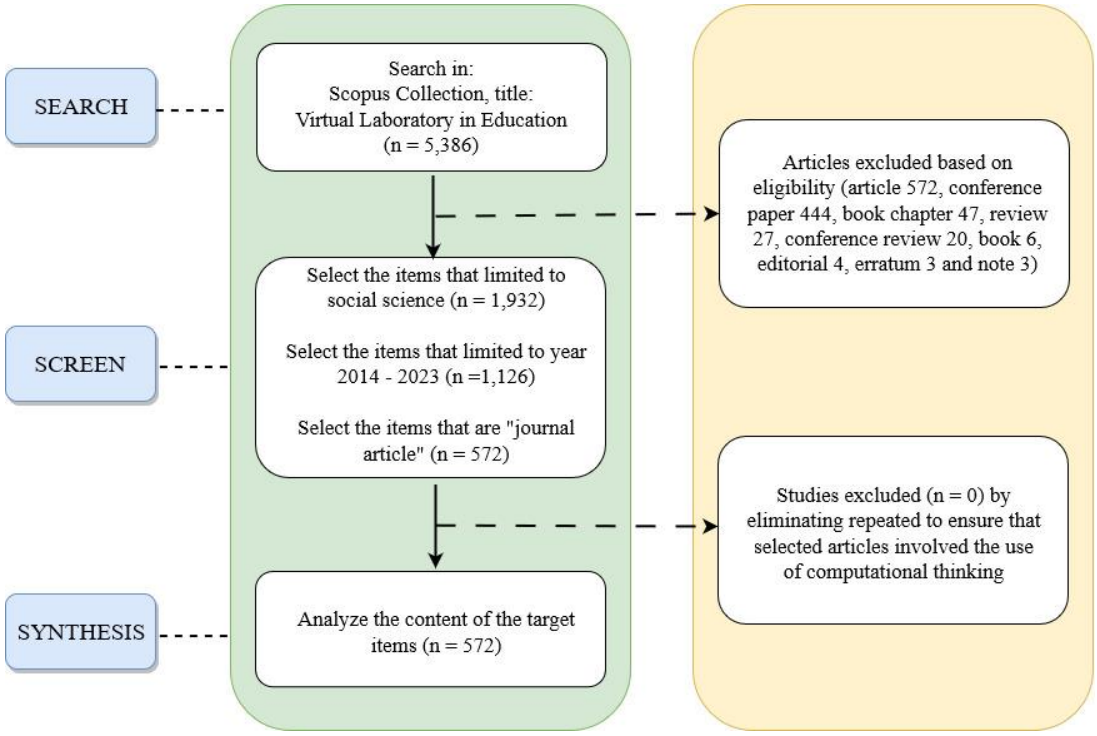


Figure 1: Shows the publication records and their percentages by publication years. According to the results, There are growing the research and publication

3. RESULTS AND DISCUSSION

The findings of the analyses are detailed in this section. In presenting the various categories of results from bibliometric analysis, the researchers employed a deductive approach, mirroring the methodology used by(Lee, Felps, and Baruch 2014) and Ersozlu and Karakus (2019).

The results have been structured to commence with broader discoveries and progress towards more specific ones. These include the bibliographic coupling of countries, institutions, journals, publications, authors, and the co-occurrence of author keywords. This sequential arrangement of content facilitates readers in tracing connections, starting with overarching information and subsequently delving into specific details that elucidate the earlier findings.

3.1 Bibliographic Coupling of the Countries

Bibliographic coupling of the countries is presented in Figure 1 with network visualization. A country's minimum number of publications was 5. Of the 92 countries, 34 met the threshold. For all of the countries, the number of publications, the number of citations, and total link strength were calculated. The countries with the greatest total link strengths were selected.

Number one was USA with 135 publications, 2610 citation, 23 total link strength. For the other countries, the first numbers stand for the number of publications, the second ones are the number of citations, and the third ones are the total link strengths.

The other countries were; USA, Spain, UK, then followed by China dan Indonesia. In Figure 1, different colours show different clusters that were more frequently linked with each other. It means that the studies originated from the countries in the same cluster cite each other more frequently. At the biggest cluster, there are USA,

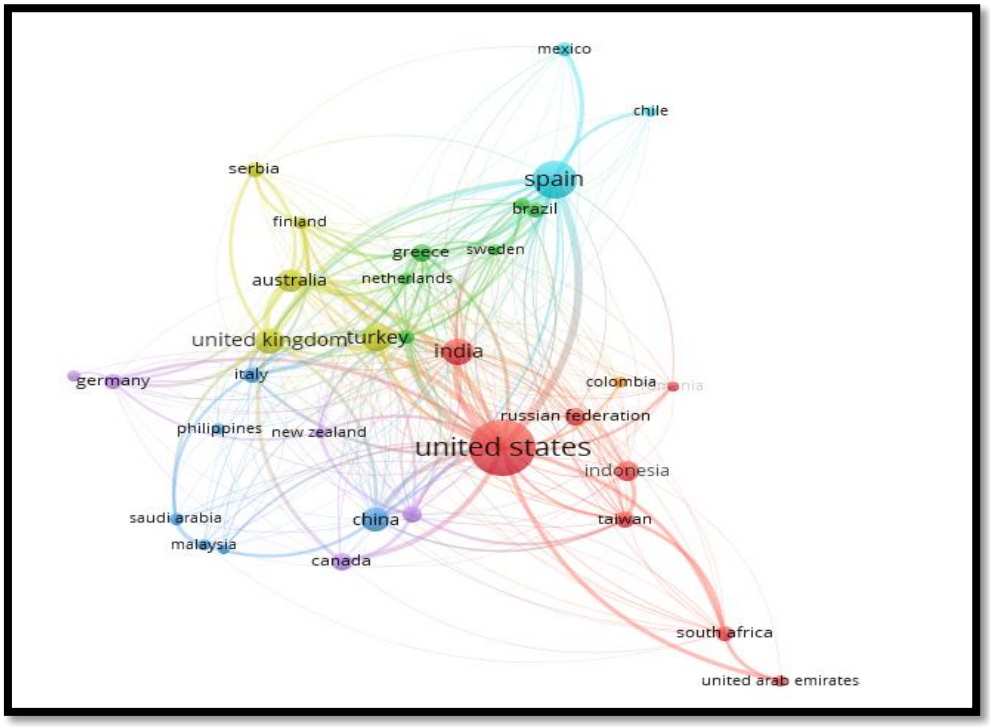


Figure 2: Bibliographic coupling of the countries (network visualization)

Bibliographic coupling of the countries shows that the United States is the most prolific country with 135 publications and 2610 citations based on VosViewer data. The top 10 countries based on publications and citations are displayed in the table below.

Table 2: Publication and Citation by Country data

No	Country	Publication	Citation
1	United States	135	2610
2	Spain	63	1700
3	Australia	24	1086
4	United Kingdom	29	923
5	Serbia	11	599
6	Finland	8	597
7	Canada	14	359
8	India	32	350
9	Greece	14	322
10	Denmark	9	263

Source : VosViewers\

Based on the table above, the United States is the country with the most publications and citations on the subject of virtual labs. The high number of publications is correlated with a high number of citations in several countries.

It can be concluded that the US is the most influential country in research on virtual laboratories in science education

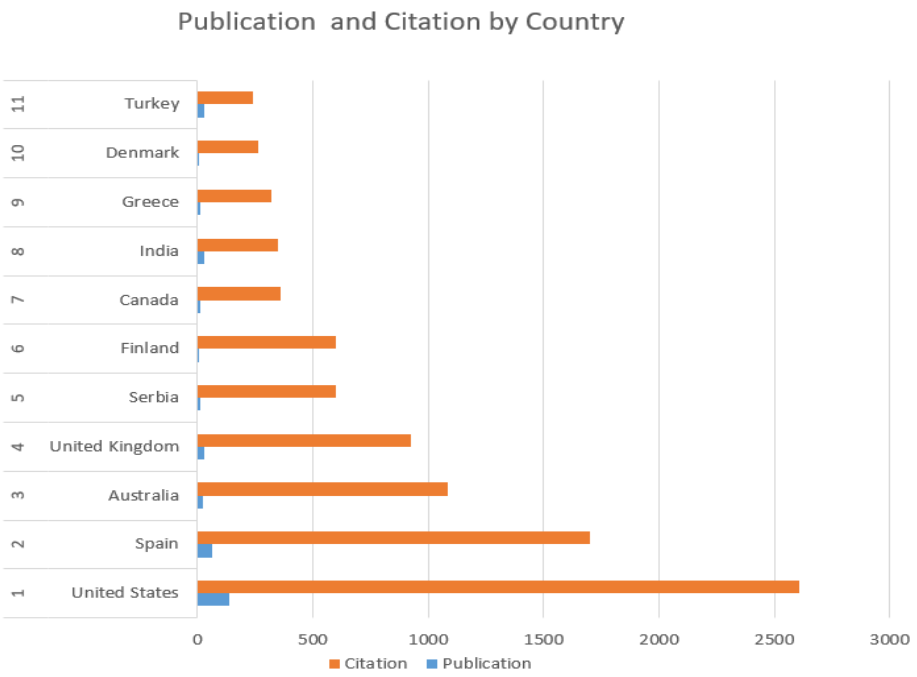


Figure 3: Publication and Citation by the countries

In addition to the United States, several other countries are also actively involved in publications regarding the use of virtual labs in science education. Bibliometric data reveals that Spain has 63 publications with 1,700 citations, Australia has 24 publications with 1,086 citations, the United Kingdom has 29 publications with 923 citations, Serbia has 11 publications with 599 citations, Finland has 8 publications with 597 citations, Canada has 14 publications with 359 citations, and India has 32 publications with 350 citations. While the United States leads in terms of the number of publications, other countries also make significant contributions to the advancement of research on virtual labs in science education, and international collaborations can enrich insights and practices in this domain.

The question that arises is why the United States has a significantly higher number of publications compared to other countries in this analysis. There are several reasons that may explain this phenomenon based on (Piwowar et al. 2018)(Smith 2014):

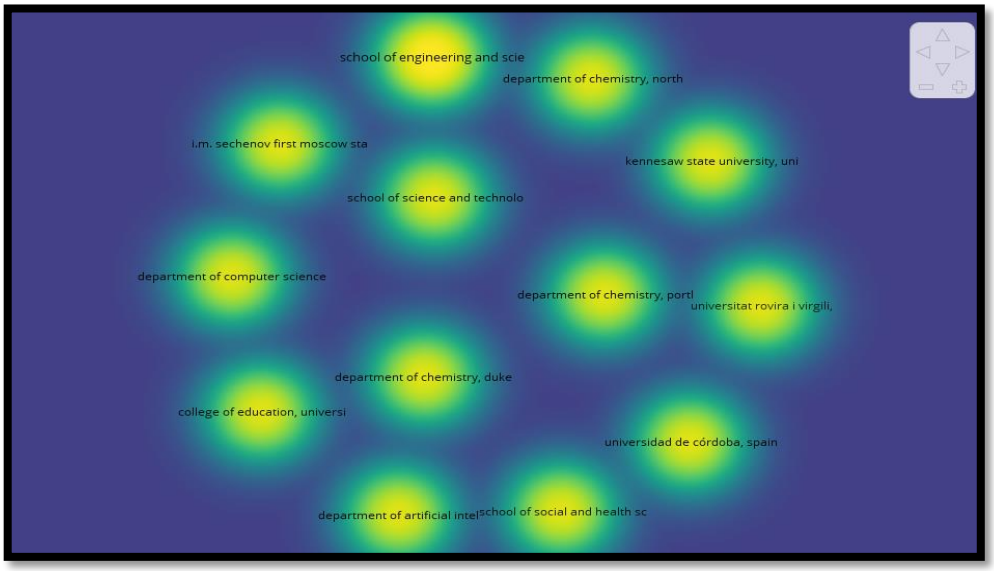
1. Resources and Investment: The United States possesses abundant resources for research and development across various fields, including science education. Substantial investments in research and educational development may have facilitated the production of a higher quantity of high-quality publications on virtual labs.
2. Prominent Educational Institutions: The United States is home to numerous renowned higher education institutions, such as universities and research organizations, which actively promote research in various educational domains. The presence of these institutions can significantly contribute to the publication output related to virtual labs.
3. Research Collaborations: Collaboration between academic institutions, researchers, and industries in the United States is likely to have driven research on virtual labs. Such partnerships can result in more publications in this field.

4. International Conferences and Journals: The United States frequently hosts various international conferences related to science and technology education. Additionally, there are many high-quality scientific journals open to research from around the world. This may have encouraged more research and publications on virtual labs originating from the United States.
5. Focus on Science Education: The country may have a strong focus on developing innovative science education methods, including the utilization of virtual labs. Robust initiatives in science education can encourage research and publications in this domain.

While the United States dominates in terms of the number of publications on virtual labs in science education, it is important to acknowledge the contributions of other countries in this field. This bibliometric analysis can serve as a foundation for a better understanding of global research trends in science education and encourage international collaboration to enhance the quality of science education through technology, such as virtual labs.

3.2 Bibliographic Coupling of the Organization

Bibliographic coupling of the Institution only the organization that have the minimum number of 2, 1277 of Organization, 13 meet the threshold Organization were included in the analysis.



Source : VosViewers

Figure 4: Bibliographic Coupling of the Organization

Through the VosViewer application, it was found that the institutions are evenly balanced or equally strong, with no prominent differences By the citation the most cited Organization was Kannesaw State University,US. With 191 Citation, Departemen of Chemistry North Carolina,US 100 citation

3.3 Bibliographic Coupling of the Publication

Only the Source publication that have the minimum number of 5, 189 of source publication, 27 meet the threshold publications were included in the analysis.

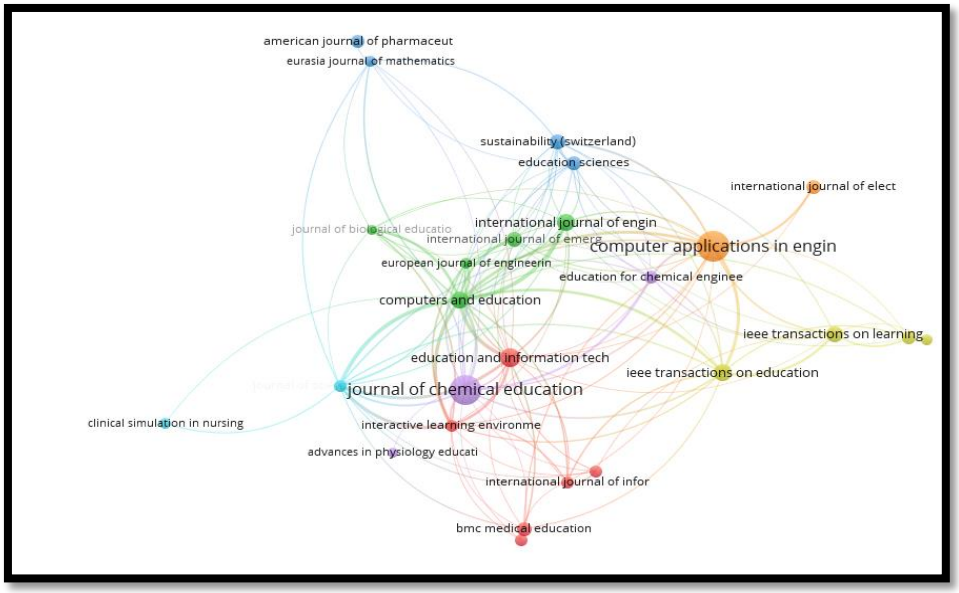
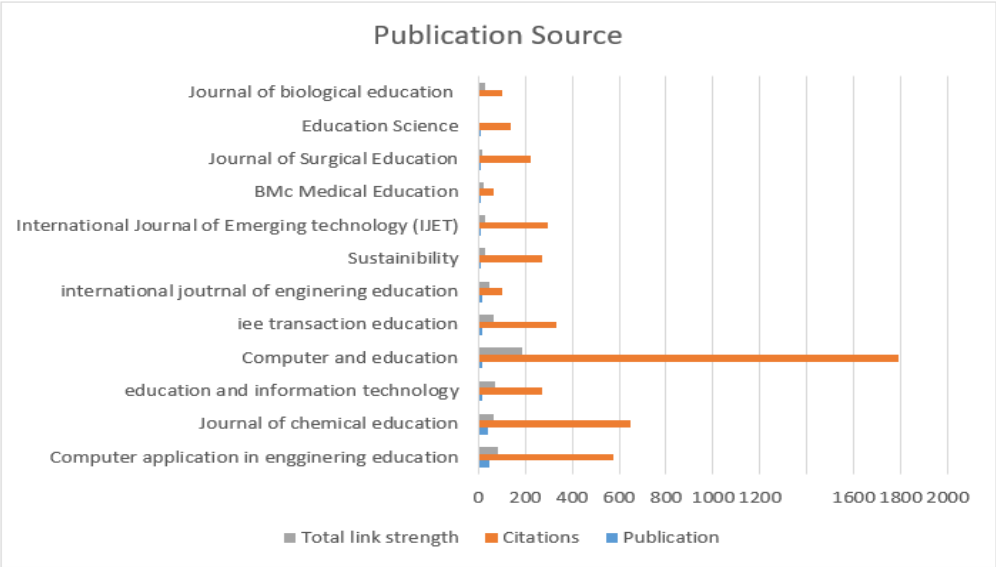


Figure 5: Bibliographic Coupling of the Publication Journal of Virtual Laboratory in Science Education



Tabel 3: Top 12 Source Publication and Citation

No	Source	Publication	Citations	Total link strength
1	Computer application in enginering education	48	574	86
2	Journal of chemical education	43	649	66
3	Education and information technology	19	273	73
4	Computer and education	15	1791	188
5	IEE transaction education	15	333	65
6	International joutrnal of enginering education	14	100	46
7	Sustainibility	13	272	28
8	International Journal of Emerging technology (IJET)	11	297	29
9	BMc Medical Education	11	64	23
10	Journal of Surgical Education	10	221	15
11	Education Science	10	137	0
12	Journal of biological education	5	99	27

Based on the results from VosViewer, it is evident that the most dominant source publication is "Computer Applications in Engineering Education" with 48 published documents and 574 citations. This is followed by the "Journal of Chemical Education," and then "Education and Information Technology." "The Journal of Computer and Education" is notable for having the highest number of citations, totaling 1791, despite having only 15 published documents.

3.4 Bibliographic Coupling of the Authors

Only the Author that have the minimum number of 2, 5 meet the treshold of Coupling Author were included in the analysis. The strongest author was Forsberg e, Ziegert in Subject area nursing and medical education Nurse Education Today Swedeen Department of Clinical Sciences, Intervention and Technology (CLINTEC) Bibliographic coupling of the authors is presented in Figure 5 with overlay visualisation. An author's minimum number of publications was 2 to be included in this analysis. Of the 573 authors, 5 met the threshold. For all the authors, the number of publications, the number of citations, and their total link strengths were calculated. The authors with the greatest total link strengths were selected. The strongest author was Forsberg e, Ziegert Subject area nursing and medical education Nurse Education Today Swedeen Department of Clinical Sciences, Intervention and Technology (CLINTEC), Karolinska Institutet, Stockholm, Sweden; Department of Computer and Systems Sciences (DSV), 2 publication and 58 citation

Source : VosViewers

Figure 6: Bibliographic coupling of the Author (network visualization)

There is a difference in data when using the VOSviewer application compared to manual data calculation. For instance, when examining author data:

Using the VOSviewer application, out of 573 authors, only 5 authors meet the criteria, with a minimum of 2 publications. The most prominent author is Forsberg E. Ziegert with 2 publications and 18 citations. However, when manually analyzing the data, the author with the highest number of publications is Achutan with 10 publications, and this author also has the largest percentage compared to other authors, as shown in Figure 6.

We observe differences finding when obtaining data from the VosViewer application compared to manual data collection. The following results are obtained through manual calculations. On the other hand, the most publication author was Achutan K.

3.5 Most Cited Articles

The article with the most citations in the manual data search is authored by Potkonjak V., Gardner M., Callaghan V., Mattila P., Guetl C., Petrović V.M., Jovanović K., titled "Virtual Laboratories for Education in Science, Technology, and Engineering: A Review," with 498 citations from the journal "Computers and Education."

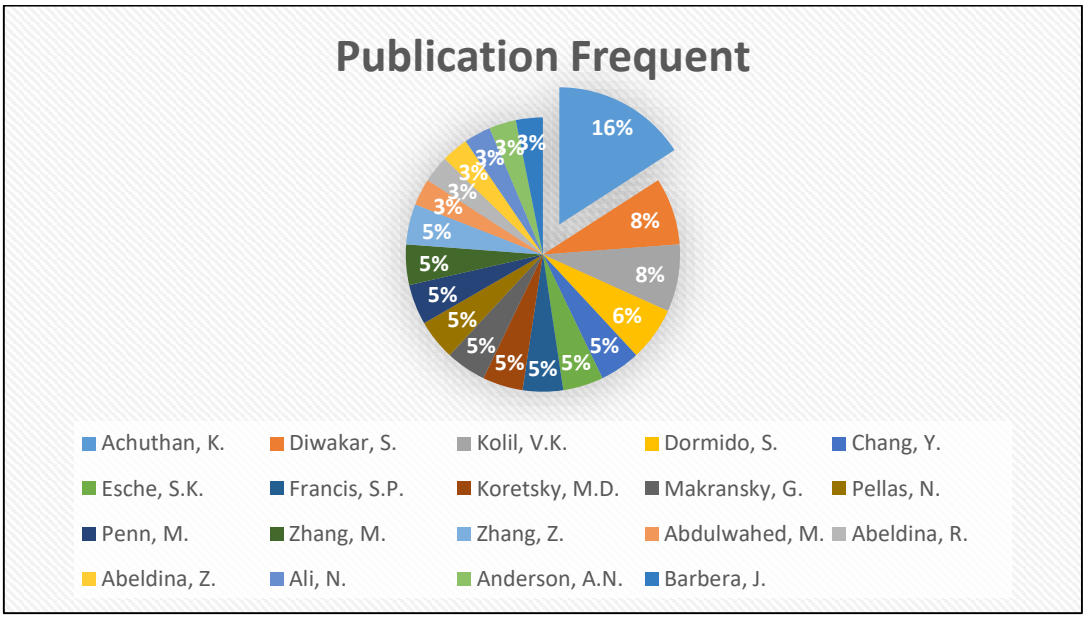
Table 4: Most Cited Article based on manual calculations

Authors	Title	Cited by	Source title
Potkonjak V.; Gardner M.; Callaghan V.; Mattila P.; Guetl C.; Petrović V.M.; Jovanović K.	Virtual laboratories for education in science, technology, and engineering: A review	498	Computers and Education
Martín-Gutiérrez J.; Mora C.E.; Añorbe-Díaz B.; González-Marrero A.	Virtual technologies trends in education	409	Eurasia Journal of Mathematics, Science and Technology Education
Heradio R.; De La Torre L.; Galan D.; Cabrerizo F.J.; Herrera-Viedma E.; Dormido S.	Virtual and remote labs in education: A bibliometric analysis	347	Computers and Education
Brinson J.R.	Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research	307	Computers and Education
de Jong T.; Sotiriou S.; Gillet D.	Innovations in STEM education: the Go-Lab federation of online labs	183	Smart Learning Environments
Estriegana R.; Medina-Merodio J.-A.; Barchino R.	Student acceptance of virtual laboratory and practical work: An extension of the technology acceptance model	172	Computers and Education
Konak A.; Clark T.K.; Nasereddin M.	Using Kolb's Experiential Learning Cycle to improve student learning in virtual computer laboratories	114	Computers and Education
Day T.; Chang I.-C.C.; Chung C.K.L.; Doolittle W.E.; Housel J.; McDaniel P.N.	The Immediate Impact of COVID-19 on Postsecondary Teaching and Learning	111	Professional Geographer
Chiu J.L.; Dejaegher C.J.; Chao J.	The effects of augmented virtual science laboratories on middle school students' understanding of gas properties	108	Computers and Education

Source : Scopus Database

The most frequently cited article in this list is "Virtual laboratories for education in science, technology, and engineering: A review," which has been cited 498 times from the journal "Computers and Education." This article appears to be one of the primary references in the literature concerning the use of virtual laboratories in science, technology, and engineering education. Additionally, the article "Virtual technologies trends in education" has garnered significant attention with 409 citations from the

"Eurasia Journal of Mathematics, Science, and Technology Education," indicating the significance of virtual technology trends in education. The article "Virtual and remote labs in education: A bibliometric analysis" published in "Computers and Education" also has a strong impact with 347 citations, demonstrating that bibliometric analysis of the use of virtual labs in education is highly relevant and contributes to the understanding of the field. Furthermore, the articles "Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research" from "Computers and Education" and "Innovations in STEM education: the Go-Lab federation of online labs" from "Smart Learning Environments" have also received attention in the literature, with 307 and 183 citations respectively. These articles provide insights into learning outcome achievement in non-traditional versus traditional laboratories and innovations in STEM (Science, Technology, Engineering, Mathematics) education.



Source : Scopus Database

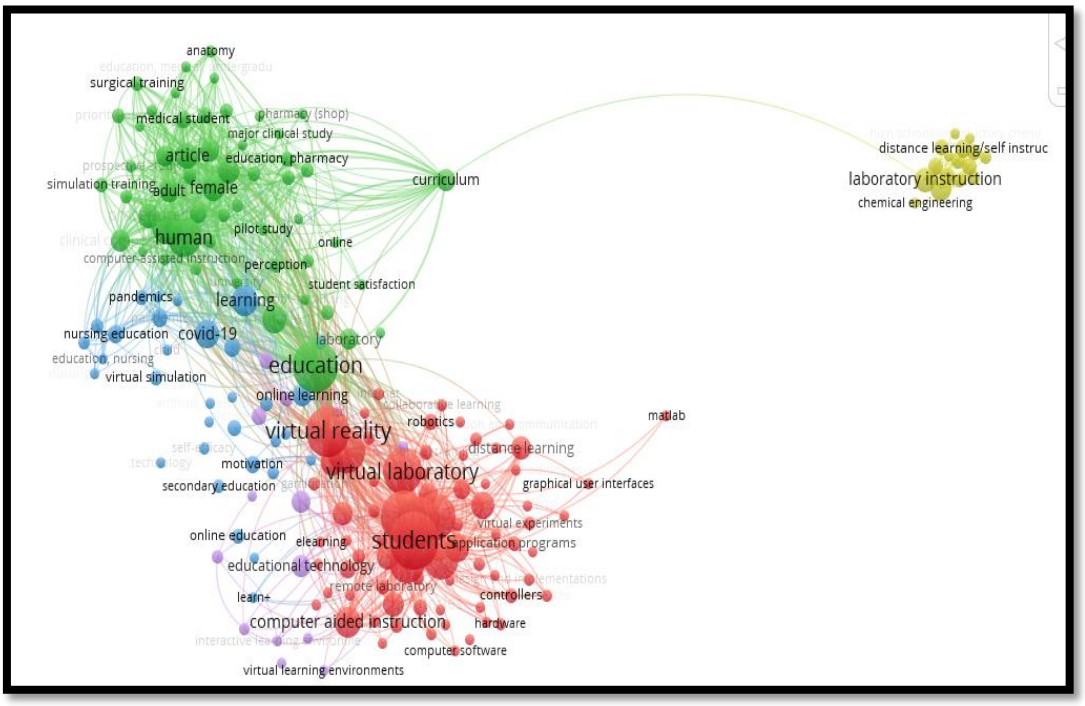
Figure 7: Publication Frequent by Author shows that Achutan, is the most cited Author

Based on manual Scopus data, it was found that the author Achutan K, known as Krishnashree Achuthan, is a highly prolific and frequently cited researcher from India. She holds a PhD degree from Clarkson University, NY, USA, and possesses multi-disciplinary interests, including Cybersecurity & governance, Mathematical Modeling of Systems, Cybersecurity policy, IoT Security, Public Safety, Innovation, Educational Technologies & Entrepreneurship. Dr. Krishnashree leads research teams at Amrita University, with a primary focus on enhancing laboratory education through virtual laboratories. Her remarkable contributions to the field are underscored by her 33 US patents and over 130 publications in journals and conferences. Moreover, she has actively participated in several strategic initiatives for the Government of India and served as the Principal Investigator, demonstrating her significant impact on both research and policymaking. Krishnashree Achuthan's work in virtual laboratories has a profound impact on innovative educational methods, and further investigation into her specific research projects, collaborations, and influential findings can provide a

more comprehensive understanding of her research endeavors (Achuthan, Kolil, and Jyothy 2023; Radhamani et al. 2021).

3.6 Co-Occurrences of Keywords

Co-occurrences of the author keywords are presented in Figure 8 with network visualisation. As inclusion criteria, the minimum number of occurrences of a keyword was 8. Of the 1098 keywords, 18 met the threshold. For all the keywords, the number of occurrences and their total link strength with other keywords were calculated. The keywords with the greatest total link strength were selected.



Source : VosViewers

Figure 8: Co-occurrences of the author keywords (network visualization)

The colours show different clusters in which the terms are more frequently linked with each other. The biggest cluster is virtual reality, followed by students, human, education, laboratory instruction, etc. In this journal article, we delve into the intricate web of connections among keywords associated with the utilization of virtual laboratories in the realm of education.

The pertinent keywords include "COVID," "virtual laboratory," "inquiry-based learning," and "environment." Furthermore, we aim to elucidate the rationale behind the conspicuous prevalence of the term "student" in the co-ocurrence analysis based on data extracted from 573 articles cataloged under the title "Virtual laboratory in science education" in the Scopus database.

It is imperative to comprehend that co-occurrence signifies the extent to which two specific keywords appear in conjunction within the corpus of articles. The higher the frequency of their co-occurrence, the stronger the association between them within the context of this research.

Order of Most Frequent Co-occurrences:

1. Student (136 co-occurrence): The keyword "student" takes precedence as the most frequently encountered term within the articles pertaining to virtual laboratories in educational contexts. This underscores the pivotal role of students in this research, suggesting that they are a central focal point in the implementation of virtual laboratories in science education.
2. Education (116 co-occurrence): The term "education" shares a substantial interconnection with virtual laboratories, signifying that the integration of virtual laboratory technology is a crucial facet of scientific education.
3. E-Learning (113 co-occurrence): "E-learning" proves to be highly relevant as virtual laboratories are frequently deployed as tools for online learning, especially during the COVID-19 pandemic.
4. Virtual Reality (108 co-occurrence): "Virtual reality" illustrates the relationship between the use of simulation technology and virtual laboratory-based learning, providing students with immersive learning experiences.
5. Virtual Laboratories (92 co-occurrence) and Virtual Laboratory (86 co-occurrence): Both keywords highlight the core concept of virtual laboratories in this research, potentially indicating the use of varied terminology within the academic literature.
6. Teaching (80 co-occurrence): The keyword "teaching" emphasizes the role of educators or professors in guiding students in their utilization of virtual laboratories.
7. COVID-19 (36 co-occurrence): The presence of "COVID" in the co-occurrence analysis underscores the pandemic's impact on education and the increased utilization of virtual laboratories for remote learning.
8. Inquiry-Based Learning (8 co-occurrence): Despite its significance in educational contexts, "inquiry-based learning" appears with lower frequency, possibly indicating that this aspect has not been a primary focus of research in this domain.
9. Environment (7 co-occurrence): The infrequent appearance of "environment" suggests that the relationship between virtual laboratories and the physical or contextual environment has not been a primary focus in this research.

In sum, the data analysis results indicate that virtual laboratory-based learning exhibits strong associations with students, education, e-learning, and virtual reality technology. Additionally, the COVID-19 pandemic has significantly impacted the discourse around virtual laboratories in education(Hassan, Devi, and Ray 2022; Tri et al. 2022).

Future research may delve into ways to enhance the efficacy of virtual laboratories in scientific education and address the challenges faced in contemporary education, including remote learning.

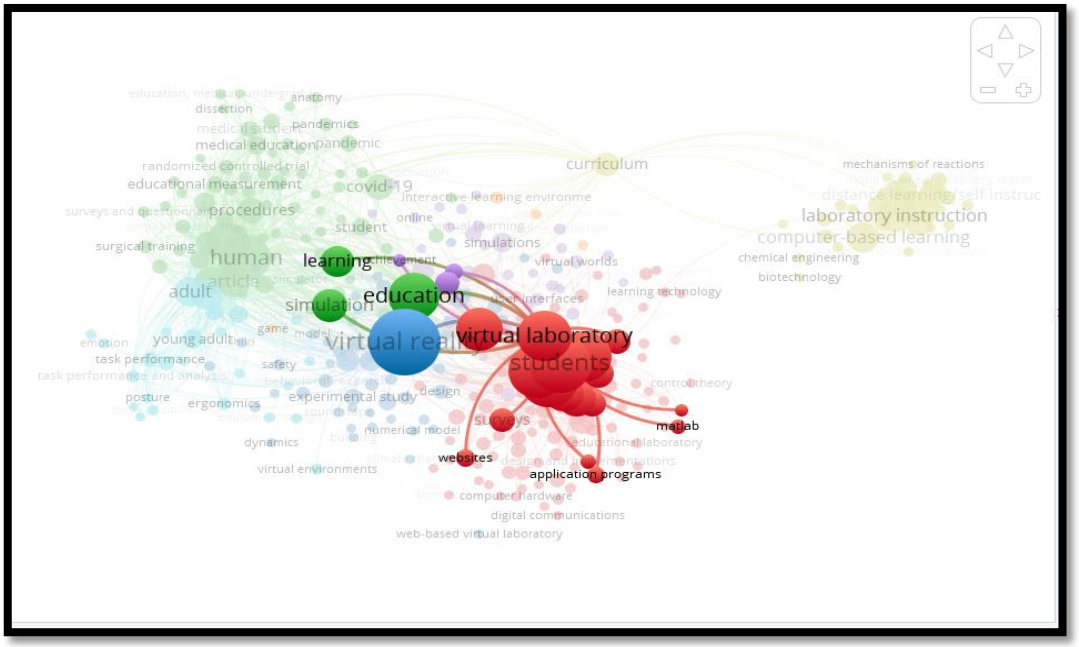


Figure 9: Co-occurrences of the author keywords when focusing on Virtual Laboratory

The following is the relationship between keywords. When focusing on the virtual laboratory, the closest association is primarily with students. The colors indicate various clusters in which terms are frequently interconnected. The largest cluster pertains to virtual reality, followed by students, education, learning, simulation, application programs, website, and MATLAB.

3.7 Based on Subject Area

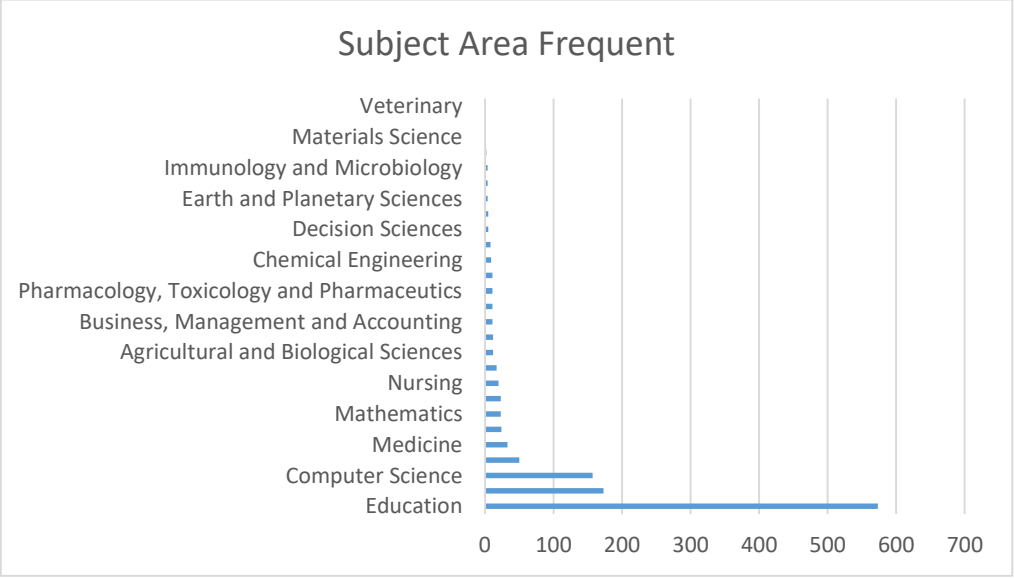


Figure 10: Subject Area Frequent based on Scopus dara

When considering the frequency of subject areas analyzed manually, it becomes evident that the utilization of virtual laboratories varies across disciplines. Notably, the Social Sciences emerge as the predominant subject area employing virtual laboratories, followed by Computer Science, Medicine, Mathematics, Nursing,

Agricultural and Biological Sciences, Business and Management Accounting, Pharmacology and Toxicology, Immunology, and Microbiology. This diversity of subject areas highlights the broad applicability and relevance of virtual laboratories in contemporary research and educational contexts.

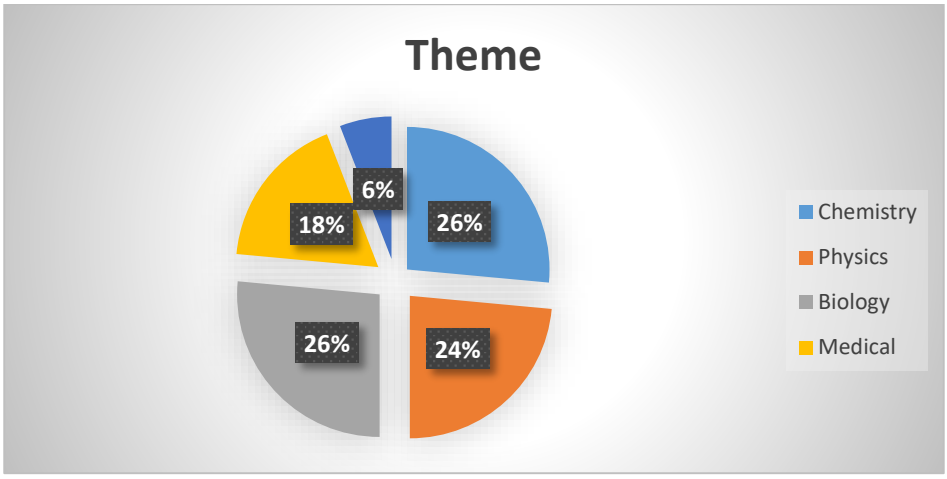


Figure 11: Themes that often appear and integrate with virtual labs(VL) based on Scopus data

Based on the themes that utilize virtual laboratories, Chemistry, Physics, and Biology stand out as the most common fields where virtual laboratories (vL) are extensively employed. This prevalence can be attributed to several compelling factors. Firstly, these natural sciences heavily rely on experimental work and practical applications, making virtual laboratories an efficient and cost-effective means for conducting experiments, simulations, and data analysis, particularly when access to physical laboratories may be limited or safety concerns are present.

This is particularly beneficial in educational settings, where students can learn and practice experimental techniques without the need for extensive physical resources. Secondly, the use of virtual labs in these fields ensures a controlled and standardized environment, allowing for consistent experiments and predictable outcomes. Such control is crucial in scientific research and education.

Moreover, the increasing availability of digital resources, software advancements, and improved internet connectivity have made virtual laboratories more accessible and user-friendly. This accessibility empowers researchers, educators, and students to seamlessly integrate virtual labs into their work, even in fields like medical and nursing education, where virtual labs can simulate medical procedures and patient care scenarios, offering a secure and effective learning environment.

In conclusion, the preference for virtual laboratories in Chemistry, Physics, and Biology reflects their suitability for experimental and practical applications, their capacity to provide controlled environments, and the growing accessibility and user-friendliness of virtual lab technologies. This trend mirrors the evolving landscape of science and education, where technology plays a pivotal role in enhancing learning and research experiences.

Content Analysis Virtual Laboratory in Science education

A. Virtual labs (VL) Benefit

Based on content Analysis, Virtual labs have emerged as a valuable solution, addressing several challenges while offering unique benefits:

1. Enhanced Learning Across Disciplines:

Virtual laboratories are being embraced across a multitude of disciplines. They facilitate practical exercises and hands-on experiences in fields ranging from STEM disciplines to biosafety training (Mohsin, Arfin, and Sarwar, 2022). They offer a versatile solution for teaching concepts and skills in areas such as histology and microscopic anatomy in veterinary medical education (Kogan et al., 2014).

2. Interactivity and Engagement:

Virtual labs introduce interactive elements, making learning more engaging and effective. They have the potential to improve students' problem-solving skills, as observed in studies focused on electricity concepts (Harjono, Sahidu, and Herayanti, 2017). The incorporation of augmented reality can further enhance learning experiences, particularly in biology and anatomy (Arslan, Kofoğlu, and Dargut, 2020).

3. Scalability and Cost-Efficiency:

The cost-effectiveness and scalability of virtual labs make them practical for accommodating larger class sizes and reducing maintenance costs (Kogan et al., 2014). This feature is particularly beneficial in the context of rapidly evolving educational demands.

4. Bridge to Real-World Application:

Virtual laboratories play a crucial role in bridging the gap between academic knowledge and real-world industrial needs, particularly in vocational education (Mohsin, Arfin, and Sarwar, 2022). They prepare students for the challenges and practical requirements of their chosen fields.

5. Improved Teacher Training and Support:

Effective virtual laboratory teacher training programs can significantly enhance educators' ability to leverage these resources for the benefit of students. These programs are essential for building a knowledgeable and skilled workforce of educators (Abdulrahman Nami Alshaikh, 2022).

6. Challenges and the Need for Development:

While virtual labs offer substantial advantages, challenges persist, such as the need for user-friendly interfaces (Toth, 2015) and the transfer of knowledge gained in virtual labs to real-world scenarios (Yusuf and Widyaningsih, 2020).

B. Virtual Lab (VL) in science education

Virtual labs enhance the learning experience by allowing students to engage in practical exercises within a virtual environment, providing unique contexts that may not be easily reproducible in real laboratories (Potkonjak et al. 2016). **User-friendly interfaces** are essential for enhancing the learning experience in virtual control laboratories. (Chacón et al. 2015) **Customization and Adaptability:** Virtual simulations can be tailored to meet specific educational objectives. Educators can

modify experiments, adjust parameters, and create scenarios that cater to the unique needs of their students, enhancing the learning experience.

1. Introduction of New Concepts: They can introduce new scientific concepts, support complex topics, and foster collaborative learning, thereby enriching the educational process (Omputing and Bartolacci 2017).
2. Adaptability to Diverse Educational Settings: Virtual labs are versatile and can be adapted to various educational settings, ranging from STEM disciplines to biosafety training (Zapata-Rivera and Aranzazu-Suescun 2020).
3. Enhancing Learning Outcomes: They significantly improve learning outcomes and student engagement, particularly in specialized fields like wireless networks planning (Zapata-Rivera and Aranzazu-Suescun 2020).
4. A significant advantage of virtual laboratories is their ability to facilitate the learning of objects that cannot be readily presented in a traditional classroom setting (Bima, Saputro, and Efendy 2021). This holds true even during online classes in situations like the Covid-19 pandemic. Virtual labs can enhance learning activities by incorporating information and communication technology (ICT) (Radhamani et al. 2021).
5. Furthermore, virtual laboratories are equally effective in enhancing students' knowledge and skills. Data collected in this study were subjected to analysis using SPSS (version 16.0), with comparisons made within and between groups. The study's findings suggest that the virtual chemistry laboratory software developed is at least as effective as its physical counterpart, both in terms of student achievement within the unit and their proficiency in recognizing laboratory equipment (Ramadahan and Irwanto, 2018).

C. Type of Virtual Laboratory used in Science Education

In the realm of science education, the past decade has witnessed a rapid evolution in the utilization of virtual laboratories. These digital environments offer a dynamic and immersive approach to learning, revolutionizing the way students and educators engage with scientific concepts.

Among the plethora of virtual lab options are MOOCs (Massive Open Online Courses)(O'Malley, Agger, and Anderson 2015; Radhamani et al. 2021; Zapata-Rivera and Aranzazu-Suescun 2020), which provide flexible and accessible learning experiences. Virtual microscopy opens new horizons in the study of microscopic structures, while virtual computer laboratories offer a hands-on approach to experimenting with software and simulations.

VLs (Virtual Laboratories), VCLs (Virtual Control Laboratories), and VRLs (Virtual Laboratories) broaden the spectrum of hands-on experimentation, breaking the barriers of physical presence(Ayas and Altas 2016; Tatli and Ayas 2013). Remote and virtual labs (RVLs) enable experiments to be conducted from afar, enhancing accessibility. The Virtual Cloud Automotive Laboratory (VCAL) advances automotive engineering education.

Virtual Reality and Mixed Reality (a hybrid of augmented and virtual reality) bring an element of immersion and interactivity that was previously unparalleled(Veer, Phelps, and Moro 2022). In the field of chemistry, the Virtual Periodic Table (VPT) in 3D format is a groundbreaking educational tool (Ali, Ullah, and Raees 2022).

Additionally, Virtual and Augmented Reality (VAR) technologies continue to merge physical and digital worlds. With these diverse virtual lab options, science education has become more engaging, flexible, and accessible than ever before, fostering a deeper understanding of scientific principles (Marks and Thomas 2022).

4. CONCLUSION

In this comprehensive examination of Virtual Laboratories (VL) in education, we have unveiled the transformative impact of these digital tools. Our conclusions, drawn from bibliometric data and insightful research trends, illuminate the significant role of VLs in reshaping contemporary education.

The analysis spotlights the United States as the epicenter of VL research, fostering prolific authors and collaborative endeavors that extend across global boundaries. This leadership position reflects the nation's dedication to pushing the boundaries of education through innovative technology.

Moreover, the examination underscores the versatility and adaptability of VLs, with diverse subject areas embracing these tools. The prominence of keywords like "virtual reality" and "students" reaffirms the centrality of interactive, technology-infused pedagogy in education.

As we gaze into the future, the educational landscape is poised to witness novel research trends within the VL sphere, continuing to shape pedagogical practices through innovation and adaptation. The multidisciplinary nature of VLs, encapsulated in the diverse array of subject areas and global collaborations, positions them as indispensable assets for advancing pedagogical practices in the modern educational milieu.

Virtual laboratories have indeed revolutionized education, transcending traditional boundaries and empowering educators and learners to chart new frontiers in the realm of educational technology. The findings presented in this examination affirm the pivotal role of VLs, setting the stage for ongoing innovations and developments in the ever-evolving landscape of education.

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Biographies of Authors

The recommended number of authors is at least 2. One of them as a corresponding author.

Please attach clear photo (3x4 cm) and vita. Example of biographies of authors:

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