Studies in Bibliometrics of Education and Technology
Homepage: https://scie-journal.net/index.php/SiBET
Email:

p-ISSN:XXXXX; e-ISSN: XXXXX
SiBET, Vol. 1, No. 3, July 2026
Page 44-58
©2026 SiBET

Mapping Study of Virtual Reality in Physics Education: A Bibliometric Review (2020-2025)

Isybi Imadillah Al Siddiqiy[1], *Dwikoranto[1], Rahmatta Thoriq Lintangesukmanjaya[1], Lindsay Natalia Bergsma[2]
[1]Department of Physics, Faculty of Mathematics and Natural Science, Universitas Negeri Surabaya, Indonesia
[2]School of Social and Behavioral Sciences, Tilburg University, Netherlands

Article Info

Article history:

Received: 29 June 2026
Revised: 14 July 2026
Accepted: 28 July 2026
Available Online: 31 July 2026

Keywords:

Bibliometric Analysis
Physics Education
Sustainable Development Goals
Virtual Reality
VOSviewer

ABSTRACT

Physics concepts are frequently abstract, microscopic, and dynamic in nature, which can make them difficult for students to understand through conventional instruction, and Virtual Reality (VR) has been increasingly applied in physics education to provide immersive, interactive, and visualization-based learning experiences; however, bibliometric data specifically describing the development of VR research within physics education remain limited, so this study was conducted to map the publication trends, contributing countries, leading sources, and keyword relationships associated with VR applications in physics education. This study used a bibliometric literature review approach, guided by the PRISMA flow diagram for document identification, screening, and eligibility, and supported by VOSviewer for network visualization. We retrieved 332 documents published between 2020 and 2025 from the Scopus database using the keywords "Virtual Reality" AND Physics AND Education. The results show a fluctuating but overall increasing publication trend, with the highest output in 2025, dominated by conference papers and led by the United States, China, and India, with Indonesia among the top contributors. Keyword mapping revealed "virtual reality," "physics education," and "virtual laboratories" as the most interconnected themes. This study offers novel insight into the intellectual structure of VR-physics education research and concludes that immersive technology holds strong potential to advance quality science education aligned with SDG 4.

Check for updates OPEN ACCESS CC BY NC ND

INTRODUCTION

In the current era of rapid technological transformation, education, including physics education, is increasingly required to adapt through the integration of digital technology into teaching and learning processes. This transformation is particularly relevant to physics, which is often perceived as a challenging subject because many of its concepts are abstract, microscopic, and dynamic, making them difficult for students to comprehend through conventional instruction alone. Topics such as electricity, magnetism, waves, and modern physics require not only conceptual understanding but also the ability to visualize phenomena and processes that are often difficult to observe directly. Consequently, the use of conventional instructional approaches supported primarily by verbal explanations and static representations may be insufficient to facilitate students' understanding of complex physical phenomena. In this context, digital learning media offer opportunities to represent scientific phenomena through visualizations, simulations, and interactive activities, enabling students to explore concepts that are difficult to demonstrate directly in the classroom (Jupri & Sulisworo, 2024). Interactive digital learning environments can further promote student engagement, facilitate scientific exploration, and develop problem-solving skills by allowing learners to manipulate learning objects, observe simulated phenomena, and investigate relationships between physical variables through active learning experiences (A'yun et al., 2026; Campos et al., 2022). Therefore, the integration of visual and interactive digital media into physics education is increasingly important as a means of addressing the abstract nature of physics concepts while supporting more active,

meaningful, and effective learning experiences in accordance with the demands of technology-oriented education (Matovu et al., 2023).

Virtual Reality (VR) has emerged as a promising educational technology for physics learning because it provides immersive and interactive experiences that can facilitate the visualization of abstract and complex scientific concepts (Zhao et al., 2023). Through three-dimensional virtual environments, students can observe and interact with phenomena that are difficult to represent through conventional instructional media, thereby supporting deeper conceptual understanding (Jupri & Sulisworo, 2024). The use of immersive digital technologies has also been associated with increased learning motivation, student engagement, and academic achievement by encouraging active participation and meaningful interaction during the learning process (Korlat et al., 2024). Moreover, VR-based learning environments enable students to explore scientific phenomena, manipulate variables, and conduct virtual experiments in safe and controlled settings, which can support the development of problem-solving and higher-order thinking skills (Castillo et al., 2025; Acevedo et al., 2024). These characteristics make VR particularly relevant to physics education, where students are frequently required to construct mental representations of phenomena that cannot be directly observed. However, despite the growing interest in immersive technologies and their potential for physics learning, research specifically examining the use of VR in physics education remains relatively limited. A systematic review of immersive VR research in post-primary science education identified 30 studies, of which only 10 focused on physics, indicating that research attention remains uneven across science disciplines (Tene et al., 2024). This limited representation suggests that, although VR has demonstrated considerable potential for supporting physics learning, its application and effectiveness in addressing the specific challenges associated with abstract physics concepts still require further investigation.

Recent years have witnessed a significant increase in research on the application of Virtual Reality (VR) in education, reflecting the growing recognition of immersive technologies as innovative tools for enhancing teaching and learning processes (Elaish et al., 2025). Bibliometric studies have shown that VR research has expanded rapidly across diverse educational contexts, with increasing scientific publications, broader international collaborations, and evolving research themes related to immersive learning, educational technology, and digital innovation (Rojas-Sánchez et al., 2023). Furthermore, recent analyses indicate that VR research continues to diversify, encompassing various educational levels, disciplines, and learning approaches while highlighting the growing influence of emerging technologies in contemporary education (Samala et al., 2025). Similarly, (Abdullah et al., 2025) reported that the literature on immersive VR has experienced substantial growth and has increasingly focused on improving learning effectiveness, student engagement, and innovative instructional practices (Amarulloh & Aswie, 2024). Nevertheless, these bibliometric studies have primarily examined Virtual Reality from a general educational perspective and have not specifically mapped the development of VR research within the field of physics education (Andriani et al., 2025; Yolla Yulia Astuti Y, Farida, 2021). Consequently, comprehensive information regarding publication trends, influential authors, productive countries and institutions, collaboration networks, keyword evolution, and emerging research themes in Virtual Reality research for physics education remains limited. Therefore, a dedicated bibliometric review is needed to provide a comprehensive overview of the intellectual structure of this research field and to identify future research opportunities.

In response to the identified research gap, this study aims to comprehensively map the development of Virtual Reality (VR) research in physics education through a bibliometric approach. Specifically, this study analyzes publication trends, influential authors, productive countries and institutions, collaboration networks, highly cited publications, keyword co-occurrence, and emerging research themes to provide a systematic overview of the intellectual structure of this research field. The findings are expected to contribute to the existing literature by offering a comprehensive understanding of the evolution and current state of VR research in physics education while identifying potential directions for future investigations. Furthermore, the existing literature has not yet fully captured recent developments in VR and mixed reality (MR) technologies or their application across diverse physics learning contexts. This limitation is particularly relevant in developing educational contexts such as Indonesia, where the implementation of VR in schools remains relatively limited despite its potential to provide immersive and interactive learning experiences. In addition, much of the existing research has focused on general outcomes such as student engagement, motivation, and learning achievement, while fewer studies have examined how VR can support conceptual understanding of specific abstract and cognitively demanding physics topics, including electromagnetism and wave phenomena. Therefore, although VR offers considerable potential for addressing the challenges associated with abstract physics concepts, its implementation for specific physics

topics, particularly within educational settings with limited technological resources, remains insufficiently investigated. This research gap highlights the need for further empirical studies to examine the effectiveness and educational value of VR in supporting students' understanding of complex physics concepts.

RESEARCH METHOD

This study employed a bibliometric literature review approach, a non-experimental research design that utilizes secondary data in the form of scientific publication metadata as the primary unit of analysis rather than primary data collected directly from research participants (Ninkov et al., 2022)**.** Unlike experimental or survey-based studies, which examine causal relationships or individual perceptions, bibliometric research aims to systematically identify and describe the patterns, trends, and intellectual structure of a research field through the statistical analysis of published scientific literature (Mondal, 2026). Furthermore, this study can be classified as a quantitative literature review, as it does not conduct an in-depth methodological quality appraisal of individual studies, as is typically performed in conventional systematic reviews. Instead, it emphasizes large-scale mapping of the scientific literature to examine publication volume, temporal trends, collaborative networks, and conceptual relationships concerning the application of Virtual Reality (VR) in physics education (Moral-Muñoz et al., 2020)**.** The research design can be seen it figure 1.



Figure 1. Research Design

This study employs a Systematic Literature Review (SLR) instrument in processing bibliometric data, which is used to measure publication trends, observe distribution maps, and visualize the relationships among keywords with the assistance of VOSviewer (Page et al., 2021). The SLR process is guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram, which structures the identification, screening, and eligibility stages of document selection in accordance with the selected research topic. The PRISMA chart design can be seen in figure 2.

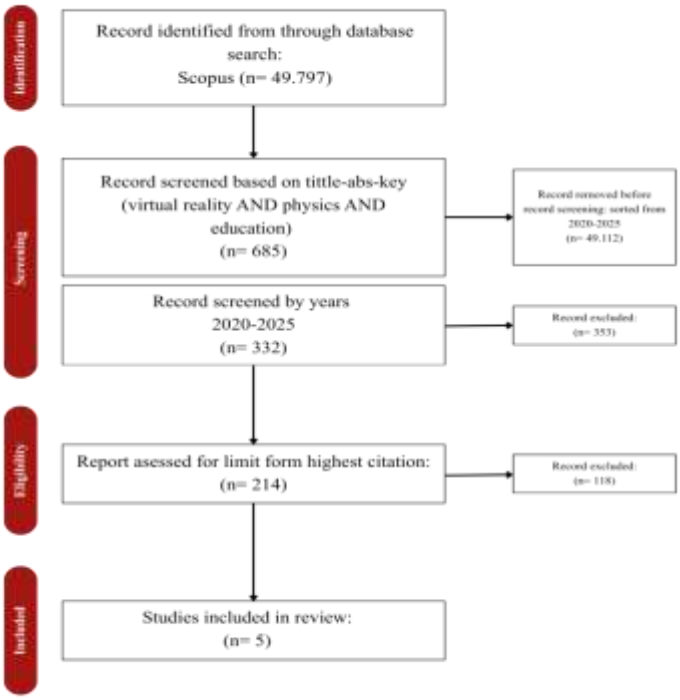


Figure 2. PRISMA Chart

From the data, document sources, leading affiliations, citation performance, contributing countries, subject areas, source titles, authorship patterns, and keyword co-occurrence. The five most highly cited studies were further synthesized based on four main aspects: the type of immersive technology employed, the learning outcomes addressed, the conditions influencing its effectiveness, and the limitations and future research directions identified by each study. This synthesis was intended to identify common patterns and differences across the selected studies rather than merely summarize their individual findings. The analysis focused particularly on how VR and AR contribute to conceptual understanding, visualization, engagement, motivation, problem-solving, and knowledge retention in physics and science education. In addition, attention was given to the role of instructional design, teacher guidance, infrastructure, and assessment quality in determining the effectiveness of immersive learning. This analysis provides a comprehensive mapping of the research landscape, collaboration patterns, and emerging themes in Virtual Reality in Physics Education during the last 6 years.

RESULTS AND DISCUSSION

Result

Publication trends over the period 2020–2025 were obtained based on a search using the keywords "Virtual Reality" AND Physics AND Education in the Scopus database. The search results identified 332 documents published during this period, which were subsequently used as the basis for the bibliometric analysis. The distribution of the number of publications per year is presented in Figure 3.

Based on Figure 3, it can be observed that the publication trend regarding the use of Virtual Reality (VR) in physics education fluctuated during the early part of the research period, before showing a significant increase in the following years. In 2020, there were 48 documents, which then decreased to 44 documents in 2021 and further declined to 39 documents in 2022. Entering 2023, the number of publications began to rise to 47 documents, followed by an increase to 56 documents in 2024. The highest increase occurred in 2025, with 98 documents, representing the highest number of publications throughout the observation period.

This trend indicates that research on the application of Virtual Reality in physics education is continuously developing and gaining greater attention from researchers. The increasing number of publications reflects growing interest in the use of VR technology as a learning medium capable of visualizing abstract physics concepts, enhancing learning interactivity, and providing a more immersive learning experience. Furthermore, the advancement of increasingly accessible VR hardware and software has also contributed to the growing body of research in this field. These findings indicate that Virtual Reality has become one of the potential learning innovations supporting the transformation of physics education in the digital era, improving the quality of the learning process through an approach that is more engaging, effective, and student-centered (Pellas et al., 2021).



Figure 3. Document per Year

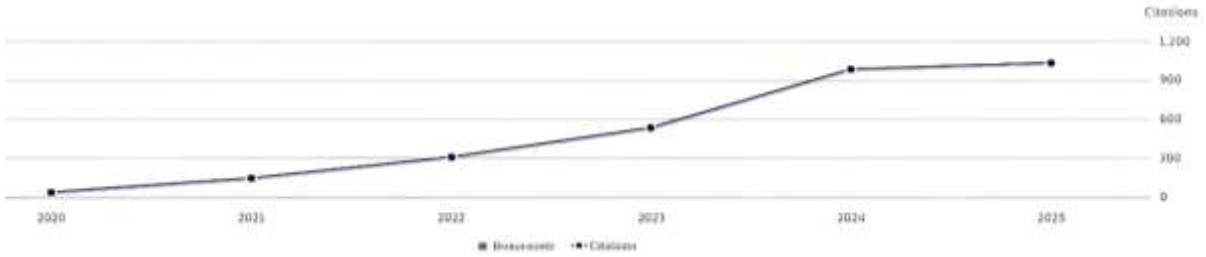


Figure 4. Citation per Year

Furthermore, the distribution of publication source types regarding Virtual Reality in physics education is presented in Figure 5. Based on the analysis of 332 documents, the most dominant publication type was conference papers, with 162 documents, followed by articles with 117 documents. The dominance of conference papers indicates that research findings on Virtual Reality in physics education are predominantly published through scientific conferences. This suggests that this research field is developing dynamically, leading researchers to favor conferences as a medium for disseminating their latest findings, obtaining feedback from the academic community, and building research collaboration networks. On the other hand, the relatively high number of articles indicates that a substantial number of studies have advanced into scholarly works published in reputable journals following a peer-review process, thereby producing more comprehensive findings with a high level of scientific validity (Tlili et al., 2022).

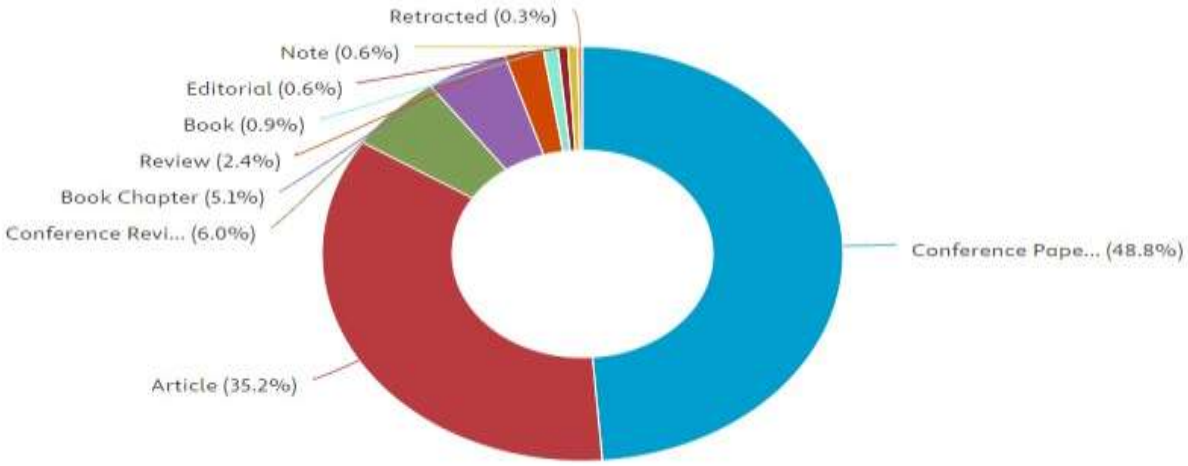


Figure 5. Document Types



Figure 6. Top 10 Countries Contributed to Virtual Reality in Physics Education Publication

Figure 6 shows the ten countries with the largest publication contributions to research on Virtual Reality (VR) in physics education. Based on the analysis results, the United States ranked first with 58 documents, followed by China (35 documents), India (22 documents), Indonesia (21 documents), Germany (20 documents), Japan (14 documents), the Russian Federation (14 documents), Italy (12 documents), Kazakhstan (9 documents), and the United Kingdom (9 documents). The dominance of the United States indicates that this country remains the leading center for the development of Virtual Reality-based educational technology, supported by a strong research ecosystem, substantial investment in educational technology, and close collaboration among universities, research institutions, and technology industries. This finding is consistent with previous bibliometric studies reporting that the United States is the country

with the largest publication contribution in VR research, particularly in the fields of education and physics (Jamlludin et al., 2022).

The contributions of India and Indonesia also show a positive trend. The increasing number of publications from both countries indicates that research on VR is no longer dominated solely by developed countries, but has also begun to grow rapidly in developing countries. In Indonesia, the increase in publications has been driven by the expanding implementation of digital learning, the development of virtual laboratories, and support for educational transformation in the era of Industry Revolution 4.0. Previous bibliometric studies have also shown that Indonesia's contribution to VR research continues to increase and holds significant potential for further growth through international collaboration (Devianti et al., 2021). Overall, the distribution of publications across countries indicates that research on Virtual Reality in physics education has developed into a globally significant research field. Although the United States and China remain the primary contributors, the increasing number of publications from Asian countries, including Indonesia, reflects the growing adoption of VR technology as a learning medium to visualize abstract physics concepts, enhance student engagement, and support experiential learning. This condition also opens up broader opportunities for international collaboration in the future development of VR-based physics learning media (Molina-Carmona et al., 2018). The figure 7 illustrates the collaboration network among countries contributing to research on virtual reality in physics education



Figure 7. The Relation of Countries Contributing to Virtual in Physics Education Publication

The visualization shows that the United States occupies the most central position in the network, forming direct connections with a wide range of countries, including Germany, Japan, India, Mexico, Israel, Ecuador, the United Kingdom, Italy, and the Russian Federation. This centrality is consistent with the earlier finding that the United States also leads in terms of publication output, as shown in Figure 6. Countries with the highest research productivity tend to become the most attractive collaboration partners, since they typically possess stronger research infrastructure, greater funding availability, and more established academic reputations that draw international researchers into joint projects.

Meanwhile, Indonesia forms a distinct sub-cluster together with China and Ukraine, suggesting that its collaboration pattern is more regionally oriented rather than globally distributed. This may be attributed to geographical proximity, alumni networks, or bilateral research programs rather than large-scale research capacity. Taken together, this network pattern reinforces the argument that VR research in physics education remains concentrated around a small number of technologically advanced countries, while developing countries such as Indonesia are still in the early stages of establishing broader international collaboration networks. Details of the distribution of the top 10 sources supporting this research are as follows figure 8.

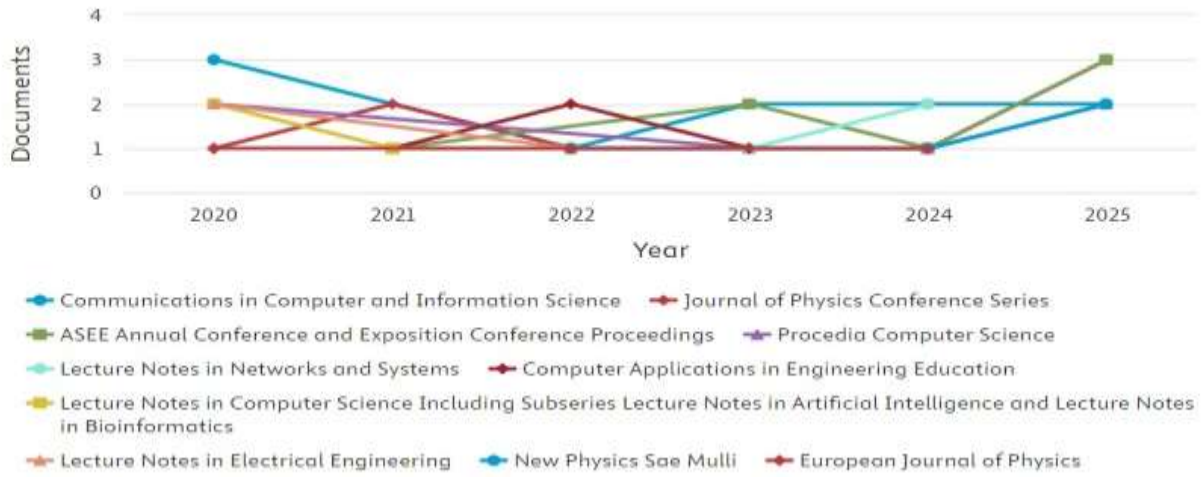


Figure 8. Number of Article by Sources

Figure 8 presents the ten most frequent publication sources supporting research on virtual reality in physics education. Notably, eight of the ten leading sources are conference proceedings or lecture-note series, such as Communications in Computer and Information Science, ASEE Annual Conference and Exposition Conference Proceedings, Procedia Computer Science, and several Lecture Notes series, while only two sources, Journal of Physics: Conference Series and European Journal of Physics, represent dedicated physics-oriented outlets. This distribution is consistent with the earlier finding in Figure 5, which showed that conference papers dominate the overall document type.

The dominance of conference proceedings can be explained by their considerably shorter publication cycle compared to peer-reviewed journals, making them a more suitable outlet for disseminating findings in a rapidly evolving technological field such as VR, where researchers often need to share prototypes or preliminary results without waiting for a lengthy review process. In addition, the interdisciplinary nature of this research area, situated at the intersection of computer science, engineering, and education, explains why the leading sources originate primarily from computer science and engineering communities rather than from physics education journals. This pattern suggests that the development of VR technology itself remains the primary focus of current scholarship, whereas publication in dedicated physics education journals is still comparatively limited. It further indicates that research on VR in physics education has not yet fully matured into an established subdiscipline with its own dedicated publication venues, but instead continues to rely on publication spaces provided by the broader engineering and computer science communities. The network visualization can be seen it figure 9

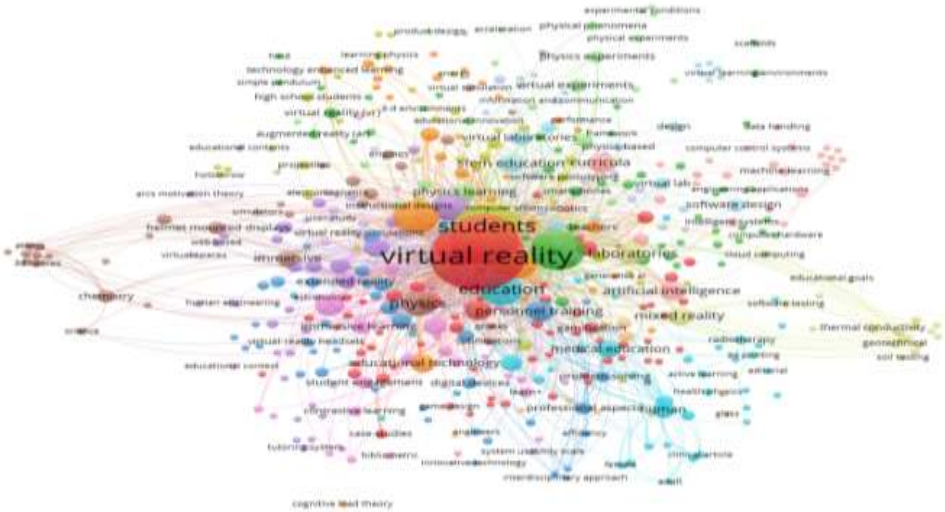


Figure 9. Network Visualization

Cluster 1 contained the highest-occurring keyword, "virtual reality," with 227 items. In cluster 2 was dominated by the keyword "e-learning," which appeared 119 items. Then in cluster 3 was characterized by the keyword "students," with 105 items, indicating a strong emphasis on learner-centered research. In cluster 4 was primarily represented by "engineering education," with 76 items. Cluster 5 was dominated by the keyword "augmented reality," which appeared 66 items. . Next, the results of the mapping of keywords that support virtual reality in physics education publications found the highest occurrence value of 227 for the words "Virtual Reality" and the top 10 keywords based on distribution were found as follows.

Table 1. Top 10 Keywords by Author

Rank	Keywords	Total Link Strength	Rank	Keywords	Total Link Strength
1	Virtual Reality	2073	6	Learning systems	546
2	E- Learning	1272	7	Augmented Reality	539
3	Students	1206	8	Education Computing	529
4	Engineering Education	944	9	Eduation	445
5	Teaching	590	10	Physics Education	443

The frequency of keyword occurrence serves as a key indicator of the central themes that have drawn the most attention from researchers within this field of study. Keywords with high occurrence values reflect the dominant research focus, while those appearing less frequently tend to represent emerging or niche subtopics, one such example being "Virtual Reality in Physics Education," which appears as a more specialized area within the broader Virtual Reality and Education research landscape. Accordingly, in order to identify potential research novelty at the intersection of Virtual Reality and education, this study examines the keyword occurrence visualization presented in Figure 9, which maps the relative prominence and interconnection of terms across the analyzed publications.

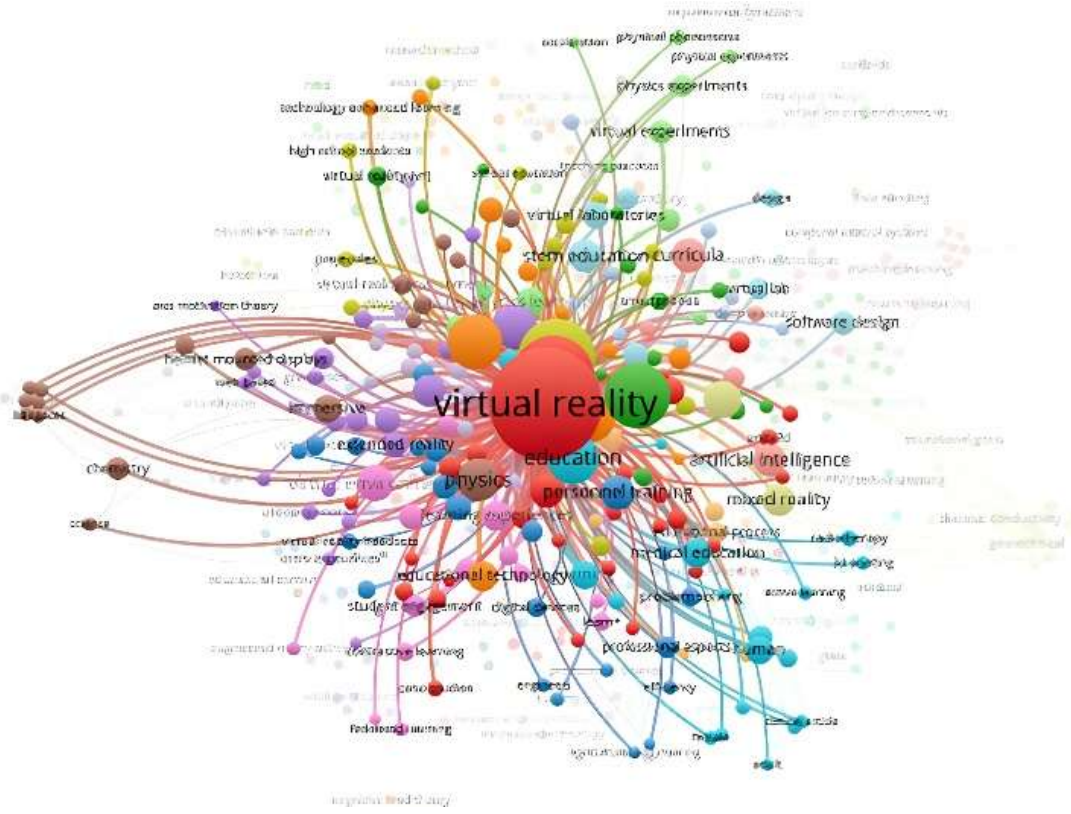


Figure 10. Keyword Co-occurrence Network Visualization of Virtual Reality Research in Education.

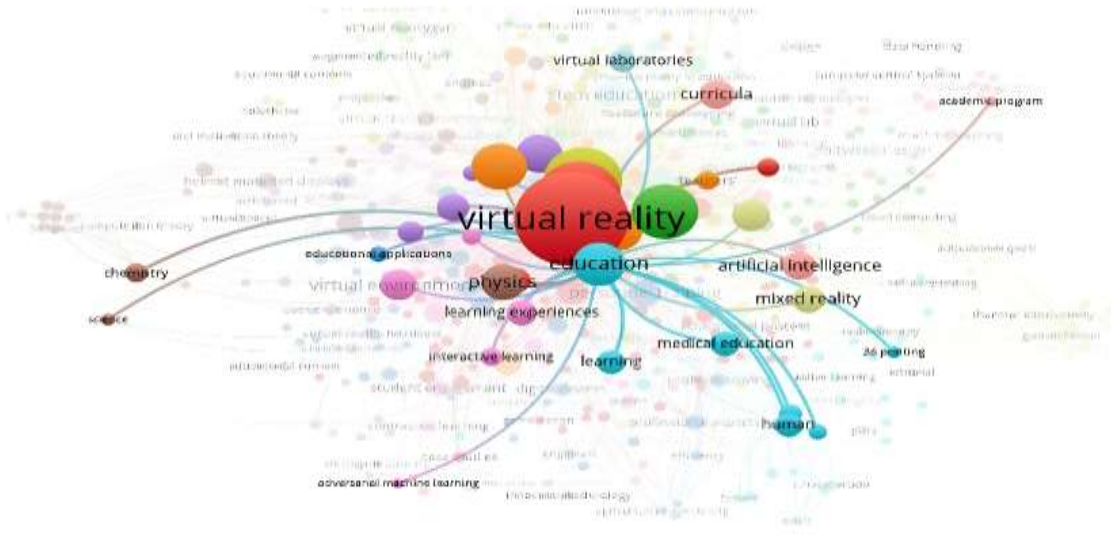


Figure 11. Highlighted Network Visualization Showing the Core Cluster of Virtual Reality and Education.

Figure 10 and 11 shows a more specific keyword mapping of the correlation of virtual reality applications in education-related publications. The main trends discussed in this study are shown in Figures 10 and 11, which relate to potential future research directions. In Figure 10, the main keyword, *virtual reality*, is closely related to various keywords such as *education*, *STEM education*, *curricula*, *virtual laboratories*, *artificial intelligence*, *physics*, *mixed reality*, and *medical education*, among others. This finding is consistent with prior studies showing that VR-based virtual laboratories support STEM curricula by allowing students to conduct simulated experiments in physics and chemistry without physical constraints (Hamash et al., 2025)**.**

Furthermore, to link virtual reality with education, it can be seen in Figure 11, where *virtual reality* and *education* form the two largest and most dominant nodes, showing the strongest co-occurrence relationship in supporting technology-oriented educational research. This aligns with findings that VR positively influences student engagement, motivation, and learning outcomes across educational levels, particularly for students with diverse learning needs. Similarly, in higher education contexts, VR integration with established pedagogical frameworks has been shown to enhance immersive and interactive learning experiences (Mallek et al., 2024). The Keyword co-occurrence network visualization highlighting the "Virtual Reality in Physics Education" cluster can be seen it figure 12.

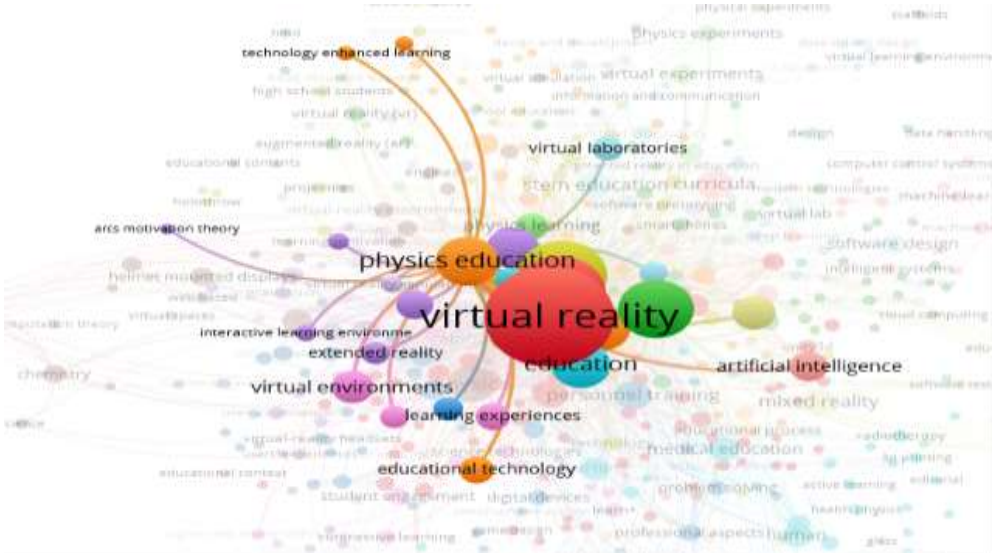


Figure 12. Keyword Co-occurrence Network Visualization Highlighting the "Virtual Reality in Physics Education" Cluster.

Figure 12 illustrates that the trajectory of research development is strongly oriented toward the domain of physics education and its integration with virtual reality technology. This is evidenced by the close proximity and strong linkage between the central keyword "virtual reality" and surrounding terms such as physics education, virtual laboratories, physics learning, stem education curricula, virtual environments, interactive learning environment, extended reality, and educational technology. The prominence of these interconnected keywords suggests that a substantial portion of current scholarship centers on how immersive technologies are being applied to enhance conceptual understanding in physics instruction.

Thus, the integration of virtual reality within physics education can be regarded as a strategic pathway for advancing more interactive, experiential, and technology-driven pedagogical practices. In other words, the convergence between virtual reality and physics-based learning environments reflects an emerging research trend that bridges immersive technology with STEM education, supporting the broader goal of improving the quality and accessibility of science education.

To further sharpen the findings and recommendations of this study, it is essential to examine the most highly cited publications within this research domain. Such an examination, conducted through a structured literature review, allows for the identification of existing strengths and limitations in prior studies, thereby providing a foundation for uncovering future research opportunities in the field of virtual reality-based physics education.

Table 2. Overview of Most Cited Papers in Virtual Reality in Physics Education

Author(s)	Citation; SJR	Research Findings and Recommendation
(Hamilton et al., 2021).	912; 1.7 (Q1)	A systematic literature review of 29 studies shows that Immersive Virtual Reality (IVR) generally produces better learning outcomes compared to conventional methods or desktop VR. However, most studies used short intervention durations, did not measure long-term retention, and largely focused on science-related fields such as physics and biology. The author also found that the quality of learning assessment instruments in many studies remained low, which affected the validity of the results. Therefore, it is necessary to employ stronger experimental designs, longer instructional durations, measure knowledge retention, use validated instruments, and expand the implementation of IVR into various fields of learning beyond science.
(Altmeyer et al., 2020).	172; 3.8 (Q1)	A study using a pretest–posttest design showed that Augmented Reality (AR)-based laboratories were more effective in improving conceptual understanding, particularly on parallel circuit material, with a high level of usability without increasing extraneous cognitive load. However, AR did not yet show a significant improvement in transfer ability or in reducing extraneous cognitive load. It is recommended to test AR implementation in real classroom learning, collaborative learning, and various STEM fields, as well as to explore smart glasses, eye-tracking, learner characteristics, and long-term effects through longitudinal studies.
(Ullah et al., 2022).	109; 0.7 (Q1)	Research shows that Virtual Reality (VR) and Augmented Reality (AR) in serious games improve motivation, engagement, problem-solving ability, and understanding of science concepts, particularly physics, through more interactive visualization of abstract concepts. Most studies employed a quantitative approach and focused on physics and biology. Future research is recommended to expand the application of VR to various physics topics and developing countries, improve the quality of interfaces and learning assessments, and conduct longitudinal studies to assess long-term impacts.
(Campos et al., 2022).	92; 0.7 (Q1)	Experimental study on engineering students showed that the use of VR in learning three-dimensional vectors improved spatial visualization ability compared to conventional learning. Students expressed positive perceptions toward the use of VR, as it helped them understand abstract concepts, increased learning engagement, and enriched their learning experience. Improvements in learning outcomes were particularly evident in problems requiring visualization ability. VR is recommended for physics topics that involve abstract concepts and require visualization ability, such as vectors, forces, and three-dimensional space. The implementation of VR should ideally be combined with well-designed instruction, collaborative activities, and lecturer guidance to maximize the learning benefits.

(Lai & Cheong, 2022).	59; 0.8 (Q1)	This article explains that Augmented Reality (AR) is able to enhance the visualization of physics phenomena, learning motivation, student engagement, and experiential learning. AR enables students to understand concepts that are difficult to observe directly through interactive simulations. However, the implementation of AR still faces challenges such as limited infrastructure, teacher readiness, institutional support, and pedagogical designs that are not yet optimal. The development of AR needs to be accompanied by integration with instructional strategies, teacher training, institutional support, and collaboration between educators and technology developers. Future research is recommended to evaluate the effectiveness of AR using pedagogical frameworks such as the SAMR Model and Design Research Framework in order to achieve more sustainable implementation.

Overall, Virtual Reality technology, as part of the broader Industry 4.0 landscape, has generally demonstrated a positive contribution toward achieving the Sustainable Development Goals (SDGs), particularly SDG 4 on Quality Education (Cabrera-Duffaut et al., 2024). A holistic approach to education one that integrates immersive technologies such as virtual reality represents a more effective strategy in addressing the increasingly complex challenges of global learning demands.

Discussion

The trend analysis for 2020–2025 shows a clear increase in scholarly attention to the use of Virtual Reality (VR) in physics education, with the highest level of research activity observed in the final year of the analysis. This trend suggests that VR is gradually moving beyond its role as an emerging technology and is becoming more established as a learning medium in education. This finding is in line with (Susilo et al., 2026), who reported an increasing interest in immersive technologies, and (Rashid et al., 2021), who identified a similar growth pattern in VR research across the broader field of education. The growing number of publications therefore indicates that VR is increasingly being considered not only as a technological innovation but also as a potential pedagogical tool. In physics education, this development is particularly relevant because VR can provide learning experiences that are difficult to achieve through conventional instructional approaches.

The growing interest in VR is closely related to the characteristics of physics as a subject. Many physics concepts involve abstract, dynamic, and spatial phenomena that are difficult for students to observe directly through conventional learning media. The analysis of the 332 documents shows that immersive visualization is an important direction in VR-supported physics education, as it allows learners to observe and interact with phenomena that may be difficult to represent in traditional classroom settings (Tene et al., 2024). This finding can be understood from a constructivist learning perspective, in which students develop knowledge through active interaction with learning experiences and representations. Through a virtual environment, students can explore three-dimensional representations, observe changes in physical phenomena, and relate their observations to theoretical concepts. Therefore, the contribution of VR is not limited to providing attractive visualizations; rather, it lies in its ability to make abstract physics concepts more accessible through interactive learning experiences.

The importance of interactive visualization is also supported by previous research. (Jiang et al., 2025), reported that role-based simulation and interactive three-dimensional observation are commonly used approaches in VR-supported STEM learning. Similarly, (Elme et al., 2022) found that immersive simulation combined with self-explanation can support knowledge retention among higher-education students. These findings are consistent with the present bibliometric results, particularly the growing emphasis on simulation and interactive learning. However, they also suggest that the use of VR alone does not necessarily guarantee better learning outcomes. The effectiveness of immersive learning depends on how the technology is integrated with instructional activities, conceptual explanations, and opportunities for students to reflect on and interpret what they experience. Thus, future research in physics education should focus not only on the development of VR environments but also on how these environments can be incorporated into appropriate instructional designs.

The analysis also indicates that research on VR and related immersive technologies has expanded across different educational levels, ranging from K-12 to higher education. This broader development demonstrates the flexibility of VR as a learning technology, but it also highlights the importance of the context in which the technology is implemented. (Abdullah et al., 2025), identified teacher readiness and infrastructure as continuing challenges in the implementation of immersive technologies in education. This

issue is important when interpreting the increasing number of publications identified in the present study. A growing research output does not necessarily mean that VR has been widely implemented in classrooms. Instead, the increasing number of studies reflects growing academic interest, while actual implementation remains influenced by technological facilities, teacher competence, and pedagogical considerations. Therefore, future studies should consider these contextual factors when examining the effectiveness and feasibility of VR-based physics learning.

Evidence from other disciplines also provides useful insight into the potential application of immersive simulation. (Far et al., 2026), for example, reported that immersive simulation can be used in medical sciences education to support or replace certain high-risk and resource-intensive laboratory activities. A similar potential can be considered in physics education, particularly for experiments that are difficult to conduct because of safety concerns, limited equipment, high costs, or restricted laboratory access. VR can provide an additional environment in which students can explore physical phenomena before or alongside conventional laboratory activities. However, the findings from medical education cannot be directly generalized to physics because the learning objectives and experimental characteristics of the two fields differ. Therefore, the potential application of immersive simulation in physics still requires specific instructional designs and empirical testing within physics learning contexts.

The keyword and citation patterns further indicate a change in the focus of VR research. The field appears to be moving from initial studies concerned mainly with feasibility and technology acceptance toward investigations of learner behavior, cognitive load, engagement, and knowledge retention. This pattern is consistent with (Sakr & Abdullah, 2024), who identified a similar development in global VR research, and (Firdaus et al., 2025), who reported comparable trends in school and university contexts. This shift may indicate that VR research is becoming more mature. Rather than simply asking whether VR can be used in education, researchers are increasingly examining how and under what conditions immersive environments can influence learning. For physics education, this development is important because effective learning requires more than student engagement with technology; it also requires students to develop conceptual understanding and connect observations with scientific principles.

This development also has theoretical implications for the use of VR in physics education. VR should not be viewed merely as a medium for presenting three-dimensional content. When combined with exploration, self-explanation, problem solving, reflection, and conceptual integration, VR can provide an environment that supports active knowledge construction. Consequently, the educational effectiveness of VR is likely to depend on the interaction between the affordances of the technology and the instructional design in which it is used. The present findings therefore suggest that greater immersion does not automatically result in better learning. Instead, future research needs to examine how immersive features can be deliberately aligned with learning objectives and pedagogical strategies to support meaningful and sustained learning.

Overall, the bibliometric findings show that research on VR in physics education during 2020 - 2025 has developed in several important directions. These include increasing publication activity, greater attention to immersive visualization and simulation, wider application across educational levels, and growing interest in cognitive and behavioral learning outcomes. The findings are generally consistent with previous bibliometric and systematic studies, while also highlighting areas that require further investigation. Future research should pay greater attention to specific physics concepts, learning outcomes, teacher readiness, infrastructure, cognitive load, knowledge retention, and long-term learning effects. In particular, the development of standardized behavioral and learning-outcome measures could help researchers better evaluate the sustained effects of immersive learning environments. Thus, the contribution of this study is not only to demonstrate the increasing research interest in VR-based physics education but also to identify the direction of the field, which is gradually shifting from technological feasibility toward more pedagogically grounded investigations of how immersive environments can support meaningful and sustained physics learning.

CONCLUSION

This bibliometric analysis shows that research on Virtual Reality (VR) in physics education is expanding and increasingly focused on its pedagogical potential for visualization, simulation, and interactive learning. VR can support the understanding of abstract and dynamic physics concepts, but its effectiveness depends on purposeful integration with pedagogy, learning objectives, teacher readiness, infrastructure, and cognitive considerations. This study is limited by its reliance on Scopus, the 2020–2025 period, quantitative bibliometric methods, and analysis of only the five most cited publications. Future

research should use multiple databases and complementary empirical approaches, particularly longitudinal and comparative studies, to determine how VR can produce meaningful and sustained learning outcomes. Ultimately, VR should be viewed not as a replacement for conventional instruction, but as a complementary learning environment aligned with pedagogical needs.

REFERENCES

A'yun, Q., Dwikoranto, Lintangesukmanjaya, R. T., & Sya'roni, I. (2026). Digital learning aid systems for enhancing students' problem-solving skills in physics education: A systematic literature review. *Journal of Digitalization in Physics Education, 2*(1), 52037.https://doi.org/10.26740/jdpe.2.1.52037

Abdullah, N. H. I., Phon, D. N. E., Zulkifli, N. S. A., & Razak, M. F. A. (2025). Reviewing trends and the impact of immersive virtual reality on education: A bibliometric study. *International Journal on Informatics Visualization, 9*(6), 2711-2721. https://doi.org/10.62527/joiv.9.6.3278

Acevedo, P., Magana, A. J., Walsh, Y., Will, H., Benes, B., & Mousas, C. (2024). Embodied immersive virtual reality to enhance the conceptual understanding of charged particles: A qualitative study. *Computers and Education: X Reality, 5*, 100075. https://doi.org/10.1016/j.cexr.2024.100075

Altmeyer, K., Kapp, S., Thees, M., Malone, S., Kuhn, J., & Brünken, R. (2020). The use of augmented reality to foster conceptual knowledge acquisition in STEM laboratory courses-Theoretical background and empirical results. *British Journal of Educational Technology, 51*(3), 611-628. https://doi.org/10.1111/bjet.12900

Amarulloh, R. R., & Aswie, V. (2024). Bibliometric analysis of virtual reality in science education over the three decades (1993-2023). *Science Education International, 35*(3), 270-280. https://doi.org/10.33828/sei.v35.i3.10

Andriani, W., Kaniawati, I., Suhyani, N. O., Afandi, A., & Wati, E. (2025). Exploring the potential of augmented reality and virtual reality in physics education: A systematic review of innovations and educational impact. *The Eurasia Proceedings of Educational and Social Sciences, 46*, 150-162. https://doi.org/10.55549/epess.975

Cabrera-Duffaut, A., Pinto-Llorente, A. M., & Iglesias-Rodríguez, A. (2024). Immersive learning platforms: Analyzing virtual reality contribution to competence development in higher education-A systematic literature review. *Frontiers in Education, 9,* 1391560. https://doi.org/10.3389/feduc.2024.1391560

Campos, E., Hidrogo, I., & Zavala, G. (2022). Impact of virtual reality use on the teaching and learning of vectors. *Frontiers in Education, 7*, 1-15. https://doi.org/10.3389/feduc.2022.965640

Devianti, W., & Anggaryani, M. (2021). Virtual reality in earth physics learning: Research trends through bibliometric analysis (2016-2020). *Prosiding Seminar Nasional Fisika (SNF), 5,* 8-18. https://fisika.fmipa.unesa.ac.id/proceedings/index.php/snf/article/view/156

Elaish, M. M., Yadegaridehkordi, E., & Ho, Y. S. (2025). Publication performance and trends in virtual reality research in education fields: A bibliometric analysis. *Multimedia Tools and Applications, 84*(10), 6999–7026. https://doi.org/10.1007/s11042-024-19238-0

Elme, L., Jørgensen, M. L. M., Dandanell, G., Mottelson, A., & Makransky, G. (2022). Immersive virtual reality in STEM: Is IVR an effective learning medium and does adding self-explanation after a lesson improve learning outcomes? *Educational Technology Research and Development, 70*(5), 1601-1626. https://doi.org/10.1007/s11423-022-10139-3

Far, S. S. T., Marzaleh, M. A., Soltani, R., & Golab, F. G. (2026). Applications and challenges of virtual reality in medical sciences education: A systematic review. *Journal of Advances in Medical Education and Professionalism, 14*(1), 21-31. https://doi.org/10.30476/jamp.2025.104655.2076

Firdaus, T., Wardani, E., Pratiwi, S. E., Kurniasih, S., Hidayah, N., Ferdi, M., & Putra, O. (2025). Research trend virtual reality in education: Bibliometric analysis. *Journal of Multidisciplinary Studies in Education, 9*(1), 28-46. https://izlik.org/JA77BC25JD

Hamash, M., Tiernan, P., & Young, G. (2025). Virtual reality in post-primary education research trends from 2013 to 2024: A systematic-narrative review. *Computers and Education: X Reality, 7*, 100123. https://doi.org/10.1016/j.cexr.2025.100123

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education, 8*(1), 1-32. https://doi.org/10.1007/s40692-020-00169-2

Nina Fajriyah Citra & Mita Anggaryani. (2022). One decade trends of virtual reality publication in physics (2012-2021). *Jurnal Pendidikan MIPA, 23*(4), 1583-1597. http://dx.doi.org/10.23960/jpmipa/v23i4.pp1583-1597

Jiang, H., Zhu, D., Chugh, R., Turnbull, D., & Jin, W. (2025). Virtual reality and augmented reality-supported K-12 STEM learning: trends, advantages and challenges. *Education and Information Technologies*, 30, 12827–12863. https://doi.org/10.1007/s10639-024-13210-z

Jupri, J., & Sulisworo, D. (2024). Visualization of particle physics concepts using virtual reality as a learning support tool for physics undergraduate. *Jurnal Riset Dan Kajian Pendidikan Fisika, 11*(2), 88–96. https://doi.org/10.12928/jrkpf.v11i2.1077

Korlat, S., Kollmayer, M., Haider, C., Hlavacs, H., Martinek, D., Pazour, P., & Spiel, C. (2024). PhyLab – A virtual reality laboratory for experiments in physics: A pilot study on intervention effectiveness and gender differences. *Frontiers in Psychology, 15,* 1284597. https://doi.org/10.3389/fpsyg.2024.1284597

Lai, J. W., & Cheong, K. H. (2022). Educational opportunities and challenges in augmented reality: Featuring implementations in physics education. *IEEE Access, 10*, 43143–43158. https://doi.org/10.1109/ACCESS.2022.3166478

Mallek, F., Mazhar, T., Shah, S. F. A., Ghadi, Y. Y., & Hamam, H. (2024). A review on cultivating effective learning: Synthesizing educational theories and virtual reality for enhanced educational experiences. *PeerJ Computer Science, 10*, e2000. https://doi.org/10.7717/peerj-cs.2000

Matovu, H., Ungu, D. A. K., Won, M., Tsai, C. C., Treagust, D. F., Mocerino, M., & Tasker, R. (2023). Immersive virtual reality for science learning: Design, implementation, and evaluation. *Studies in Science Education, 59*(2), 205–244. https://doi.org/10.1080/03057267.2022.2082680

Molina-Carmona, R., Pertegal-Felices, M. L., Jimeno-Morenilla, A., & Mora-Mora, H. (2018). Virtual reality learning activities for multimedia students to enhance spatial ability. *Sustainability, 10*(4), 1074. https://doi.org/10.3390/su10041074

Mondal, H. (2026). A technical note on bibliometric analysis by Biblioshiny and VOSviewer. *Indian Journal of Radiology and Imaging, 36*(2), 167–174. https://doi.org/10.1055/s-0045-1810060

Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. *Profesional de La Información, 29*(1), e290103. https://doi.org/10.3145/epi.2020.ene.03

Ninkov, A., Frank, J. R., & Maggio, L. A. (2022). Bibliometrics: Methods for studying academic publishing. *Perspectives on Medical Education, 11*(3), 173–176. https://doi.org/10.1007/S40037-021-00695-4

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372,* n71. https://doi.org/10.1136/bmj.n71

Pellas, N., Mystakidis, S., & Kazanidis, I. (2021). Immersive virtual reality in K-12 and higher education: A systematic review of the last decade scientific literature. *Virtual Reality, 25*, 835-861. https://doi.org/10.1007/s10055-020-00489-9

Rashid, S., Khattak, A., Ashiq, M., Rehman, S. U., & Rasool, M. R. (2021). Educational landscape of virtual reality in higher education: Bibliometric evidences of publishing patterns and emerging trends. *Publications, 9*(2), 17. https://doi.org/10.3390/publications9020017

Rojas-Sánchez, M. A., Palos-Sánchez, P. R., & Folgado-Fernández, J. A. (2023). Systematic literature review and bibliometric analysis on virtual reality and education. *Education and Information Technologies, 28*, 155-192. https://doi.org/10.1007/s10639-022-11167-5

Sakr, A., & Abdullah, T. (2024). Virtual, augmented reality and learning analytics impact on learners, and educators: A systematic review. *Education and Information Technologies, 29*, 19913-19962. https://doi.org/10.1007/s10639-024-12602-5

Samala, A. D., Rawas, S., Rahmadika, S., Criollo-C, S., Fikri, R., & Sandra, R. P. (2025). Virtual reality in education: Global trends, challenges, and impacts-Game changer or passing trend? *Discover Education, 4*, 229. https://doi.org/10.1007/s44217-025-00650-z

Susilo, A. D., Irwanto, I., & Cahyana, U. (2026). Global research trends on immersive technology in education: A bibliometric analysis (2007-2025). Journal of Mathematics Education, Science and Technology, *11*(1), 60-85. https://doi.org/10.30651/must.v11i1.3192

Tene, T., Bonilla García, N., Coello-Fiallos, D., Borja, M., & Vacacela Gomez, C. (2024). A systematic review of immersive educational technologies in medical physics and radiation physics. *Frontiers in Medicine, 11*, 1384799. https://doi.org/10.3389/fmed.2024.1384799

Tene, T., Marcatoma Tixi, J. A., Palacios Robalino, M. de L., Mendoza Salazar, M. J., Vacacela Gomez, C., & Bellucci, S. (2024). Integrating immersive technologies with STEM education: A systematic review. *Frontiers in Education, 9,* 1410163. https://doi.org/10.3389/feduc.2024.1410163

Tlili, A., Huang, R., Shehata, B., Liu, D., Zhao, J., Metwally, A. H. S., Wang, H., Denden, M., Bozkurt, A., Lee, L. H., Beyoglu, D., Altinay, F., Sharma, R. C., Altinay, Z., Li, Z., Liu, J., Ahmad, F., Hu, Y., Salha, S., & Burgos, D. (2022). Is metaverse in education a blessing or a curse: A combined content and bibliometric analysis. *Smart Learning Environments, 9*, 24. https://doi.org/10.1186/s40561-022-00205-x

Ullah, M., Amin, S. U., Munsif, M., Safaev, U., Khan, H., Khan, S., & Ullah, H. (2022). Serious games in science education: A systematic literature review. *Virtual Reality and Intelligent Hardware, 4*(3), 189-902. https://doi.org/10.1016/j.vrih.2022.02.001

Villada Castillo, J. F., Bohorquez Santiago, L., & Martínez García, S. (2025). Optimization of physics learning through immersive virtual reality: A study on the efficacy of serious games. *Applied Sciences, 15*(6), 3405. https://doi.org/10.3390/app15063405

Zainuddin, Z., Misbah, M., Mastuang, M., Qamariah, Q., Amiruddin, M. Z. B., & Rahman, N. F. A. (2025). Mapping a decade of research on artificial intelligence and augmented reality in physics education: A bibliometric analysis (2016–2025). *Online Learning in Educational Research, 5*(2), 537–557. https://doi.org/10.58524/oler.v5i2.901

Zhao, X., Ren, Y., & Cheah, K. S. L. (2023). Leading virtual reality (VR) and augmented reality (AR) in education: Bibliometric and content analysis from the Web of Science (2018–2022). *SAGE Open, 13*(3), 1–23. https://doi.org/10.1177/21582440231190821

Author (s):

Isybi Imadillah Al Siddiqiy
Department of Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Surabaya, Indonesia
Email: isybi.23031@mhs.unesa.ac.id

*Dwikoranto (Corresponding Author)
Department of Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Surabaya, Indonesia
Email: dwikoranto@unesa.ac.id

Rahmatta Thoriq Lintangesukmanjaya
Department of Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Surabaya, Indonesia
Email: 25030966025@mhs.unesa.ac.id

Lindsay Natalia Bergsma
School of Social and Behavioral Sciences
Tilburg University, Netherlands
Email: u187576@uvt.nl