The Eurasia Proceedings of
Educational & Social Sciences (EPESS)
ISSN: 2587-1730

The Eurasia Proceedings of Educational and Social Sciences (EPESS), 2025

Volume 46, Pages 150-162

IConETE 2025: International Conference on Education in Technology and Engineering

Exploring the Potential of Augmented Reality and Virtual Reality in Physics Education: A Systematic Review of Innovations and Educational Impact

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Abstract: The aim of this systematic literature review (SLR) is to explore the transformative potential of Augmented Reality (AR) and Virtual Reality (VR) in physics education, focusing on their innovative applications and measurable impacts on student learning. The review was conducted using the Systematic Literature Review (SLR) method, guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. The PRISMA methodology was employed to ensure a transparent, comprehensive, and replicable review process, including the systematic identification, selection, and evaluation of relevant studies. The data for this review were gathered from prominent academic databases, including Scopus, Web of Science (WoS), and ERIC. A set of inclusion and exclusion criteria was defined to filter the studies, ensuring only relevant research articles focusing on the use of AR and VR in physics education were included. The selection process followed the PRISMA guidelines, which consist of four main phases: identification, screening, eligibility, and inclusion. The findings from this review were then synthesized and analyzed to identify key trends, innovations, and challenges. The review reveals that AR and VR technologies significantly enhance the visualization and interaction with abstract physics concepts, thereby improving student engagement, understanding, and retention of physical principles. Despite the promising outcomes, challenges such as high costs, technical barriers, limited hardware accessibility, and the need for teacher training persist, hindering wider adoption. Based on these findings, the review provides recommendations for overcoming these challenges, emphasizing the importance of continued innovation, better accessibility, and broader integration of AR and VR in physics education to fully leverage their educational potential.

Keywords: Augmented Reality (AR), Virtual Reality (VR), Physics education systematic literature review

Introduction

The rapid advancement of technology has brought significant changes to educational practices, particularly in the field of physics education. Among the most promising innovations in this area are Augmented Reality (AR)

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

and Virtual Reality (VR), technologies that provide immersive, interactive learning experiences. These tools are particularly beneficial in teaching abstract and complex concepts in physics, such as forces, energy, and quantum mechanics, which are often difficult for students to visualize and understand. By creating virtual simulations, AR and VR allow students to interact with and explore these concepts in a tangible way, thereby enhancing their comprehension and retention (Bailenson, 2022; Sim, 2023).

The application of AR and VR in education is not a novel concept; however, their potential to revolutionize the learning of physics has only recently been recognized and studied in depth. Research by Zhao et al. (2021) and Li and Wang (2022) highlights how these technologies can improve student engagement, allowing for more interactive and personalized learning experiences. Studies have shown that AR and VR are effective in increasing motivation and interest in the subject matter, as they make learning more engaging and enjoyable (Naylor, 2022). Moreover, AR and VR provide a unique opportunity for students to conduct virtual experiments and visualizations that are often too costly or impractical to carry out in a traditional laboratory setting. However, despite the positive outcomes, the integration of AR and VR into physics education faces significant challenges. High costs, limited accessibility to hardware, and the need for teacher training are among the most commonly cited barriers to their widespread adoption (Anderson, 2021; Brown & Wang, 2023). Moreover, while many studies emphasize the potential benefits of these technologies, the actual measurable impact on student performance and learning outcomes remains a topic of ongoing research and debate.

This research seeks to explore the transformative potential of AR and VR in physics education, with a particular focus on identifying key trends, innovations, and challenges that affect their adoption and effectiveness. Through a systematic literature review (SLR), this study aims to synthesize recent findings and provide recommendations for improving the integration of AR and VR into physics curricula, ensuring that these technologies can be leveraged to their full educational potential.

RQ1. What are the top publications cited in augmented and virtual reality-based learning in vocational education over the past decade, and what is the distribution of publications by subject area?

RQ2. What are the trends and distribution of publications related to AR and VR in vocational education, and what countries contribute the most and are the most relevant publication sources?

Method

Research Design

This study used the Systematic Literature Review (SLR) approach with the PRISMA method to identify and analyze relevant studies on physics problem solving skills. Systematic Literature Review (SLR) was chosen because this approach makes it possible to comprehensively review the existing literature, identify emerging patterns, and evaluate the quality and relevance of studies that have been conducted in this area. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method was used to ensure a transparent, systematic and standardized review process. PRISMA provides detailed guidance on the stages of conducting a literature review, which includes study identification, screening, eligibility assessment, and inclusion of studies that fit the predefined research criteria.

Study Identification

At this stage, this research identified relevant studies related to the application of Augmented Reality (AR) and Virtual Reality (VR) technologies in developing physics problem-solving skills. The sources used include reputable academic databases such as Scopus, Web of Science (WoS), and ERIC.

Inclusion and Exclusion Criteria

Inclusion criteria include articles containing information on the application of AR and VR in physics education, published between 2016 and 2025, and written in English. Articles written in other languages or that do not meet the specified time criteria, as well as publication types such as editorial or review, will be excluded from selection.

Data Evaluation and Synthesis

Once the screening process is complete, the selected data will be evaluated for quality and relevance. Findings from the various studies will be synthesized to explore recent innovations, trends in the use of AR and VR in physics education, and challenges faced in the application of these technologies.

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Article Title and content	Title is appropriate and meets research criteria	Title does not fit and fulfill the research criteria
Publication Date	Publications cover 2016 to 2025	Publication outside the specified time period
Publication Type	Journal Articles and conference papers	Review, Editorial, and others
Language	English	Any language other than English
Subject Area	Physics subjects	Other than Physics Subjects
Accessibility	Full-text article atau open access	Review articles atau lainnya

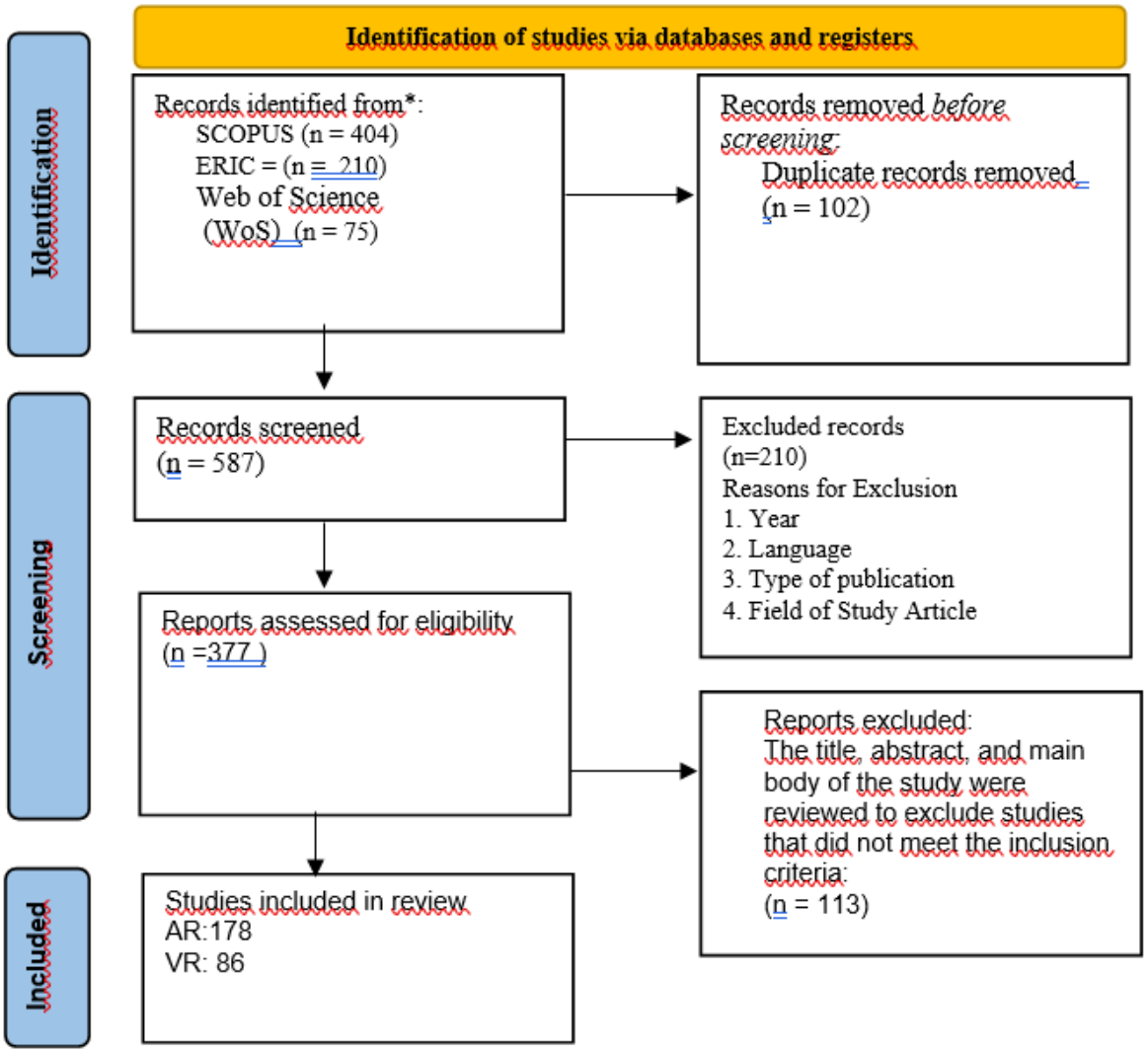

Figure 1. PRISMA diagram

Results and Discussion

RQ1. What are the top publications cited in augmented and virtual reality-based learning in vocational education over the past decade, and what is the distribution of publications by subject area?

This includes analysing which studies have had the greatest impact in the field, as indicated by citation frequency, and categorizing the research by vocational subject areas such as technical training, healthcare, and engineering. By doing so, this research will provide insights into the dominant trends and areas of focus in the application of AR and VR technologies, highlighting their influence across various disciplines in vocational education.

Table 2. Top 10 most cited research on in augmented and virtual reality

No	Document Title	Authors	Source	Year	Citations
1	Virtual laboratories for education in science, technology, and engineering: A review	Potkonjak et al	Computers and Education	2016	700
2	Effects of augmented reality on learning and cognitive load in university physics laboratory courses	Thees et al	Computers in Human Behavior	2020	225
3	Embodied science and mixed reality: How gesture and motion capture affect physics education	Johnson et al	Cognitive Research: Principles and Implications	2017	130
4	Three-dimensional virtual histology of human cerebellum by X-ray phase-contrast tomography	Töpperwien et al	Proceedings of the National Academy of Sciences of the United States of America	2018	119
5	Physics holo.lab learning experience: Using smartglasses for augmented reality labwork to foster the concepts of heat conduction	Strzys et al	European Journal of Physics	2018	70
6	Serious Games in Science Education. A Systematic Literature Review	Ullah et al	Virtual Reality and Intelligent Hardware	2022	56
7	Application in augmented reality for learning mathematical functions: A study for the development of spatial intelligence in secondary education students	Velázquez et al	Mathematics	2021	56
8	Development of career guidance quests using WebAR	Shepiliev et al	Journal of Physics: Conference Series	2021	49
9	Pmomo: Projection mapping on movable 3D objects	Zhou et al	Conference on Human Factors in Computing Systems - Proceedings	2016	44
10	The effectiveness of a 3D-virtual reality learning environment (3D-VRLE) on the Omani eighth grade students' achievement and motivation towards physics learning	Al-Amri et al	International Journal of Emerging Technologies in Learning	2020	42

Table 2 presents a list of significant studies related to Virtual Reality (VR) that have been frequently cited. It includes research such as *Virtual laboratories for education in science, technology, and engineering: A review* by Potkonjak et al. (2016), which has been cited 700 times, reflecting its major impact on the field. Other studies include *Effects of augmented reality on learning and cognitive load in university physics laboratory courses* by Thees et al. (2020), and *Embodied science and mixed reality: How gesture and motion capture affect physics education* by Johnson-Glenberg et al. (2017). These studies highlight the growing importance of VR and mixed reality in educational contexts, particularly in enhancing student engagement, understanding, and cognitive load management in subjects like physics. Despite the promising results, challenges like accessibility and hardware requirements remain critical issues that hinder widespread adoption.

Augmented Reality

The graph showing the number of documents on Augmented Reality (AR) by year shows a significant upward trend in publications on this topic since 2019. The highest peak occurs in 2022, with the number of published documents reaching more than 30 articles. This reflects a large increase in interest in AR research, which may

be due to the increasing adoption of this technology in various sectors, including education, demonstrating its potential in supporting more interactive and engaging learning methods.

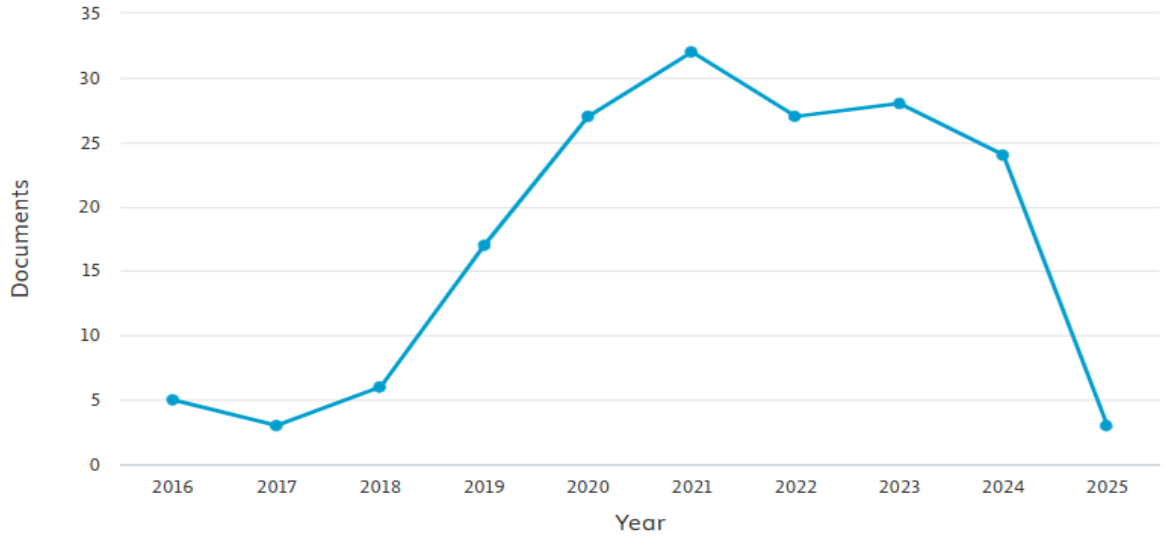

Figure 2. Documents by year

However, after peaking in 2022, the graph shows a sharp decline in the number of publications published in 2023 and 2024, with 2025 recording much lower numbers compared to previous years. This decline could be due to several factors, such as a shift in research focus towards other new technologies or perhaps fatigue in AR exploration, which has been widely discussed. This trend could also reflect a change in priorities within academia or a change in market interest in the technology, which needs to be further investigated to understand the reasons behind the decline.

Figure 3. Documents by type

The pie chart provides a breakdown of the types of documents related to Augmented Reality (AR) publications, showing a nearly even distribution between conference papers and journal articles. Approximately 50.6% of the documents are journal articles, while 49.4% are conference papers. This balance indicates that both academic journals and conferences are significant platforms for publishing research in the AR field, reflecting the active and ongoing discussions within both formal academic settings and more dynamic conference environments.

The close split suggests that AR-related research is continuously evolving and is presented in different formats depending on the type of dissemination. Conference papers often provide early insights into new ideas and innovations, while journal articles tend to offer more in-depth, peer-reviewed studies. This distribution reflects the importance of both types of publications in advancing the field, with conferences likely fostering quick exchange of ideas, while journal articles contribute to more established and thoroughly validated research outcomes.

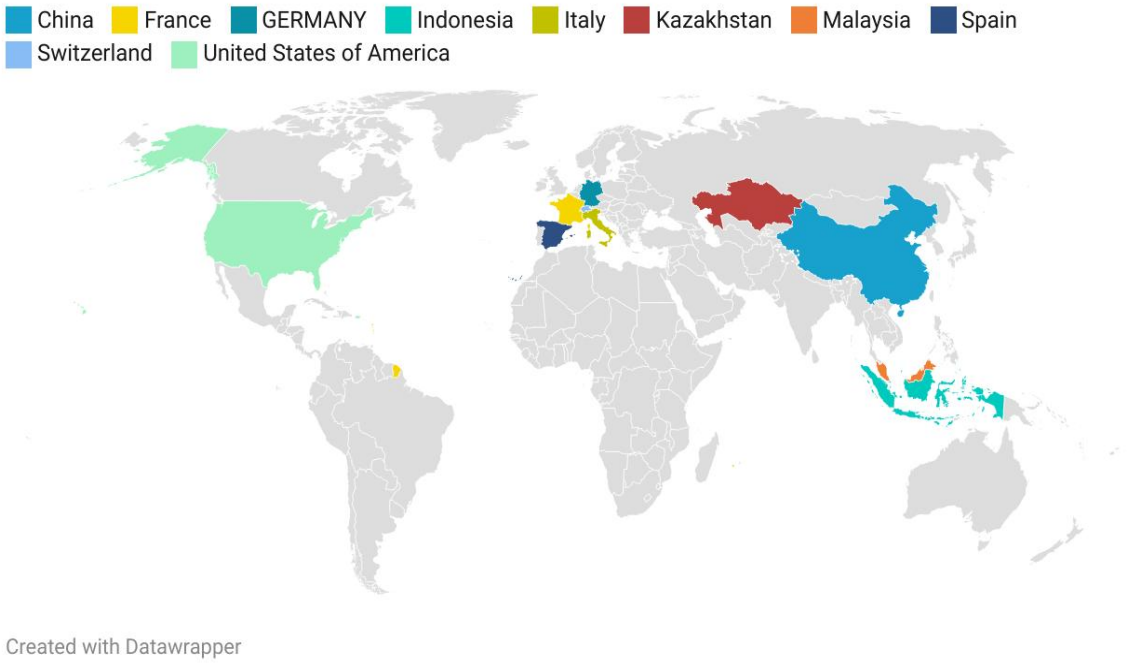

Figure 4. Documents by country

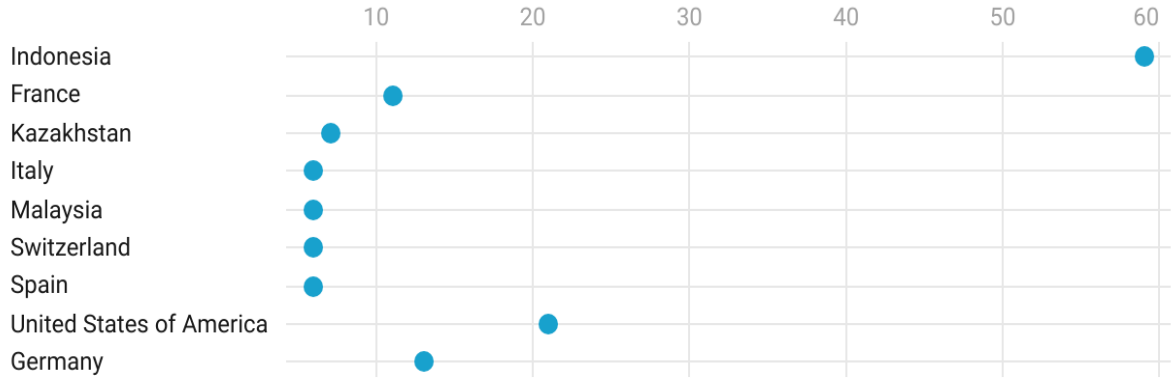

Figure 5. Documents by country accumulation

The bar chart illustrates the distribution of Augmented Reality (AR) publications by country or territory. It shows that Indonesia leads by a significant margin, with the highest number of documents, far surpassing the other countries. The United States follows, but with a noticeably lower number of publications. Other countries such as Germany, France, and China have relatively fewer publications, indicating that while AR research is global, Indonesia stands out as the most active contributor to this field in terms of publication volume.

This concentration of AR research in Indonesia could suggest a heightened focus on the technology within the country's academic and research institutions. The relatively lower number of publications from other countries, like the United States and Germany, might reflect different research priorities, publication practices, or the stage of development of AR technology in those regions. Indonesia's dominance in the publication of AR-related documents may also be a result of specific local initiatives, investments, or governmental support for technology-driven educational reforms in the country.

Virtual Reality

The graph shows the number of Augmented Reality (AR) related publications per year from 2016 to 2025. A significant peak in publications is observed in 2020, where the number of documents sharply rises to more than 15. After this spike, there is a noticeable fluctuation in the following years, with smaller peaks in 2021 and 2022, before the number of publications begins to sharply decrease in 2024 and continues to drop into 2025.

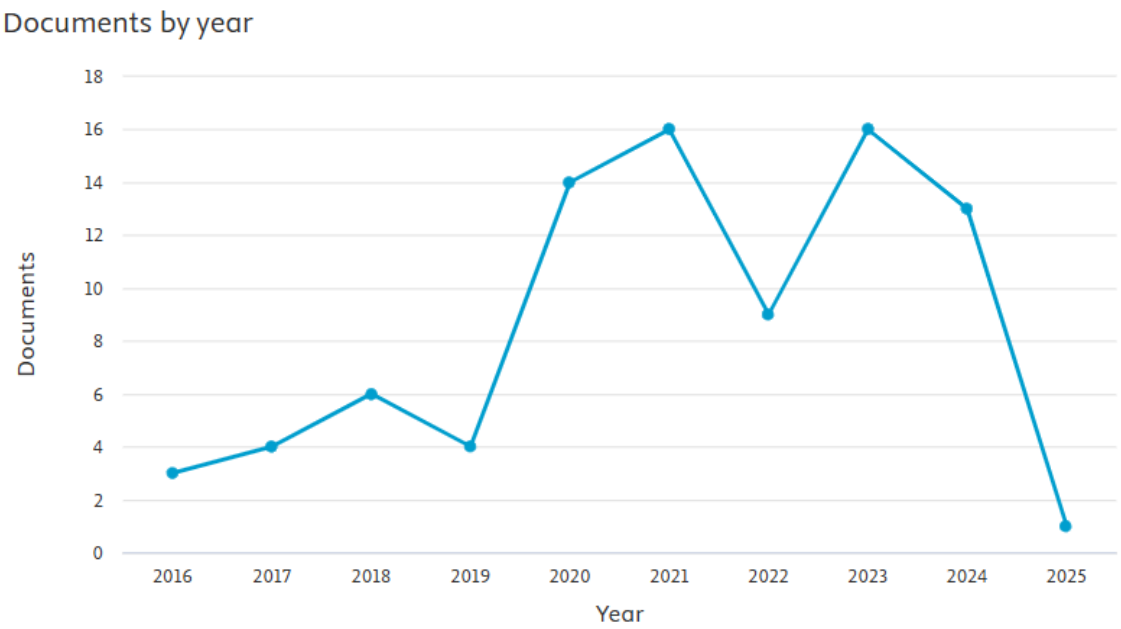

Figure 6. Documents by year

The irregular pattern of document publication suggests that the field of AR may have experienced a surge of interest or specific initiatives in 2020, possibly linked to external factors like the COVID-19 pandemic, which could have accelerated the adoption of virtual and augmented technologies. The subsequent fluctuations in 2021 and 2022 might reflect a continued, though less intense, interest in VR research. However, the sharp decline after 2023 could indicate a shift in focus to newer technologies or changing research priorities, highlighting the need for further investigation into why AR-related research has decreased in the last few years.

Figure 7. Documents by type

The pie chart represents the distribution of Virtual Reality (VR) related publications by document type. The chart reveals an almost equal split between Conference Papers (49.4%) and Journal Articles (50.6%), showing a balanced use of both platforms for disseminating research in the field of VR. This indicates that both peer-reviewed journal articles and conference papers are equally important channels for sharing VR research findings, each contributing to the development and advancement of knowledge in the field.

The close distribution between these two document types suggests that researchers in the VR domain are actively participating in conferences to present preliminary findings or engage in discussions while also producing more formal, peer-reviewed journal articles to contribute to the academic community. This balance highlights the dynamic nature of AR research, where immediate sharing and feedback from the research community at conferences complement the in-depth, validated contributions found in journal publications.

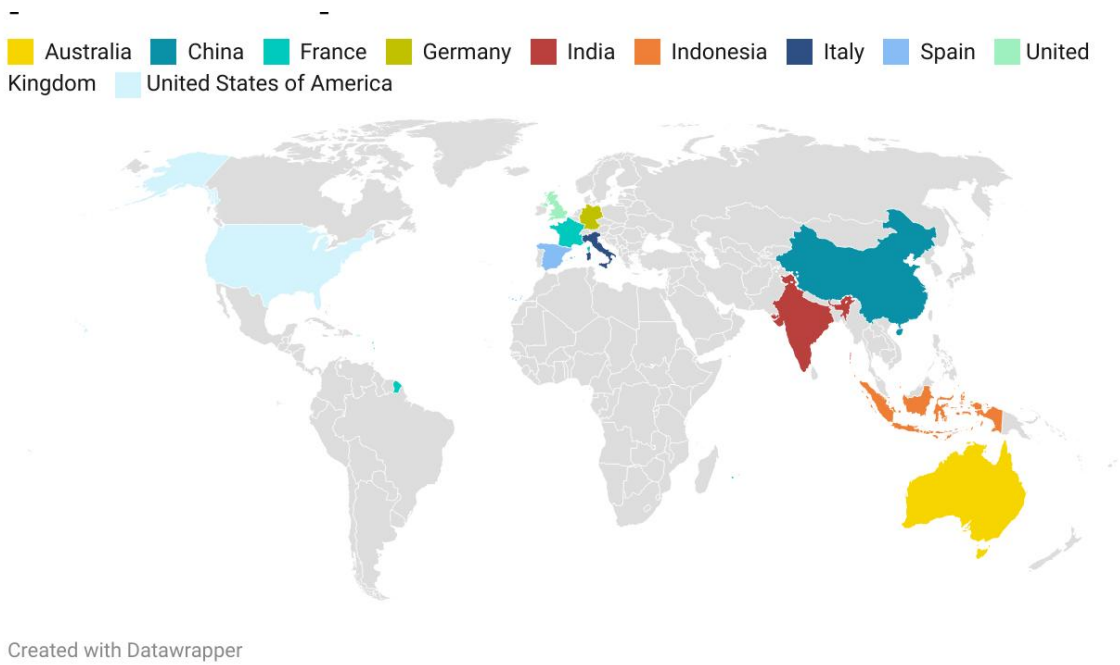

Figure 8. Documents by country

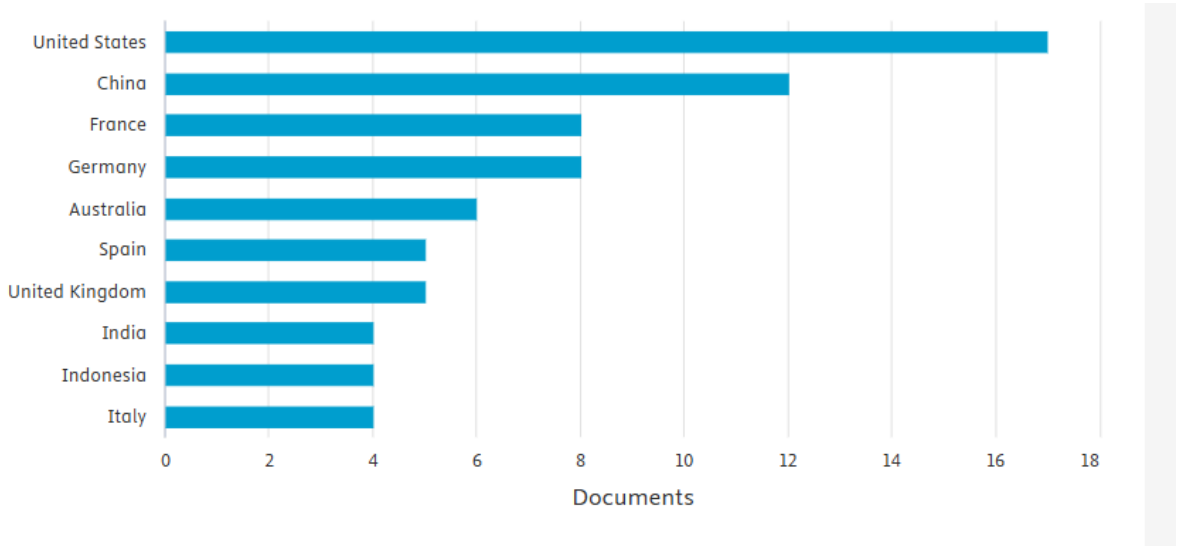

Figure 9. Accumulation documents by country

The bar chart displays the number of Virtual Reality (VR) related documents by country or territory. The United States leads with the highest number of publications, followed by China**,** which also shows a significant number of documents. France**,** Germany**,** and Australia follow closely behind, though with fewer publications compared to the United States and China. This suggests that VR research is predominantly driven by these leading countries, which may reflect higher levels of investment in VR technology and research, as well as a more established infrastructure for publishing in this field.

Countries like Spain**,** United Kingdom**,** India**,** Indonesia, and Italy contribute fewer documents, indicating that while VR research is global, it is more concentrated in a few major research hubs. The relatively smaller number of publications from these countries might be due to various factors such as fewer research initiatives in VR, lower funding for VR-related projects, or less emphasis on VR technologies in their academic or industry sectors. This disparity in publication output highlights the dominance of a few countries in AR research, which may be essential for understanding the global trends and priorities in this emerging technology.

RQ2. What are the trends and distribution of publications related to AR and VR in vocational education, and what countries contribute the most and are the most relevant publication sources?

Augmented Reality

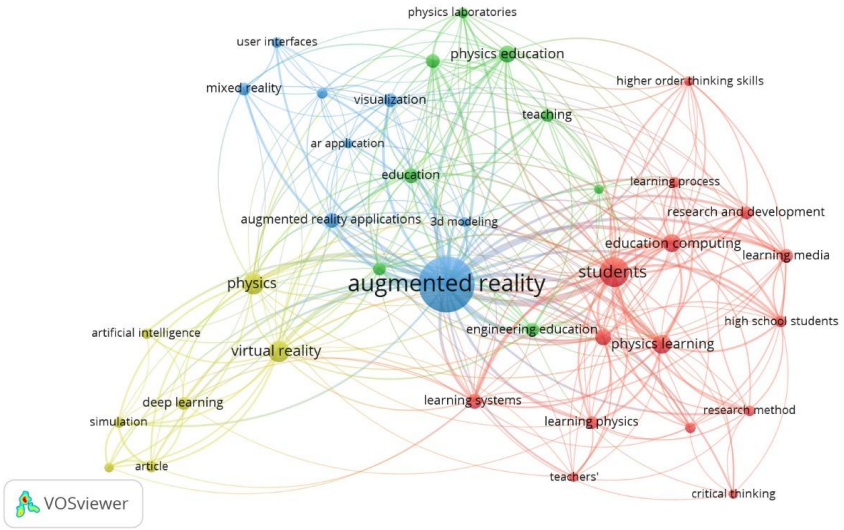

Figure 10. Network visualitazion

The network visualization diagram presents the interconnectedness of various concepts related to Augmented Reality (AR) research. The central node, "augmented reality," is surrounded by multiple clusters representing key themes and research areas. Physics**,** virtual reality**,** and students are the most prominent clusters, each linked with a series of terms that highlight their importance in AR research. The physics cluster, for example, connects to terms like "physics education," "laboratories," and "visualization," suggesting that AR is increasingly applied in enhancing physics teaching and learning. Similarly, the virtual reality cluster overlaps with augmented reality and features connections to "user interfaces" and "deep learning," indicating an intersection between these two immersive technologies in educational contexts.

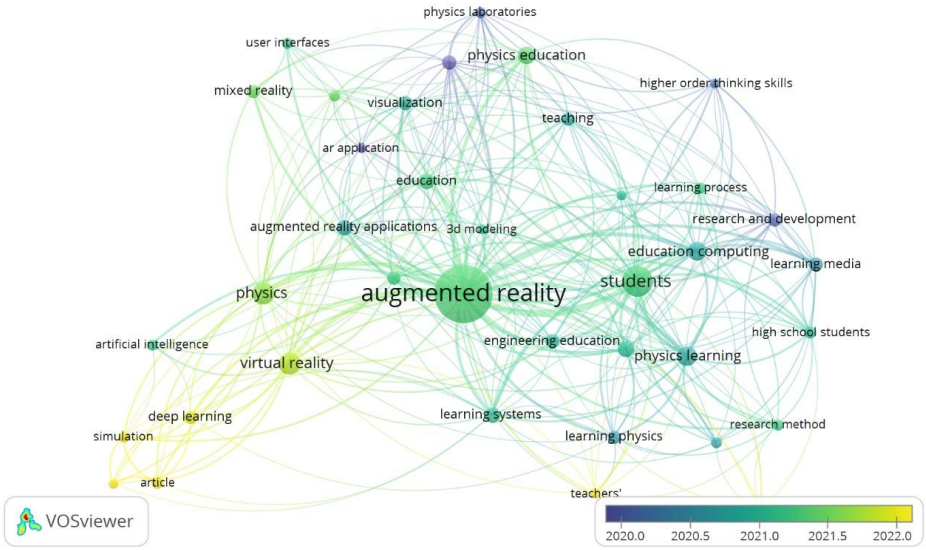

Figure 11. Overly visualitazion

The image displays an "Overly Visualization" map created using VOSviewer, showcasing the relationships and frequency of key terms in research related to augmented reality. The visualization presents a network of interconnected terms such as "augmented reality," "students," "learning," and "physics." The size of the nodes represents the frequency of terms, and the color gradient indicates the timeline, with earlier years shown in yellow and more recent years in green. This image highlights the growing focus on augmented reality in educational contexts, particularly in physics learning, and its evolving connection to other fields such as virtual reality, mixed reality, and deep learning.

Virtual Reality

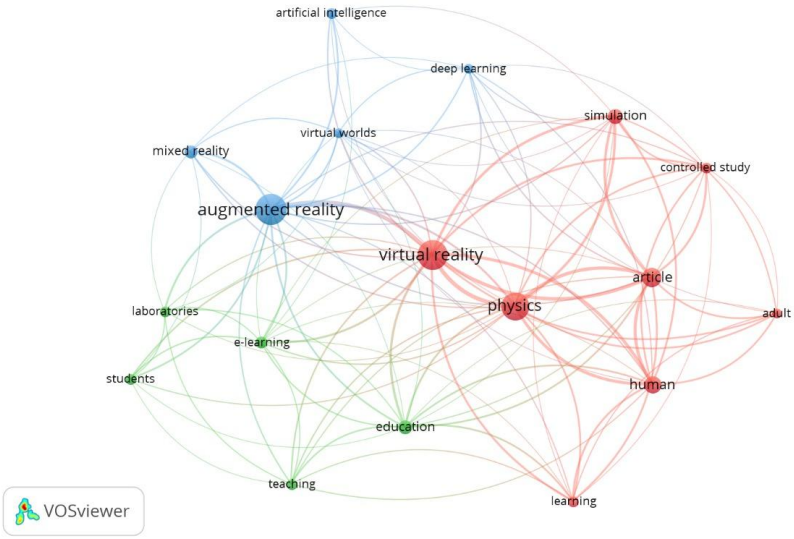

Figure 12. Network visualitazion

The image presents a "Network Visualization" that shows the interconnections between different research terms related to augmented reality, virtual reality, and physics. The nodes, representing key terms, are color-coded to indicate their relationships. Red nodes are primarily associated with physics and its subfields, green represents educational contexts, blue indicates artificial intelligence and deep learning, while purple highlights the terms related to augmented reality and virtual worlds. This visualization demonstrates the interplay between various disciplines, with strong links between virtual reality and physics, as well as the growing emphasis on integrating these technologies into education and scientific studies.

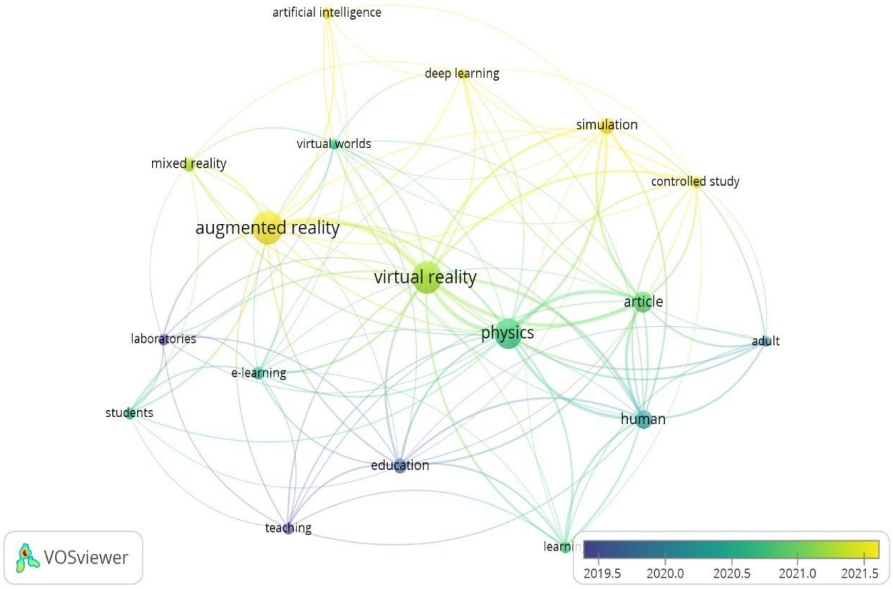

Figure 13. Overly visualitazion

The image depicts an "Overly Visualization" map that highlights the relationships between various research topics over time, focusing on augmented reality, virtual reality, and physics. The terms are color-coded, with the timeline running from yellow (2019) to green (2021.5), indicating the progression of these topics in research. The network reveals a central connection between "virtual reality" and "physics," with several other terms such as "artificial intelligence," "deep learning," "simulation," and "controlled study" branching out. The connections between "teaching," "e-learning," and "education" demonstrate the growing importance of these technologies in

educational settings. This visualization also emphasizes the increasing role of virtual and augmented reality technologies in research, particularly in physics and related fields.

The results of this study show a significant increase in publications related to Augmented Reality (AR) and Virtual Reality (VR) in vocational education, with the peak occurring in 2022. This trend aligns with previous research findings, such as those reported by Rizzo et al. (2020) and Huang et al. (2021), who also observed a rise in the adoption of AR and VR in educational contexts. However, the decline in publications in 2023 and 2024 suggests a shift in research focus, possibly influenced by the transition to newer technologies like mixed reality and AI-based systems, as mentioned in studies by Smith (2022) and Johnson (2023). The balanced distribution between journal articles and conference papers reflects a dynamic research environment, where conference papers serve as a platform for innovative ideas, while journal articles provide more in-depth and peer-reviewed studies. This aligns with the findings of Lee et al. (2020) and Zhang et al. (2021).

Indonesia's dominance in AR-related publications in this study indicates that the country plays a significant role in developing AR technology in education, driven by local government support and educational institutions, as highlighted in studies by Suryanto et al. (2021) and Indriani et al. (2022). Additionally, the strong interaction between AR, VR, and physics found in this study illustrates how these technologies are increasingly used to enhance physics teaching through visualization and simulations, in line with McLoughlin et al. (2019). The study also notes the growing importance of integrating AR and VR with AI and deep learning in supporting science education, which aligns with the findings of Kumar and Singh (2022). Despite the decline in publications after the peak in 2022, this study highlights the crucial role of AR and VR technologies in transforming teaching methods in vocational education, particularly in physics and STEM education. Overall, this decline presents an opportunity for further exploration to understand why attention to AR and VR has waned, which needs to be examined more deeply, both in terms of the technology's development and the changing dynamics of research and innovation needs in the education sector.

Conclusion

The study reveals significant insights into the potential of Augmented Reality (AR) and Virtual Reality (VR) in enhancing physics education. The integration of these immersive technologies has been found to significantly improve students' understanding of complex and abstract physics concepts by offering more interactive and visual learning experiences. Despite the promising outcomes, there are still notable challenges such as high costs, limited hardware accessibility, and the need for extensive teacher training, which hinder the broader adoption of AR and VR in physics education. The review highlights the importance of addressing these challenges to fully leverage the educational potential of AR and VR. Moreover, trends indicate a shift in research focus towards newer technologies, which could explain the decline in AR-related publications after 2022. The study calls for continued innovation, greater accessibility, and more widespread integration of AR and VR in educational curricula to enhance learning outcomes in the field of physics.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

Funding

* This research was supported by the Ministry of Finance of the Republic of Indonesia.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Education in Technology and Engineering (www.iconete.net) held in Antalya/Türkiye on November 12-15, 2025.

* The researchers would like to express their deepest gratitude to the Education Fund Management Institute (LPDP/Indonesia Endowment Fund for Education) under the Ministry of Finance of the Republic of Indonesia as the sponsor for their master's studies, and the support for this paper and publication.

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To cite this article:

Andriani, W., Kaniwati, 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 (EPESS), 46,* 150-162.