Landscape of augmented reality research: A bibliometric analysis

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Abstract
This study aims to examine the trends, contributions, and impact of Augmented Reality research, particularly in physics education, from 2006 to 2025. The study employs a bibliometric analysis approach using the Scopus database. The analysis was conducted with the aid of several software tools, including R Studio with the bibliometric and biblioshiny packages, VOS viewer, and Microsoft Excel. The findings indicate a significant increase in research productivity over the past two decades. Indonesia and the United States (USA) emerged as the two main contributing countries, with Universitas Negeri Semarang and the International Information Technology University identified as the most productive affiliations. Daineko, Y. A., stands out as a leading author, demonstrating strong research presence and extensive collaborations with other scholars. Prominent articles on AR-related topics are distributed across indexed journals. The keyword trend analysis suggests that future research should shift from mere implementation in learning contexts toward optimizing the learning environment through rigorous evaluation of AR effectiveness in education.

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1. Introduction

Rapid technological advancements have brought significant changes to various aspects of life. These developments have encouraged the emergence of innovative ideas and practices, including the integration of interactive media in education (Cai et al., 2017). The use of technology in education, both online and offline, to enhance the quality of education (Aji et al., 2024). One such technological innovation is Augmented Reality (AR), a technology capable of eliminating the boundaries between virtual objects and information in real-world environments, thereby creating more interactive and contextual learning experiences (Saprudin et al., 2025; Zouhri, 2024). Augmented Reality, which has gained increasing popularity due to its accessibility through camera-enabled mobile devices, has evolved into an immersive technology with the potential to transform the educational landscape significantly (Campos-López et al., 2025; Mathew et al., 2025).

Research on AR and its integration into education began in the early 2000s; however, scholarly activity on this topic increased substantially during the COVID-19 pandemic as the need for technology-based learning grew, and this trend continues to persist (Le et al., 2025). Several studies (Y. A. Daineko et al., 2022; Le et al., 2025; Ropawandi et al., 2022; Solmaz et al., 2021) have shown that AR integration supports both online and blended learning environments. This surge was particularly evident in physics education, where laboratory closures during the pandemic drove educators to adopt AR as a strategic alternative for simulating experiments and visualizing abstract phenomena, thereby ensuring pedagogical continuity despite restricted acces to traditional facilities (Lauer et al., 2020; Putri et al., 2021). Consequently, AR-related research continues to expand in response to the growing need for immersive technology–based learning (Freese et al., 2023). Beyond serving as a supplementary learning medium, AR also supports various instructional models and approaches such as STEM (Afrizon et al., 2025; Freese et al., 2023; Rahmayani et al., 2024), inquiry–ethnoscience learning (Rizki et al., 2025), cognitive conflict–based learning (Dhanil & Mufit, 2025), problem-based learning (Cárdenas-Sainz et al., 2023; Fidan & Tuncel, 2019; Rahmasari & Kuswanto, 2023), and discovery learning (Bakri et al., 2020; Ibanez et al., 2015).

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Research on AR continues to expand over time. The demand for holistic 3D imaging in several vital sectors—such as medicine, robotics, gamification, computing, and industry—has driven AR research activities (Campos-López et al., 2025; Solmaz et al., 2021; Stefko et al., 2025; Suzuki et al., 2025). In the field of education, AR integration spans nearly all subjects, including physics, chemistry, biology, astronomy, and more (Al Buraiki et al., 2025; Zainuddin et al., 2025). The growing interest in AR is also supported by findings indicating that AR not only enhances cognitive aspects but also improves affective aspects of learners, such as motivation, interest, and positive attitudes toward learning. As a result, research continues to explore the broader potential of AR in various educational contexts (Cai et al., 2020; Rizki et al., 2025). In physics, for example, AR is used to visualize abstract concepts such as optics (Cai et al., 2020), temperature and heat (Novita, 2023; Saprudin et al., 2025), kinematics and dynamics (Cárdenas-Sainz et al., 2023; Dewi & Kuswanto, 2025), phase changes (Iatraki & Mikropoulos, 2025), fluid mechanics (Dhanil & Mufit, 2025), and electricity and magnetism (Cai et al., 2017; Ropawandi et al., 2023; Sholeh et al., 2024). These studies clearly illustrate that AR aligns well with the characteristics of physics topics that are inherently abstract. Bibliometric studies have previously examined AR integration in education broadly (Anesti & Irwanto, 2025; López-Belmonte et al., 2023; Singh et al., 2024; Zhao et al., 2023). However, these studies have not specifically addressed AR within physics education as a distinct domain, nor have they captured trends up to 2025. This gap underscores the need for a focused bibliometric analysis targeting physics education specifically, offering a more nuanced understanding of fields's current trajectory.

Bibliometric analysis is a widely used method for conducting systematic research on scientific literature, with the aim of identifying patterns, trends, and research impacts within a specific field (Donthu et al., 2021; Passas, 2024). Beyond graphical representation, bibliometric analysis serves as a strategic navigational tool for the scientific community particularly novice researchers to systematically identify research gaps and map underexplored academic territories (R. Kumar, 2025; Mondal, 2026; Moral-Munoz et al., 2019). Bibliometric analysis can be conducted using the Bibliometrix software, which is built in the R programming environment (Aria & Cuccurullo, 2017). Bibliometrix provides various features designed to process information from source databases, such as co-citation and co-authorship analyses, which can reveal relationships between authors, publications, and institutions that contribute to the advancement of research. This approach enables the identification of collaboration patterns and highlights emerging trends and keywords across publication years, offering a clearer overview of the evolution of a research field, including AR (Zainuddin et al., 2025). To better understand the trajectory of AR research development, this study addresses the following research questions.

RQ1: What key information is required for the development of AR-based learning media?

RQ2: Which countries, affiliations, authors, and publishing journals are the most dominant?

RQ3: Which articles are the most highly cited?

RQ4: Which journals contribute most significantly to this field?

RQ5: What does the developmental landscape and thematic mapping reveal?

RQ6: What are the keyword trends and network visualizations?

RQ7: What trending and relevant topics emerge for future research?

2. Method

This study employs a bibliometric approach using the Scopus database as the primary source of publication data. This approach provides a systematic method for exploring and analyzing scientific data on a large scale. Bibliometric analysis not only enables researchers to observe research development trends within a particular field but also plays a crucial role in evaluating and analyzing scientific output, inter-university collaboration patterns, and the efficiency of educational and research systems (Donthu et al., 2021; Moral-muñoz et al., 2020). The bibliometric workflow involves a series of systematic steps, beginning with the collection and screening of scientific literature, followed by data analysis to uncover patterns and research trends. The results are then visualized in the form of maps, graphs, or networks using specialized software to generate meaningful insights

(Kumar et al., 2023; Passas, 2024). The screening of titles and abstracts was conducted by a single researcher following pre-defined criteria to ensure consistency and minimize subjectivity throughout the selection process. In this study, the R application developed by Aria and Cuccurullo (2017) was used to analyze the development trends in augmented reality (AR) research. In addition, VOSviewer was employed for network visualization. Specific minimum thresholds were applied to ensure the reliability of the visualizations: for co-authorship analysis, a minimum of five documents and 15 citations per author were set, ensuring that only authors with sufficient publication output and scientific impact were included in the network, while for keyword co-occurrence analysis, a minimum of five occurrences per keyword was established, retaining only the most consistently appearing terms across the corpus.

Figure 1 presents a comprehensive research flowchart illustrating the systematic stages of this bibliometric study, encompassing Planning, Excecution, and Reporting.

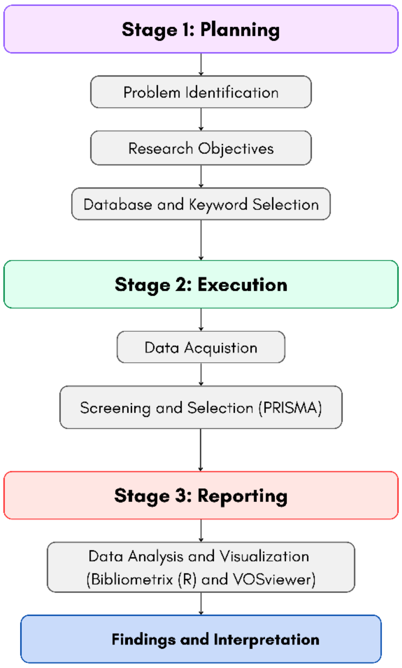

Figure 1. Bibliometric research flowchart

2.1. Scope of Investigation

In October 2025, a bibliometric analysis was conducted using the Scopus database to thoroughly examine research trends related to the development of augmented reality technology within the field of physics. Scopus is one of the largest abstract and citation databases, offering global coverage of scientific journals, conference proceedings, and books, with a rigorous content selection process to ensure the quality of indexed data (Baas et al., 2020). Scopus was chosen due to various advantages (Pranckutė, 2021), including comprehensive metadata, accurate author and institutional profiles, and reliable, manipulation-resistant impact indicators. Additionally, its integrated interface, open access to author and source information, and broad content coverage make Scopus a practical and credible database for bibliometric analysis. The data search range spans from 2006 to 2025, aiming to identify significant contributions and emerging trends in augmented reality research. The syntax and inclusion criteria applied during the data screening process are presented in Table 1.

Table 1. Summary of data characteristics from the bibliometric study

Category	Specific Standard Requirements
Research Database	Scopus
Search Keyword	(TITLE-ABS-KEY (“Augmented Reality”) AND (“Physics”)
Search period	2006 – October 2025
Document Type	Article
Language	English
Data Export Format	CSV, Ris

2.2. Data Processing

Figure 2 illustrates the article selection process following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which assist researchers in preparing and reporting selection results transparently (Page et al., 2021).

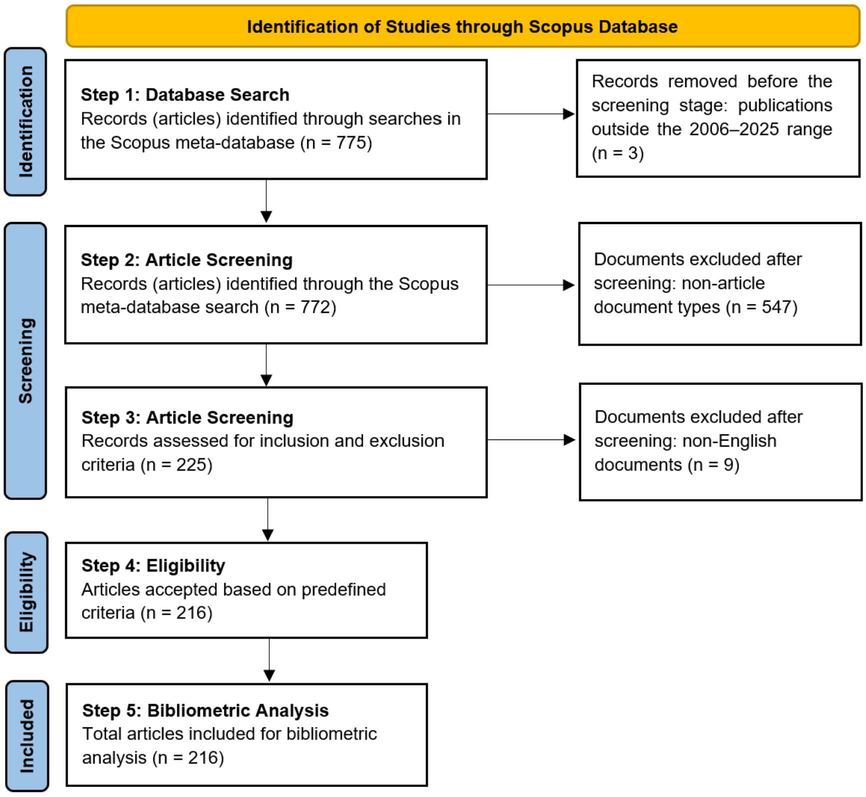

Figure 2. Article screening process

The selection process began by screening the search range with a focus on the predetermined period (2006–2025). Subsequently, the 772 documents were further filtered to include only articles written in English. Limiting the document type to articles reflects a deliberate methodological decision. While it is acknowledged that in a rapidly evolving field such as Augmented Reality, significant innovations are often first introduced through prestigious conference proceedings (e.g., IEEE), this study intentionally restricts the corpus to peer-reviewed journal articles to ensure that the synthesized data derives from studies subjected to the most rigorius multi-stage peer review process, thereby guaranteeing a higher level of methodological maturity and long-term scientific impact. English-language articles were selected because English serves as the main medium of communication in the global academic and scientific community, allowing bibliometric analyses to be more representative and freer from linguistic bias. Moreover, using a single language simplifies the screening and data processing, as language differences can introduce term variations that may disrupt analysis consistency. After the screening process, 216 articles were exported and saved in CSV and RIS formats, compatible with the software used to facilitate data visualization analysis.

2.3. Data Analysis

Bibliometric analysis utilized several applications to present more engaging and comprehensive visualizations. The first application used is R, a software developed using the R programming language for statistical computation and visualization (Team, 2018). Being programmed in R, this software is flexible, easily updatable, and can be integrated with various other statistical packages. Two widely used packages in bibliometric analysis are bibliometrix and biblioshiny, which allow users to conduct comprehensive and interactive analyses (Aria & Cuccurullo, 2017). This study employed R Studio version 2025.09.1-401. Additionally, VOSviewer version 1.6.20 and Microsoft Excel were used to further analyze and visualize bibliographic metadata in depth.

3. Results and Discussion

3.1. Key Information

After running the biblioshiny program, the initial interface of the software displays a summary of key information from all imported articles. The main information regarding documents ready for bibliometric analysis is presented in Figure 3.

Figure 3. Key information

Referring to Figure 3, a total of 216 articles from 133 sources, published between 2006 and 2025, were analyzed bibliometrically in this study. The annual publication growth rate reached 20.93%, indicating a significant increase in research productivity. A total of 807 authors contributed to these publications, with 10 authors publishing individually without collaboration. This indicates that the majority of publications are collaborative, reflecting strong cooperation among researchers and institutions. On average, there were 8.71 authors per document, with 18.52% involving international collaboration, demonstrating a substantial cross-country research network. A total of 636 keywords were used to represent diverse research topics, with 1,805 references cited across all documents. The average publication age was 3.74 years, suggesting that most articles are relatively recent and relevant. Additionally, each document received an average of 26.69 citations, indicating that research in this field has a significant scientific impact and is widely recognized within the academic community.

3.1.1. Annual Publication Trends

The annual number of AR research publications, based on the Scopus database, can be viewed through the Annual Scientific Production feature in the R application. These data were then extracted into Microsoft Excel and mapped in a graphical format to illustrate annual publication trends, as shown in Figure 4.

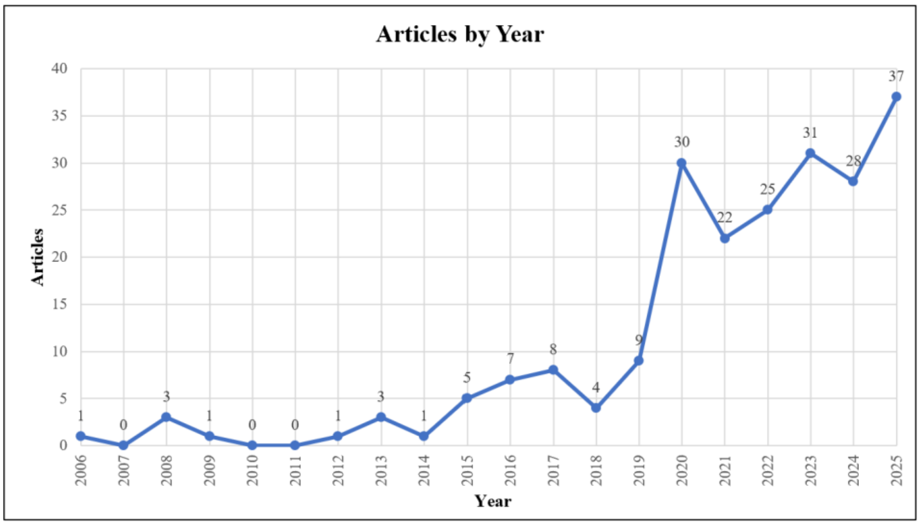

Figure 4. Annual scientific production

From 2006 to 2014, the number of published articles remained very low, often recording only 0 to 3 articles per year, indicating that AR was still in its early exploratory stage during these years. A significant turning point occurred with a surge from 4 articles in 2018 to 9 articles the following year. Rapid growth continued, reaching the first peak in 2020 with 30 articles. Although fluctuations occurred after this peak, the number of publications never returned to the previous low levels, eventually reaching the highest peak in 2025 with 37 articles. Overall, the data reflect that the field has transitioned into a highly active and important research topic since 2019, likely driven by technological innovations or increased adoption.

3.2. Top 10 Countries in Publication

The data in Figure 5 were obtained from the Countries' Scientific Production feature. To visualize the distribution of the top 10 countries contributing the most to scientific publications in this field, the data were plotted into a bar chart illustrating the total article output for each country.

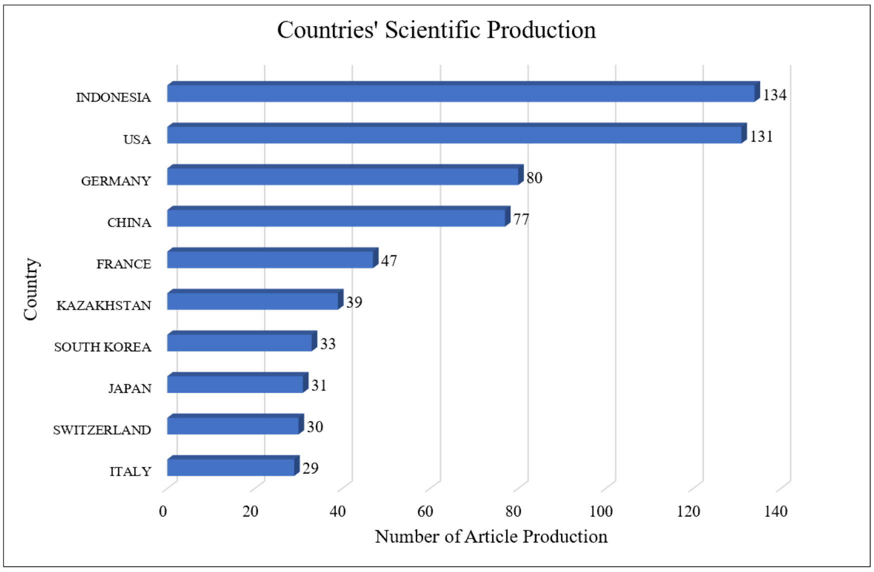

Figure 5. Article publication distribution by country

The publication chart clearly shows the dominance of Indonesia, followed closely by the United States (USA). With a total of 134 articles, Indonesia ranks first, slightly ahead of the USA, which contributed 131 articles, indicating that both countries are major contributors in this field. There is a notable gap between these two leading countries and the next group of contributors. Germany ranks third with 80 articles, followed by China with 77 articles, forming the second tier of strong contributors. Other countries, such as France (47), Kazakhstan (39), South Korea (33), and Japan (31), contributed at lower but relatively even levels. Overall, these data indicate that Indonesia and the USA serve as the primary centers of research activity in this topic, while other European and Asian countries provide significant contributions, demonstrating that this research field has a global reach, albeit concentrated mainly in the top two countries. The prominence of Indonesia in this field may be attributed to two interconnected institutional factors. First, Indonesian lecturers are mandated to conduct and publish research as part of the Tri Dharma Perguruan Tinggi framework, which institutionally obligates academics to contribute to scientific knowledge (Republik Indonesia, 2012). Second, the introduction of SINTA (Science and Technology Index) in 2017 further incentivized researchers to increase their output in Scopus-indexed international journals as part of academic promotion requirements (Fry et al., 2023). This policy-driven surge in overall research productivity may have consequently extended to emerging fields such as AR in physics education. Alternatively, this phenomenon may reflect a broader paradigm shift in Indonesian educational research toward digital and technology-based media. Nevertheless, further investigation is needed to determine the primary driver of Indonesia's dominance in this particular domain.

3.2.1. Most Productive Affiliations

Figure 6 presents the top 10 most productive institutions in terms of publications. The data indicate a dominance of Asian institutions, particularly those from Indonesia, in research contributions. Universitas Negeri Surabaya (UNESA) ranks first with the largest contribution of 22 articles, slightly ahead of the International Information Technology University with 19 articles. These two institutions form the primary contributor group. The next group shows relatively even productivity, ranging from 15 to 10 articles, with Universitas Negeri Yogyakarta (13 articles) and Universitas Negeri Padang (10 articles) also included in the top 10. The presence of three Indonesian universities (UNESA, UNY, and UNP) as leading contributors, alongside institutions from Kazakhstan, Spain, China, Greece, Australia, Germany, and South Korea, further reinforces the previous finding regarding Indonesia's significant contribution and the global diversity of research in this field.

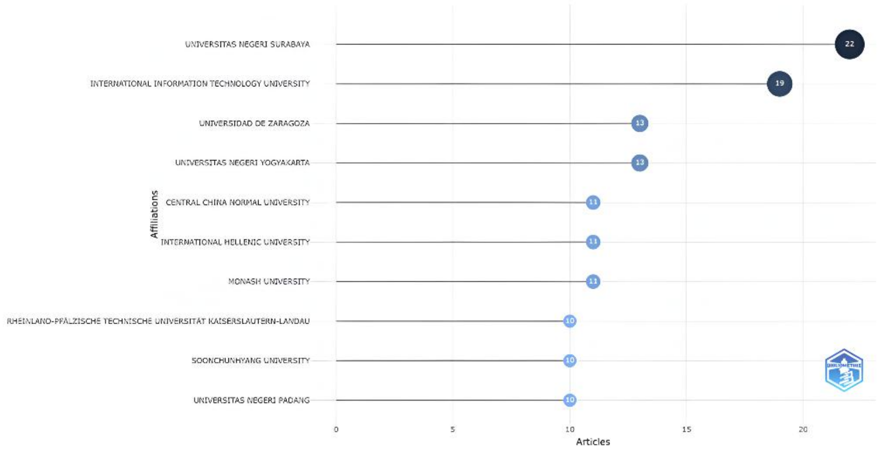

Figure 6. Most productive affiliations

3.2.2. Most Productive Authors (2006–2025)

Figure 7 presents a visual analysis of author contributions in the field of AR over the period 2006–2025, generated using VOSviewer. The data on the most productive authors reveal a core group of researchers dominating publications in this field.

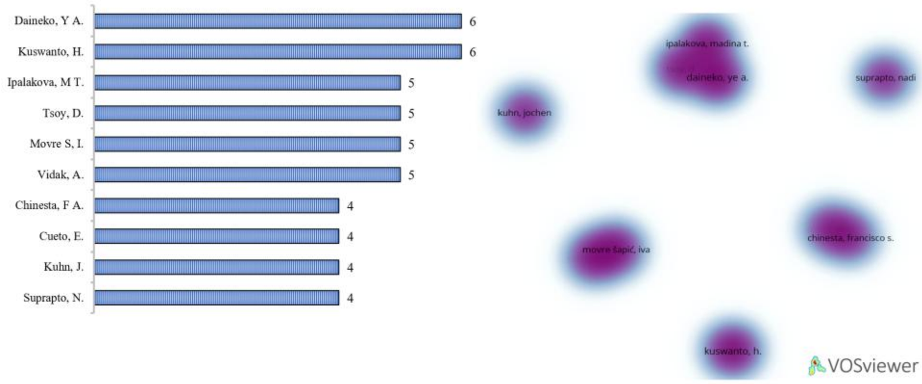

Figure 7. Most productive authors

Based on the bar chart, Daineko, Y. A. and Kuswanto, H. are the top authors, each contributing six articles. This group is followed by four other authors Ipalakova, M. T.; Tsoy, D.; Movre, S. I.; and Vidak, A. with five articles each, indicating the presence of individuals with exceptionally high research activity. The Density Visualization feature shows distinct collaboration clusters. The main cluster appears to involve groups around Daineko, Y. A., Ipalakova, M. T., and Tsoy, D. (with high density), suggesting frequent collaboration among them. Kuswanto, H. also emerges as a key author but is positioned in a separate cluster, implying that he may lead another distinct collaboration group, similar to Supratno, N. and Chinesta, Francisco S. Overall, this research field is driven by several independent research clusters led by highly productive individuals, with intensive collaboration occurring within each cluster. Notably, the prominence of Kuswanto, H. whose work is closely tied to AR integration in physics education reflects the growing pedagogical demand for AR as a solution to the abstract nature of physics concepts and practical limitations of real-world experimentation in classroom settings. This suggests that bibliometric landscape of AR research is not merely shaped by prolific output, but is increasingly driven by the need to address specific instructional challenges faced by physics practitioners.

3.2.3. Most Published Journals

Using the Most Relevant Sources feature, the distribution of journals that published the most articles related to this research field is presented in Figure 8.

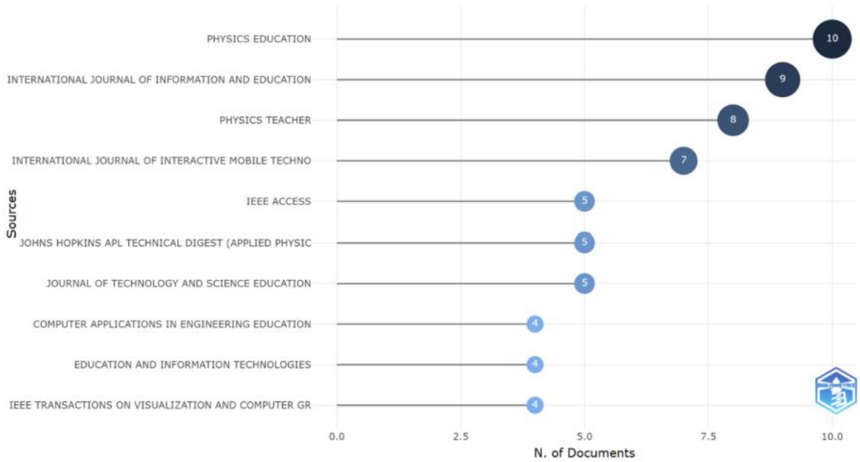

Figure 8. Most productive journals

The figure above presents the journals and publication sources that have published the most articles in this research field. The data indicate that the research primarily focuses on journals related to education, particularly physics education, and information technology. Physics Education dominates with the highest contribution, totaling 10 documents, followed by International Journal of Information and Education and Physics Teacher, contributing 9 and 8 documents, respectively. Collectively, these sources indicate that the core of this research lies in physics pedagogy enriched with technology and information integration. Additionally, other sources in the top 10, such as International Journal of Interactive Mobile Technology (7 documents) and journals focused on technology, engineering, and computing, further underscore the interdisciplinary nature of this research.

3.3. Most Cited Articles

To identify the most influential and significant articles in this field, the following table presents the top 10 most cited articles based on the Most Global Cited Documents feature. Table 2 shown a most cited articles.

Table 2. Most cited articles

Rank	Authors	DOI	Journal	Total Citations	TC per year	Normalized TC
1	Potkonjak et al. (2016)	10.1016/j.compedu.2016.02.002	Computers & Education	744	74.40	4.00
2	Akçayir et al. (2016)	10.1016/j.chb.2015.12.054	Computers in Human Behavior	435	43.50	2.34
3	Fidan & Tuncel (2019)	10.1016/j.compedu.2019.103635	Computers & Education	311	44.43	5.62
4	Saidin et al. (2015)	10.5539/ies.v8n13p1	International Education Studies	251	22.82	2.98
5	Thees et al. (2020)	10.1016/j.chb.2020.106316	Computers in Human Behavior	248	41.33	9.84

Rank	Authors	DOI	Journal	Total Citations	TC per year	Normalized TC
6	Enyedy et al. (2012)	10.1007/s11412-012-9150-3	International Journal of Computer-Supported Collaborative Learning	199	14.21	1.00
7	Cai et al. (2012)	10.1080/10494820.2016.1181094	Interactive Learning Environments	187	20.78	3.63
8	Choi et al. (2021)	10.1145/3478513.3480542	ACM Transactions on Graphics (TOG)	157	31.40	4.16
9	Cai et al. (2021)	10.1111/bjet.13020	British Journal of Educational Technology	144	28.80	3.81
10	Jesionkowska et al. (2020)	10.3390/educsci10080198	Education Sciences	142	23.67	5.63

Table 2 presents the ten most influential articles in the field, measured by total global citations (Total Citations), which indicate the research impact and quality. Research in this area is dominated by publications closely related to technology, computing, and education. The journals Computers & Education and Computers in Human Behavior emerge as primary platforms for the most impactful research, each contributing two articles to the top 10 list. The top article, by Potkonjak et al. (2016) published in Computers & Education, demonstrates a substantial impact with 744 citations and the highest annual citation rate of 74.40. These articles indicate that the most recognized research focus lies in the integration of technology and computing within educational and human behavior contexts. Moreover, although these articles were published over a relatively broad period (2012–2021), the high Normalized TC values for some more recent publications (e.g., Thees et al., 2020) suggest that the trend of research impact continues, producing relevant and frequently cited work in a short period of time.

3.4. Most Impactful Journal

Table 3 presents journals with the greatest impact in the field, measured by H-index, G-index, M-index, and Total Citations (TC), as obtained through the Sources' Local Impact feature.

Table 3. Most impactful journals

No	Source	H-index	G-index	M-index	TC
1	Journal of Technology and Science Education	5	5	0.833	72
2	Physics Education	5	8	0.625	80
3	Computer Applications in Engineering Education	4	4	0.667	158
4	IEEE Access	4	5	1.000	125
5	IEEE Transactions on Visualization and Computer Graphics	4	4	0.444	203
6	International Journal of Information and Education Technology	4	6	1.000	43
7	International Journal of Interactive Mobile Technologies	4	7	0.667	54
8	International Journal of Emerging Technologies in Learning	3	4	0.500	65
9	Journal of Theoretical and Applied Information Technology	3	4	0.250	21
10	Physics Teacher	3	6	0.231	39

Journal of Technology and Science Education and Physics Education lead with the highest H-index (5), indicating the quality and consistency of frequently cited articles. Meanwhile, the G-index reflects citation depth: Physics Education (8) and International Journal of Information and Education Technology (6) achieve the highest values, suggesting that these journals have a collective set of articles reaching substantial citation levels. IEEE Transactions on Visualization and Computer Graphics stands out with the highest Total Citations (TC) at 203. Additionally, IEEE Access and International Journal of Information and Education Technology demonstrate high efficiency with an M-index of 1.000. Overall, these data confirm that interdisciplinary journals spanning Education, Science/Technology, and Computing serve as the primary platforms with the greatest impact and authority in this research field.

3.5. Thematic Development

Figure 9 illustrates the thematic development using the Three-Field Plot feature, which presents a Sankey diagram depicting the connectivity between countries, authors, and keywords, revealing the actual collaboration structure and research focus within this study.

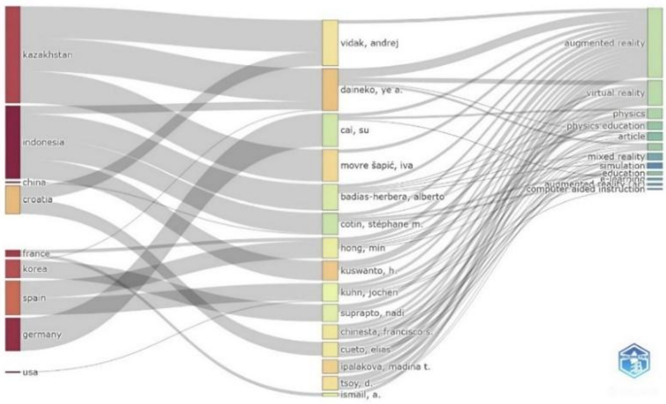

Figure 9. Sankey diagram

The left-to-center connection analysis highlights patterns of author involvement. According to the diagram, research on Augmented Reality is primarily conducted by researchers from Kazakhstan, Indonesia, and China, indicating that these three countries play a dominant role in AR-themed publications. Other countries, such as Croatia, Spain, Germany, Korea, and France, also contribute, though to a lesser extent, while the USA appears to have the smallest involvement in this dataset. Several authors stand out due to their extensive connections with countries and research keywords, including Vidak, Andrej; Daineko, Ye. A.; Movre Šapić, Iva; Cai, Su; Kuswanto, H.; and Suprapto, Nadi. This suggests that they are active contributors to Augmented Reality research and exert significant influence on the development of the topic. In terms of research themes, the most frequently appearing keywords are augmented reality, virtual reality, mixed reality, simulation, and e-learning, indicating that research in this field focuses heavily on developing immersive technologies to support digital learning processes. Additionally, the presence of keywords such as physics, physics education, and computer-aided instruction shows a strong tendency toward applying Augmented Reality in science education contexts, particularly physics. Overall, the diagram illustrates that Augmented Reality research is multidisciplinary and transnational, with a primary focus on integrating immersive technology into education. The dominance of countries such as Kazakhstan, Indonesia, and China, along with the emergence of authors and keywords related to physics education, indicates that the global research direction in this field is moving toward leveraging AR/VR to enhance the effectiveness of science learning across various educational contexts.

3.5.1. Thematic Map

The thematic map presented in Figure 10 aims to classify and visualize the relative status of research topics within the field.

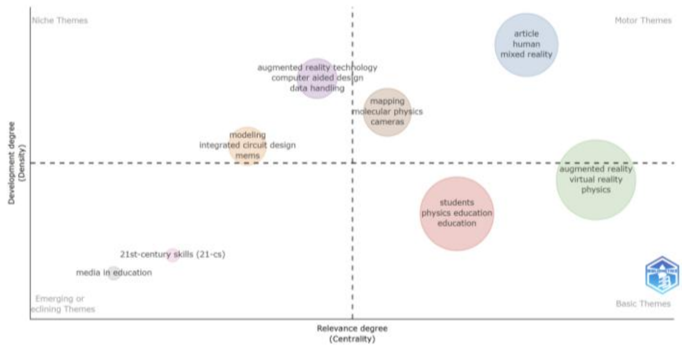

Figure 10. Thematic map

The thematic map effectively classifies the research focus within this field based on how relevant (centrality) and how developed (density) a topic is. The lower-right quadrant is dominated by Basic Themes, such as augmented reality, virtual reality, physics education, and students, which exhibit high centrality but relatively low density. This indicates that these topics form the theoretical and contextual foundation of nearly all research, remaining consistently relevant without requiring extensive new literature development. This positioning also signals that AR research within physics education has reached a stage of scientific maturity, having established a solid and widely accepted knowledge base that no longer requires foundational redefinition. In contrast, the upper-right quadrant contains Motor Themes, such as mixed reality, human, and article. These topics have both high centrality and density, making them the main driving forces actively connecting various subfields. The emergence of Mixed Reality as a Motor Themes suggest a gradual transition toward more sophisticated reality integration frameworks, reflecting the field's evolving trajectory beyond conventional AR and VR. This suggests that current research is heavily focused on the integration of mixed reality. Meanwhile, the upper-left quadrant is occupied by Niche Themes, such as computer-aided design and data handling. These topics show high density, indicating very specific and in-depth research development, but low centrality, meaning their impact is limited to specialized research groups. Finally, the lower-left quadrant includes Emerging or Declining Themes, such as 21st-century skills and media in education. Low centrality and density suggest that these topics are either newly emerging, seeking connections to main themes, or are older topics that have been supplanted by a focus on more advanced technologies (AR/VR/MR). Overall, this thematic map indicates that the field has a strong foundation in physics education and immersive reality technologies (AR/VR), and is currently being propelled forward by research on the integration of mixed reality as the next frontier of immersive learning.

3.6. Keyword Trends and Network Visualization

Figure 11 presents a tree map visualization depicting the frequency distribution of keywords in publications related to augmented reality.

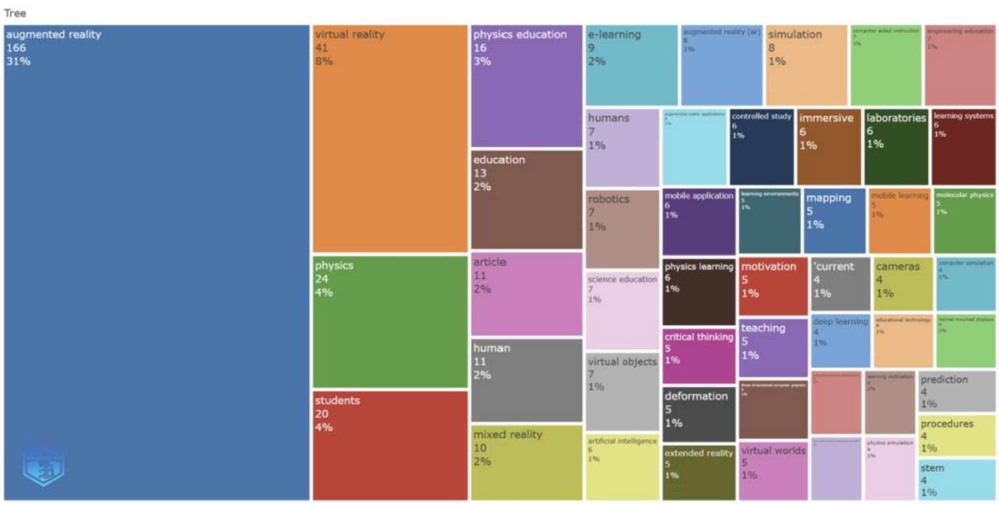

Figure 11. Tree map keyword

Larger boxes represent keywords that appear more frequently, while variations in color and size reflect differences in topics and their level of connectivity. The figure shows that the keyword augmented reality dominates with 166 occurrences (37%), indicating that this term is the primary focus of research. Other frequently used keywords include virtual reality (9%), physics (5%), and students (4%), highlighting that AR research is often examined within the context of physics education and student learning. Additionally, keywords such as mixed reality, e-learning, simulation, critical thinking, and laboratories suggest a trend toward linking AR with digital learning innovations and the development of critical thinking skills. Keywords like robotics, immersive, and extended reality indicate an expansion of research into broader interactive and immersive technologies. Overall, this tree map demonstrates that augmented reality research is multidisciplinary, with a strong focus on applications in education particularly physics education and integration with various modern learning technologies. Figure 12 presents a network visualization of Augmented Reality research based on bibliometric analysis using VOSviewer.

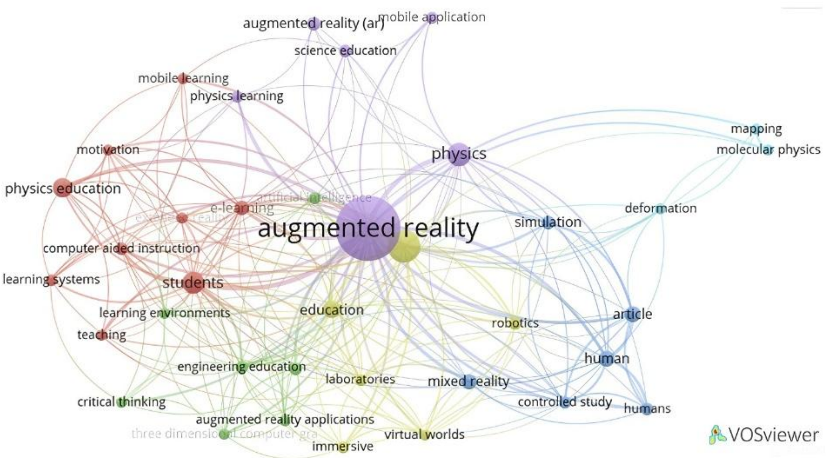

Figure 12. Network visualization

The size of each node represents the frequency of a keyword's occurrence in publications, while the colors and connecting lines indicate thematic relationships among research topics. The keyword augmented reality occupies the central position with the largest node, signifying its dominance and role as the primary focus of research. The red cluster shows connections between AR and physics education, computer-assisted learning, motivation, and e-learning, illustrating the application of AR in educational contexts. The green cluster relates to education, learning environments, and critical thinking, indicating a focus on developing learning environments and enhancing cognitive skills. The blue cluster links AR with simulation, robotics, and mixed reality, highlighting research directions in technology and experimental applications. Meanwhile, the purple cluster connects AR with physics and science education, demonstrating its implementation in science and laboratory-based learning. Overall, this visualization shows that Augmented Reality research spans multiple domains, with strong concentrations in education and science, while increasingly intersecting with technology areas such as robotics and virtual simulations.

3.7. Trending and Relevant Topics for Future Research

3.7.1. Trending Topics

Figure 13 illustrates the evolution and main focus of AR research from approximately 2016 to 2024.

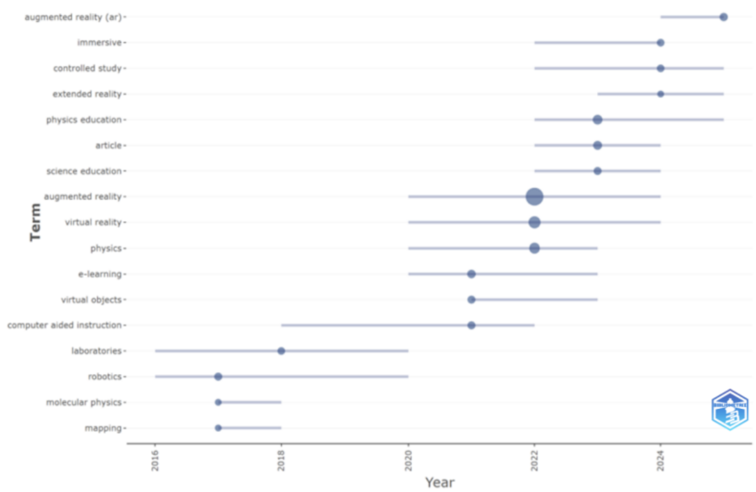

Figure 13. Trending topics in AR research

Overall, the trend shows a shift from more specific and fundamental topics toward broader, immersive, and education-oriented topics, particularly in the fields of science and physics. In the early phase (2016–2020), research initially focused on more specific and technical aspects, highlighted by terms such as mapping, molecular physics, robotics, and laboratories. The term computer-aided instruction also appeared during this phase, indicating an early emphasis on technology applications in teaching. During the mid-phase (2020–2022), there was a significant surge in topic popularity. Augmented reality emerged as the primary focal point, represented by the largest node, indicating the highest research intensity. Dominant topics included virtual reality, physics, and e-learning, suggesting that AR began to be actively integrated into online and science learning contexts. In the latest phase (2022–2024), the trend shifted toward more advanced and applied concepts. Terms such as immersive, extended reality (XR), and controlled study dominated, indicating that current research focuses on deep user experiences and validating the effectiveness of AR/XR applications through rigorous research methodologies. Topics like physics education and science education during this period emphasize AR's growing relevance as a pedagogical tool in STEM fields.

3.7.2. Relevant Topics for Future Research

Using the Conceptual Structure Map feature, relevant topics for future research can be identified, as shown in Figure 14.

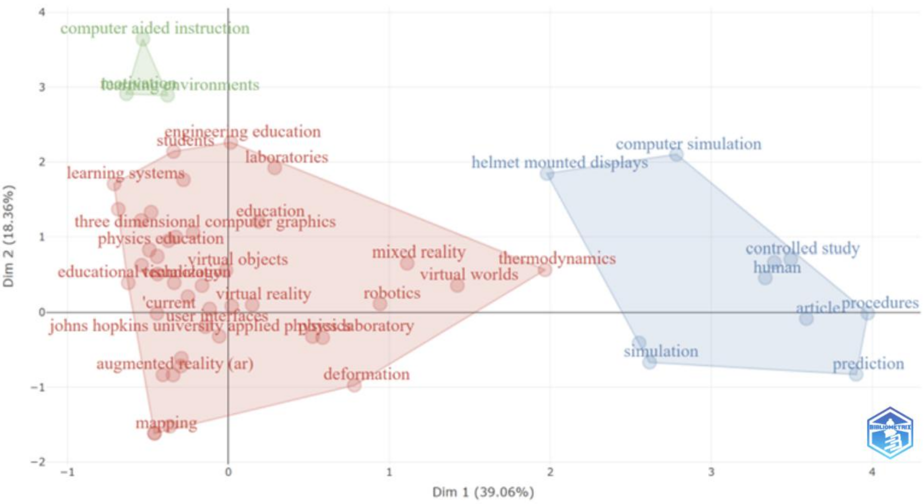

Figure 14. Conceptual structure map

Figure 14 divides research topics into several major clusters based on co-occurrence and proximity within the literature. These clusters represent related research areas with potential directions for future study. The lower-left cluster (pink) focuses on immersive applications and education. This cluster occupies the largest area and appears to be the center of the current research ecosystem. Topics are dominated by immersive technologies and educational applications, including core technologies (augmented reality, virtual reality, virtual objects, user interfaces, computer graphics, mapping), educational applications (physics education, educational technology, learning systems, three-dimensional computer graphics, laboratories), and applied details (terms such as robotics and deformation indicate AR/VR use in technical experiments and visualization of physical phenomena). The lower-right cluster (blue) emphasizes methodology, simulation, and validation. Positioned away from the central cluster, this group reflects a different focus, namely on methodological rigor and evaluative aspects of research. The upper-left cluster (green) centers on interventions and learning environments. This small, isolated cluster represents a more specific domain, concentrating on instructional design and learning intervention frameworks. Key topics include computer-aided instruction and learning environments. Its position, distant from other clusters, indicates that while related, this research emphasizes pedagogical frameworks and instructional design rather than the implementation of immersive technology itself. Future research is likely to lie at the intersection of the pink and blue clusters, meaning studies should shift from merely developing AR/VR experiences (pink) to rigorously testing their effectiveness through controlled studies and computer simulations (blue) within the context of physics or engineering education. The green cluster can serve as the context in which these AR/VR interventions are implemented to optimize learning environments.

The trend of augmented reality (AR) research from 2006 to 2025 shows a significant annual growth in publications, indicating a substantial increase in research productivity. This study highlights extensive collaboration among researchers, as evidenced by 807 authors, with only 10 working individually without collaboration. As shown in Figure 3, there was a notable surge in AR publications in 2020, likely driven by the rising demand for technology during and after the COVID-19 pandemic. Furthermore, in 2025, AR research reached a peak of 37 publications, indicating that AR studies have become increasingly widespread. Among the top ten countries in terms of publication output, Indonesia leads with a total of 134 documents, narrowly surpassing the USA in second place with 131 documents. These top ten countries are distributed across multiple continents, demonstrating the global development and international relevance of this topic. The institutions most active in producing scholarly works on this topic are led by Universitas Negeri Surabaya with 22 publications, while the universities ranked 8th, 9th, and 10th each contributed 10 publications, showing that the publication range among the top ten affiliations is relatively narrow. The most productive author is Daineko, Y. A., with a total of six publications, frequently collaborating with Ipalakova, M.T., and Tsoy, D., as illustrated in Figure 7, which shows author collaboration clusters (Y. Daineko et al., 2017, 2020, 2024). The diversity of countries, institutions, and collaborative authors indicates that AR research holds global relevance and is considered important in various contexts, thus yielding more comprehensive findings with higher validity.

The distribution of the top ten journals publishing AR-related studies is presented in Figure 8. Physics Education, indexed as Q2, ranks first as the journal publishing the most articles on AR, particularly in physics education. Meanwhile, the most cited articles indicate strong influence and recognition within the scientific community. The study by Potkonjak et al. (2016) is the most cited article, with 744 citations between 2006 and 2025. It was published in the Scopus Q1 journal Computers & Education. These findings show that the journals with the highest number of publications do not always produce the most cited articles. On the other hand, journals with the greatest impact in the field can be evaluated through H-index, G-index, M-index, and total citations (TC). The H-index measures a researcher's productivity and citation impact, while the G-index reflects both the number of publications and citations per publication (Passas, 2024). Journal of Technology and Science Education (H-index 5) and Physics Education (H-index 5) indicate that both journals have collections of articles that collectively achieve a higher and substantial citation level.

In bibliometric analysis, thematic development is a representative output for observing research trends. Figure 9 illustrates thematic development through a Three-Field Plot, displaying a Sankey diagram that maps the relationships between countries, authors, and keywords, thereby revealing collaboration structures and research focus. This visual representation demonstrates that, despite variation in global output, researchers are primarily united by the in-depth exploration of immersive technology in learning contexts. Another method for analyzing conceptual structures is thematic mapping, which evaluates the relevance (centrality) and development level (density) of a theme. This method involves keyword mapping and clustering of scientific documents within relevant databases (Asriadi et al., 2023). Thematic development is closely associated with keywords (Zainuddin et al., 2025). The tree map visualization showing keyword frequency distribution (Figure 11) indicates "augmented reality," "virtual reality," and "physics" as the most frequently occurring keywords. Figures 9, 10, and 11 suggest that these keywords constitute basic themes with high centrality but relatively low density, indicating that these topics serve as the theoretical foundation and necessary context for nearly all studies. Furthermore, network visualizations of AR in physics education using VOSviewer reveal keyword frequencies and thematic relationships across topics (Yefremenko et al., 2025; Zhao et al., 2023). "Augmented reality" emerges as the central keyword connecting relevant topics. The resulting network is divided into clusters representing research areas, including AR applications in learning contexts, development of learning environments and thinking skills, technology and experimentation, and science and experimentation.

Trends and relevant topics for future research can be observed from the trend topic analysis (Figure 13), which shows the evolution of AR research over the years. There is a transition from technology application in teaching (Bakri et al., 2020; Jesionkowska et al, 2020; Vidak et al., 2021) to immersive user experiences and validation of AR/XR effectiveness through rigorous research methodologies (Cevahir et al., 2022; Laumann et al., 2024; Long et al., 2023). Future research topics can also be explored through Conceptual Structure Map clustering, grouping topics based on proximity and co-occurrence in the literature. The clusters—immersive applications and education; methodology, simulation, and validation; and interventions and learning environments—represent AR research themes. Future studies lie at the intersection of the pink and blue clusters, suggesting a shift from application-focused research to testing through controlled studies and computer simulations within learning contexts.

Despite its contributions, this study has several limitations that should be acknowledged. The analysis relies solely on the Scopus database, which may capture only a friction of relevant publications available in other sources such as Web of Science or Google Scholar, potentially introducing selection bias. The corpus was further restricted to peer-reviewed journal articles written in English, meaning that significant contributions published in conference proceedings such as those indexed by IEEE or in non-English languages were excluded, which may underrepresent certain research communities. Additionally, the screening process was conducted by a single researcher, which, despite being guided by pre-defined inclusion and exclusion criteria, may carry a degree subjectivity inherent to individual judgment. These limitations provide a basis for critical reflection and offer strategic directions for future research in this filed.

4. Conclusion

The bibliometric analysis conducted based on the PRISMA framework demonstrates that research on augmented reality (AR), particularly in physics education, has experienced significant growth over the past two decades, as reflected by the increasing rate of publications and citations in this field. Indonesia emerges as the most productive country in terms of publications (n = 134), with Universitas Negeri Surabaya being the most active affiliation contributing 22 works. Author analysis reveals that Daineko, Y.A., together with several other top-ten authors, forms collaborative clusters, indicating the presence of a concentrated yet dynamic research community. The diversity of countries, affiliations, and collaborative authors suggests that AR research holds global relevance. The distribution of leading journals and articles indicates that AR is a highly influential topic and serves as a key reference for scientific research communities. Keyword trend analysis assists researchers in identifying emerging topics over specific time periods and their relationships with other themes. Future research is recommended to boarden the scope by utilizing multiple databases incorporating non-English publications, and integrating qualitative approaches, such as Systematic Literature Review (SLR), with quantitative methods like Meta-Analysis to examine the impact of AR research in specific educational contexs. Ongoing research should shift focus from mere AR implementation to the optimization of learning environments through rigorous testing of AR effectiveness.

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