

Bibliometric Mapping and Clustering of Augmented Reality in Physics Education: Trends, Gaps, and Future Directions

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Article Info	Abstract
Article history: Received: January 17, 2026 Accepted: March 14, 2026 Published: March 22, 2026 Keywords: Augmented reality Bibliometric analysis Physics education Science mapping This article is licensed under a creative commons attribution-share alike 4.0 international license © 2026 Jurnal ilmiah Pendidikan Fisika	Augmented reality is considered to have the potential to support physics teaching by visualizing abstract concepts. However, to keep pace with the rapid developments across various disciplines in this field, bibliometric analysis was conducted to map the intellectual structure, identify emerging trends, and highlight potential directions for future research. This study systematically covers publications from 2012–2025, providing a comprehensive overview of research trends in AR for physics education. The objectives of this study are (1) to identify publication trends and main contributing institutions; (2) to identify the most productive authors, the most influential publications, and the core journals; (3) to map the main research topics and their interrelationships; and (4) to analyze collaboration patterns between countries and authors. A total of 77 documents were retrieved from the Scopus database and analyzed using descriptive bibliometric techniques and science mapping. In this study, the topics “augmented reality” and “students” emerge as the most central nodes, indicating the primary focus of the research and serving as links between research clusters. Thematic analysis also indicates that niche themes, such as “learning outcomes” and “teaching,” are not yet widely connected to motor themes, highlighting potential directions for future research, including exploring integration between these two groups and investigating more integrated approaches in technology-enhanced physics learning. These findings can provide guidance for researchers in physics education and suggest areas for further studies to explore more integrated approaches in AR-supported learning, contributing to the ongoing development of physics education research.
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INTRODUCTION

Currently, technological advances have had a significant impact on various aspects of life, including education ([Lampropoulos et al., 2022](#)), and these advances have created an interactive, efficient, and engaging learning environment and also improved the quality of teaching and encouraged the development of students' abilities ([Akram et al., 2022](#)). Education is one of the fields that has the potential to adopt technological innovation, with adoption theories and models as a basis for understanding the complexity of learning, one example of which is by involving teachers and students in teaching and learning activities

([Granić, 2022](#)), as well as providing high-quality education and meeting student needs ([Lampropoulos et al., 2022, 2023](#)).

The use of technology in education has experienced much more rapid development than before, and along with this development, various new methods have been implemented in educational environments, resulting in learning applications that can attract students' attention, arouse curiosity, and make the learning process more enjoyable and sustainable ([Yilmaz & Batdi, 2021](#)). The use of technology in education is not just a trend but rather an aspect that represents a fundamental shift in pedagogical approaches ([Dhaas, 2024](#)). Traditional teaching is considered not yet fully adequate to adopt the demands of a digital society ([Kamińska et al., 2023](#)), therefore, technological skill in education must be further enhanced, as many innovations are expected to emerge in the future, such as augmented reality, machine learning/artificial intelligence, open learning sources, and adaptive learning ([Prahani et al., 2022](#)).

The development and implementation of innovative learning methodologies indicate society's openness to new technologies and ideas ([Iqbal et al., 2022](#)). Student understanding and retention may be hindered if learning approaches that are used rely on theoretical activities and written guides, as these approaches do not yet fully provide an interactive learning experience for students ([Criollo-C et al., 2024](#)). One of the innovations in the field of education is the use of augmented reality ([Iqbal et al., 2022](#); [Mirza et al., 2025](#); [Sebastian & Kuswanto, 2024](#)) as one of the potential emerging technologies to enhance learning experiences and outcomes of students ([Cabero-Almenara et al., 2019](#); [Lampropoulos et al., 2023](#); [Mansour et al., 2025](#)).

The use of augmented reality in education has brought significant changes and has emerged as an innovative alternative to conventional learning, in line with technological advancements that are transforming traditional teaching methodologies into immersive and interactive learning experiences ([AlGerafi et al., 2023](#); [Zekeik et al., 2025](#)). It is indicated that it can complement the real world with digital information through a visual interface, thus providing an immersive learning experience that bridges the gap between theoretical knowledge and practical application ([Alhebaishi et al., 2025](#)), more interactive than enabling interaction between students and learning objects that cannot be observed directly ([Martin et al., 2023](#)), foster positive attitudes towards participation in learning projects and interaction between teachers and students ([Jang et al., 2021](#); [Zekeik et al., 2025](#)), and potentially complement traditional learning approaches by integrating AR into the teaching and learning process ([Cai et al., 2021](#); [Syskowski et al., 2024](#)).

Augmented reality is currently receiving considerable attention within the physics education community ([Vidak et al., 2021](#)). Physics is one of the fundamental sciences that explains a wide range of phenomena, ranging from fundamental particles to the boundaries of the universe, and also plays a vital role in higher education, often considered difficult and boring due to its association with abstract concepts, formulas, and equations that must be memorized ([Oral & Erkilic, 2022](#)), as well as its complex connection to everyday life. These challenges can be addressed through the use of augmented reality, which allows students to explore invisible concepts ([Rahmat et al., 2023](#)).

In understanding the learning process of students, learning theories and teaching approaches are needed to realize effective learning, including the theory of behaviorism that focuses on observable behavior and the results of reinforcement and punishment so that it is useful in classroom management and planning instructional activities. Then, there is the theory of cognitivism that emphasizes mental processes within oneself, such as memory, perception, and problem-solving, with an emphasis on the importance of understanding the mechanisms of processing and storing information needed to design efficient learning strategies ([Alhebaishi et al., 2025](#)). Physics education is one of the

branches of science that has an important role in developing student skills, such as critical thinking skills and understanding fundamental scientific concepts; therefore, innovative learning methods are needed that integrate augmented reality ([Ferdiman et al., 2023](#); [Haryadi et al., 2026](#)). Augmented reality-based pedagogical environments are considered one of the generational evolutions of traditional teaching approaches with modern technology as the main support ([Lai & Cheong, 2022](#)). Therefore, augmented reality has become one of the technologies applied across various disciplines, and its increasing popularity encourages exploration of its potential to support more innovative teaching and learning practices ([Czerkowski & Berti, 2021](#); [Koumpouros, 2024](#)).

Various studies have previously shown that the integration of augmented reality can enhance students' skills, such as understanding of concepts ([Hedenqvist et al., 2023](#); [Mystakidis et al., 2022](#)), improve inquiry skills ([Iatraki & Mikropoulos, 2025](#)), and increase long-term student retention ([Alhebaishi et al., 2025](#)). Previous researchers have conducted studies on the use of augmented reality in education, one of which is a study by [Rahmat et al., \(2023\)](#) that investigates the effect of mobile augmented reality on physics learning achievement and students' perceptions of its use. The results of the study show that students who use mobile augmented reality have higher learning achievement than students who use textbooks, because mobile augmented reality helps students understand physics concepts, visualize abstract concepts through 3D simulations, and facilitate students' understanding of physics concepts ([Rahmat et al., 2023](#)). Then, there is research conducted by [Lin et al., \(2022\)](#) to design and test an augmented reality learning model based on contextual reflective mechanisms to help students complete scientific inquiry tasks and improve higher-order thinking skills and scientific inquiry performance. The results of the study show that a scientific inquiry learning approach based on contextual reflective mechanisms with the help of augmented reality technology improves scientific inquiry learning performance and students' higher-order thinking tendencies (tendencies in solving complex problems, metacognitive awareness, and tendencies to think creatively) and reduces cognitive load compared to students who learn using conventional augmented reality-based inquiry learning approaches ([Lin et al., 2023](#)). Previous research conducted revealed the effectiveness of using a problem-based learning physics pocketbook that integrates augmented reality with local wisdom, showing that it can improve students' mathematical and graphical representation skills ([Rahmasari & Kuswanto, 2023](#)). When augmented reality is integrated into problem-based learning and inquiry-based learning, it can train and hone problem-solving skills in a safe and controlled environment. With an immersive and interactive learning experience, it is expected to increase student motivation and engagement while supporting personalized learning through direct feedback and adaptation according to the needs and learning pace of each individual ([Alhebaishi & Stone, 2024](#)).

This study conducted a bibliometric analysis, a variant of systematic literature review that employs quantitative and statistical techniques, such as descriptive analysis or knowledge mapping, to analyze bibliographic data, including publications and citations ([Mukherjee et al., 2022](#)). However, there are several bibliometric studies reviewing AR in physics education, such as the publication conducted by [Prahani et al., \(2022\)](#) entitled "Trend and visualization of virtual reality and augmented reality in physics learning from 2002-2021" and the publication conducted by [Suprpto et al., \(2023\)](#) entitled "Bibliometric analysis of peer-reviewed literature on augmented reality with an emphasis on education versus physics education" ([Prahani et al., 2022](#); [Suprpto et al., 2023](#)). Their scope of publication is limited in terms of time span and analytical approach. The use of augmented reality in physics education plays an important role because many physics materials are microscopic. Therefore, it is essential to further explore the application of augmented

reality, both in the context of education in general and specifically in physics education ([Suprpto et al., 2023](#)).

This study extends previous work by systematically covering publications from 2012–2025 and employing multiple bibliometric techniques, including citation analysis, co-word analysis, and co-authorship analysis, to provide a more comprehensive mapping of AR research in physics education. Specifically, this study addresses the following research questions:

- 1) What are the publication trends and main contributing institutions in AR research for physics education?
- 2) Who are the most productive authors and the most influential publications, and which journals form the core of the field?
- 3) What are the main research topics, and how are they interrelated?
- 4) What are the patterns of collaboration between countries and authors?

The data were retrieved from Scopus using queries targeting publications on augmented reality and physics education (including physics education or physics learning). The findings aim to provide guidance for researchers and suggest directions for future studies exploring more integrated approaches in AR-supported physics learning.

METHODS

This study employed a bibliometric research approach using descriptive analysis and science mapping techniques to comprehensively address the research objectives. A descriptive bibliometric analysis was employed to identify publication trends, main contributing institutions, core journals, the most productive authors, and the most influential publications. Science mapping techniques were applied to map key research topics and their interrelationships, as well as to analyze collaboration patterns between countries and authors. Science mapping techniques include ([Donthu et al., 2021](#)):

1. Citation Analysis

Citation analysis is a basic scientific mapping technique that states that citations represent intellectual relationships between publications, allowing the identification of influential works in a research field based on their citation frequency.

2. Co-citation analysis

Co-citation analysis is a scientific mapping technique that assumes that frequently cited publications share a common theme.

3. Bibliographic Coupling

Bibliographic coupling is a scientific mapping technique that operates on the assumption that two publications that share a common reference are also likely to be similar in content.

4. Co-word analysis

In co-word analysis, the unit of analysis is “words,” which are sourced from author keywords or from titles and abstracts, with the assumption that co-occurring words often indicate an underlying thematic relationship.

5. Co-authorship analysis

Co-authorship analysis examines the interactions between academics in a research field.

Based on the science mapping techniques described, this study employed science mapping: citation analysis, co-word analysis, and co-authorship analysis. The research process flow is shown in Figure 1. The bibliometric analysis was conducted using the Bibliometric package in RStudio, which enables large-scale data processing and is compatible with data exported from Scopus ([Wibowo et al., 2026](#)).

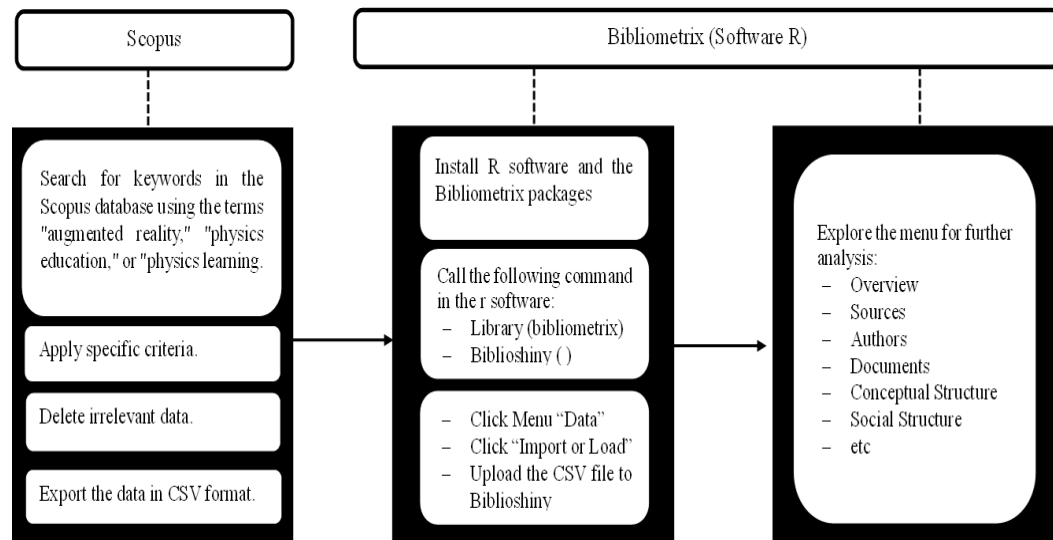


Figure 1 Research flow process

The data retrieval process in this study began with searching the Scopus database for the keywords “augmented reality”, “physics education”, or “physics learning”. Scopus was selected because it provides broad coverage of peer-reviewed journals across education, physics, and multidisciplinary fields and is widely used in bibliometric studies. Data from Scopus are commonly employed in bibliometric research, as their quality characteristics support a range of analytical approaches (Baas et al., 2020). To keep the dataset focused on the keywords, specific criteria were applied: this study included only English-language journal articles; publications were limited to the main fields of “social science”, “physics and astronomy”, and “multidisciplinary” to ensure thematic relevance; and documents such as proceedings, conferences, books, book chapters, and publications in unrelated fields, including medicine, engineering, and psychology, were excluded. The final result of the advanced query applied in the Scopus database is

(TITLE-ABS-KEY (augmented reality) AND TITLE-ABS-KEY (physics education OR physics learning)) AND (LIMIT-TO (SUBJAREA , “SOC”) OR LIMIT-TO (SUBJAREA , “PHYS”) OR LIMIT-TO (SUBJAREA , “MULT”)) AND (LIMIT-TO (DOCTYPE , “ar”)) AND (LIMIT-TO (SRCTYPE , “j”)) AND (LIMIT-TO (LANGUAGE , “English”))

The search was conducted in early December 2025, yielding 102 documents. A manual screening process was then conducted to evaluate articles for relevance to the topic. Studies not directly focused on physics learning were excluded, resulting in 77 documents for final analysis. Exclusion criteria included applications of augmented reality in non-physics domains such as chemistry, biology, soil science, medical education, or general STEM or engineering education without specific physics content; multidisciplinary conceptual reviews spanning multiple disciplines without empirical data on physics education; studies targeting basic science topics unrelated to physics; and research emphasizing virtual reality for engineering, robotics, or fluid simulation. To minimize retrieval bias, the search query was implemented using predefined filters derived from the inclusion and exclusion criteria and further refined through manual screening of titles and abstracts to confirm alignment with the research scope. The primary reason for exclusion was the absence of a clear connection to the learning of physics concepts, which is the core focus of this bibliometric

mapping study. All screening decisions were based on title and abstract information, with predefined criteria ensuring data transparency.

RESULTS AND DISCUSSION

Identify Publication Trends and the Main Contributing Institutions

Based on the annual scientific production graph shown in Figure 2, the dataset shows the number of publications per year, with the highest in 2023 ($N = 17$). From early 2012 to 2019, augmented reality publications were still considered new, with only 1 to 4 publications per year. This period was the initial stage of research. A notable increase emerged around 2020, with publication numbers rising to a peak of 17 articles in 2023. Data for 2024 contained 12 publications, and for 2025 there were 13 publications. Although the number of publications from 2024 to 2025 increased slightly, this data is categorized as incomplete because it was collected in early December 2025, but it already shows a relatively high output and has the potential to continue growing.

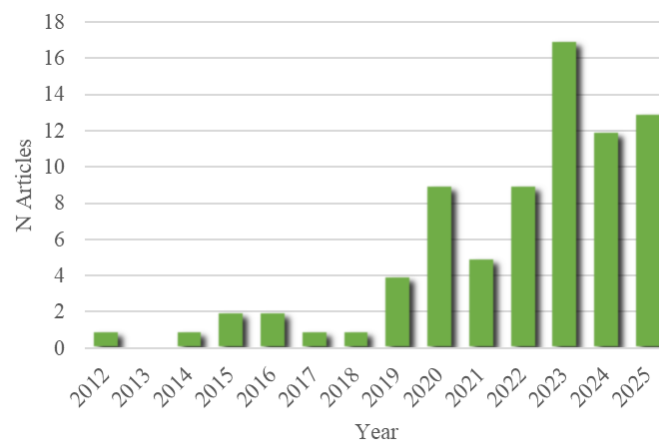


Figure 2 Annual scientific production chart

Based on the data presented in Figure 2, research on augmented reality in physics education shows a generally upward trend in publications, with some fluctuations, up to early 2025, indicating continued interest in the field. From 2012 to 2019, research productivity was relatively low, with publications ranging from 1 to 4 articles per year, indicating that this research was still in the introductory and early exploration stages. The limited publication volume indicates that AR in physics education is an emerging field that has not yet been extensively explored. A significant turning point occurred in 2020, marked by an increase in the number of publications to 9 articles. This increase is indicated by several factors, such as the rapid adoption of digital technology in education due to the pandemic ([Rof et al., 2022](#)). Furthermore, according to the chart, the number of publications increased in 2023, reaching 17 publications and making it the year with the highest number of publications in the dataset. This increase in publication output may indicate a growing research interest in augmented reality in physics education. This trend may also be associated with the contribution of institutions that consistently produce publications, as shown in Figure 3, which contains a mapping of Most Relevant Affiliations.

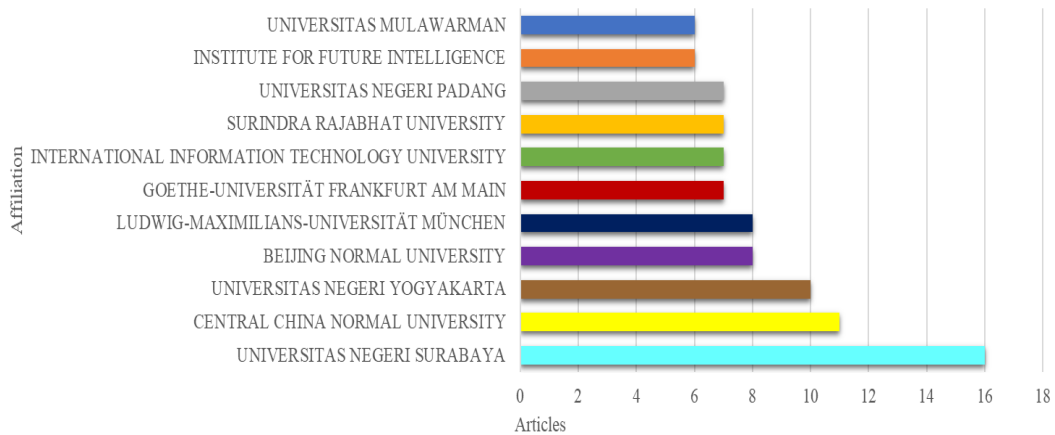


Figure 3 Mapping most relevant affiliations chart

The data in Figure 3, which shows the institutions with the highest number of publications, indicates that Universitas Negeri Surabaya is identified as the most productive institution, with 16 articles, followed by Central China Normal University in second place, with 11 articles, and Universitas Negeri Yogyakarta in third place, with 10 articles. Several other Indonesian state universities also show significant contributions. The data indicate that research on augmented reality in Indonesia is showing substantial growth. Meanwhile, at the global level, institutions such as Beijing Normal University (N=8) and Ludwig-Maximilians-Universität München (N=8) have productivity values that are included in the high category, followed by other universities. An analysis of the most relevant affiliation provides an overview of the institution with the highest number of publications, enabling a wider understanding.

In line with the first research question on publication trends and main contributing institutions in AR research for physics education, the findings show that the publication output was relatively low between 2012 and 2019, indicating that the field was still in an early developmental stage. A noticeable growth in publications emerges around 2020, which may be associated with the broader adoption of digital technologies in educational contexts. Institutional analysis shows that several universities, particularly from Indonesia, consistently appear as the most productive contributors, while institutions from other countries also play a significant role. Overall, these trends reflect an expanding research landscape, although its distribution across institutions and regions remains uneven.

Identify the Most Productive Authors, Most Influential Publications and the Core Journals

In Figure 4, the mapping of the most productive authors is presented. Based on the data, it is identified that Movre Šapić, Iva, and Vidak, Andrej, are the most productive authors based on the mapping, with 5 articles each, followed by Kuswanto H (N=4) and other researchers with two to three articles.

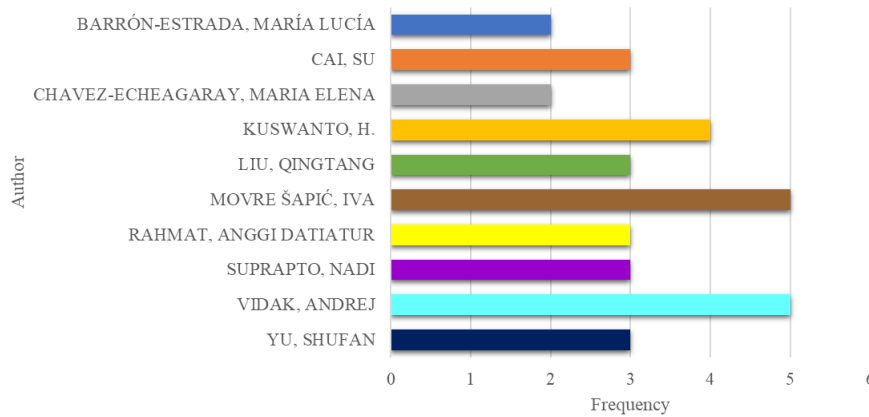


Figure 4 Sum of frequency by author production over time

After identifying the most productive authors, the next step is to analyze the publication with the highest global citation counts to identify the most influential publication, as shown in Figure 5.

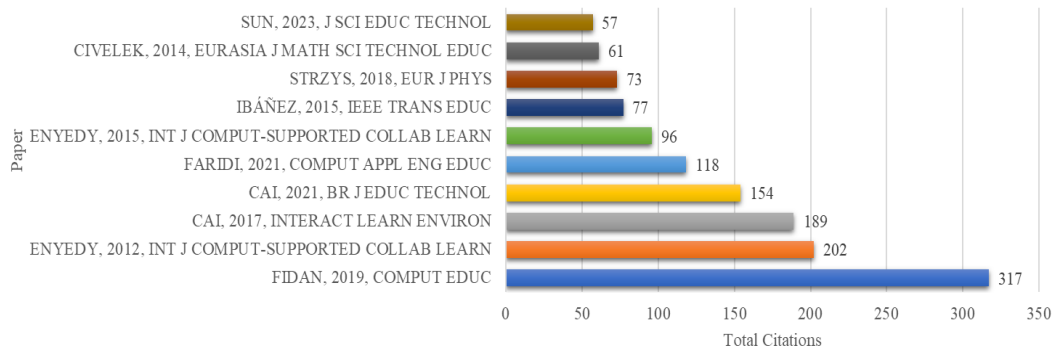


Figure 5 Mapping the list of documents with the highest number of citations (Most globally cited documents)

Based on the most globally cited document data in Figure 5, an article published in 2019 in *Computers & Education* received 317 citations, making it the most influential work in this field. The *International Journal of Computer-Supported Collaborative Learning* (2012) received 202 citations, and *Interactive Learning Environments* (2017) received 189 citations, also showing significant influence. To provide an overview of these most globally cited documents, Table 1 summarizes the information on the most globally cited publications.

Table 1 The most globally cited studies on augmented reality in physics education

Author	Year	DOI	Title	Journal	Highlight
Fidan et al.	2019	10.1016/j.compedu.2019.103635	Integrating augmented reality into problem-based learning: The effects on learning achievement and attitude in physics education	Computers and Education	Integrating augmented reality into PBL activities both increased students' learning achievement and promoted their positive attitudes towards physics subjects.

Author	Year	DOI	Title	Journal	Highlight
Enyedy et al.	2012	10.1007/s11412-012-9150-3	Learning physics through play in an augmented reality environment	International Journal of Computer-Supported Collaborative Learning	The Implementation of the Learning Physics through Play (LPP) Project was able to improve and develop students' conceptual understanding of force, net force, friction, and two-dimensional motion, as evidenced by an increase in pre-test and post-test scores.
Cai et al	2017	10.1080/10494820.2016.1181094	Applications of augmented reality-based natural interactive learning in magnetic field instruction	Interactive Learning Environments	The augmented reality-based motion-sensing software can improve students' learning attitude and learning outcome
Cai et al	2021	10.1111/bjet.13020	Effects of learning physics using Augmented Reality on students' self-efficacy and conceptions of learning	British Journal of Educational Technology	Integrating augmented reality technology into physics classrooms can significantly enhance students' physics learning self-efficacy, guide students toward higher-level conceptions of learning physics rather than lower ones, and stimulate students' motivation to learn more deeply.
Faridi et al	2021	10.1002/cae.22342	A framework utilizing augmented reality to improve critical thinking ability and learning gain of the students in Physics	Computer Applications in Engineering Education	The augmented reality-based learning environment has a significant positive impact on students' critical thinking and learning gains. The augmented reality experience helped the students visualize the abstract concepts of physics and enhanced their understanding.

As presented in Table 1, the most globally cited documents consistently report that the use of augmented reality in physics education has a positive influence on various dimensions of physics learning, including conceptual understanding, learning attitudes, learning outcomes, motivation, and students' self-efficacy. After identifying the most influential publications, the following analysis focused on the publication sources most

frequently used by researchers to publish studies on augmented reality. This data is attached to Figure 6.

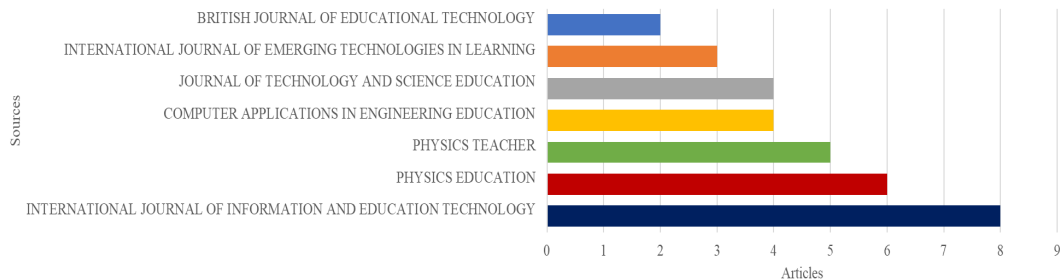


Figure 6 Mapping the list of journals that publish the most articles in the research field (Most Relevant Sources)

Based on the mapping of the most relevant sources shown in Figure 11, the International Journal of Information and Education Technology is the top source, with the highest number of articles published ($n = 8$), followed by Physics Education ($n = 6$) and The Physics Teacher ($n = 5$). After identifying the most productive publication sources, the following analysis will examine the dynamics of these sources' productivity over time, as shown in Figure 7.

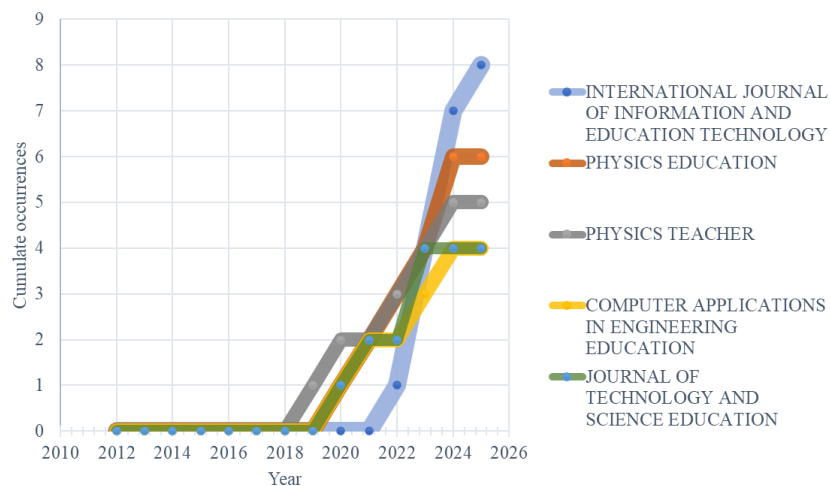


Figure 7 Graph of journal contribution evolution (Sources production over time)

Based on the source production over time graph in Figure 7, it is known that in 2025, the “International Journal of Information and Education Technology” had a significant increase in cumulative occurrences from 2022 to 2025. The next-highest cumulative occurrences in 2025 were in the journals of “Physics Education” and “Physics Teacher.” Meanwhile, the journals of “Computer Applications in Engineering Education” and “Journal of Technology and Science Education” experienced a gradual increase.

Regarding publication sources, several journals appear as primary outlets for AR research in physics education (Figure 6). The International Journal of Information and Education Technology has the highest number of publications ($n = 8$), followed by Physics Education ($n = 6$) and The Physics Teacher ($n = 5$).

In relation to the second research question, which examines the most productive authors, the most influential publications, and core journals in augmented reality research for physics education, the bibliometric analysis reveals several descriptive patterns. The author productivity mapping indicates that Movre Šapić, Iva, and Vidak, Andrej are the most productive contributors, each with five publications, followed by Kuswanto H and other authors with two to three publications. This pattern suggests a relatively focused authorship structure within augmented reality research in physics education.

Analysis of globally cited documents shows that a limited number of publications account for the highest citation counts, indicating their sustained influence on the theoretical and methodological development of the field. These highly cited studies function as key reference points within the research network. Based on Figure 5 and Table 1, *Computers & Education* received 317 citations, making it the most influential work in this field. The *International Journal of Computer-Supported Collaborative Learning* (2012) received 202 citations, and *Interactive Learning Environments* (2017) received 189 citations, also showing significant influence. As presented in Table 1, these findings indicate that augmented reality in physics education has the potential to support the visualization of abstract physics concepts and has been widely adopted as a basis for developing innovative physics learning strategies.

Through augmented reality, abstract information can be presented to students in a more concrete manner by enabling the observation of phenomena that are difficult to perceive directly in real-life contexts ([Thees et al., 2022](#); [Tian & Ironsi, 2025](#)), making one of the main advantages of immersive technology, such as augmented reality, in education its ability to facilitate a comprehensive blended learning environment that promotes critical thinking and problem-solving, as well as communication and collaboration skills, through the integration of digital and physical objects within a single environment ([AlGerafi et al., 2023](#); [Jdaitawi & Kan'an, 2022](#)). From a constructivist perspective, augmented reality is expected to be most effective when it supports students' active learning in building meaning by allowing them to explore, test ideas, and revise their understanding based on feedback, and therefore should be designed as guided inquiry or problem-based activities with clear instructions and opportunities for comparison and iteration, while evaluation should not only assess factual performance but also include indicators of conceptual understanding, transferability, and process measures that reflect constructive activity, since mere "engagement" does not guarantee knowledge construction ([Pallavicini & Anesa, 2026](#)).

Source productivity over time in Figure 7 shows that cumulative publication counts in these journals increased steadily from 2022 to 2025, while other journals, such as *Computer Applications in Engineering Education* and *Journal of Technology and Science Education*, show a gradual increase. This pattern may indicate that AR research in physics education is mainly disseminated through a few core journals, although other sources are gradually contributing more publications. Overall, the bibliometric analysis highlights recurring contributors, highly influential publications, and core journals that shape the development of augmented reality research in physics education, while maintaining a descriptive perspective without evaluative judgments regarding individual study quality.

Mapping Current Major Research Topics and The Interrelationships Between Them

Based on the co-occurrence network in Figure 8, it can be seen that all keywords are distributed across several clusters. The keywords "augmented reality" and "Students" emerge as the largest nodes, indicating that these topics are the primary focus of research

in the dataset and occupy the most central position, serving as links between research clusters.

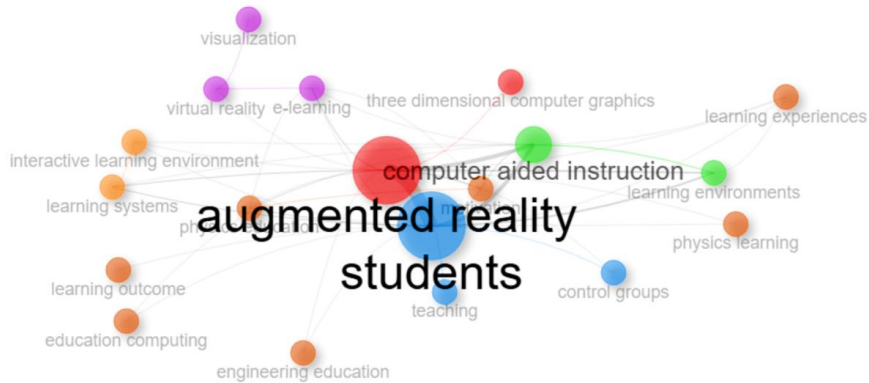


Figure 8 A network of conceptual relationships between keywords that frequently appear in the literature

The graph of the evolution of keyword popularity from 2015 to 2025 (word frequency over time) is shown in Figure 9.

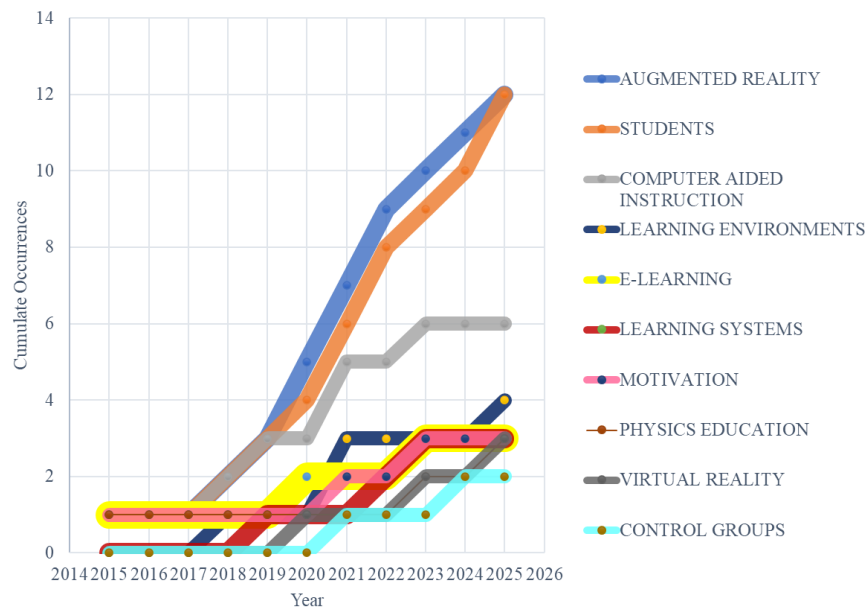


Figure 9 Keyword popularity evolution graph from 2015 to 2025 (word frequency over time)

The keywords “computer-aided instruction”, “teaching”, “learning environments”, and “physics learning” also appear significantly, indicating that the research is primarily associated with computer-aided instruction, teaching methods, and physics education contexts. In line with these findings, learning in physics topics can take place in various types of environments (Vidak et al., 2022), and the effectiveness of AR heavily depends on the learning environment employed. Most researchers use the discovery method as the primary learning strategy to facilitate physics learning with AR technology, with the most frequently applied techniques being inquiry, followed by observation and games.

Therefore, it is important to elaborate on findings related to the implementation of AR across different learning environments ([Rakhimzhanova et al., 2025](#); [Vidak et al., 2022](#)). After mapping the relationships between keywords through the co-occurrence network, the next step will be discussing word frequency over time to see how these terms' frequency changes throughout the period, as shown in Figure 9.

The term “augmented reality” is the keyword showing the most pronounced increase in frequency over time, from only one occurrence per year during the period 2015–2017 to twelve occurrences by 2025. This pattern indicates that terms related to augmented reality are appearing more frequently in the literature and are increasingly regarded as important topics in technology-based education research. A similar frequency pattern is observed for the term “students”, reflecting an increasing emphasis on learner-related aspects within technology-oriented education research. In line with this pattern, augmented reality–based learning is conceptually positioned as an approach with the potential to support learning effectiveness and provide supplementary interactive learning activities. Further research focusing on instructional design and student learning experiences is still required to examine whether AR applications can effectively enhance abstract conceptual understanding, student motivation, and creative thinking skills that are essential for problem-solving abilities ([Alkhabra et al., 2023](#); [Yousef, 2021](#)).

Conversely, the terms “computer-aided instruction,” “learning environments,” “e-learning,” and “learning systems” show a more stable trend and slower increase. This pattern reflects that these concepts remain relevant as research themes but are no longer the focus of new attention. The terms “motivation” and “physics education” also experienced an increase, though generally ranging from 1 to 3 appearances per year. Meanwhile, the term “virtual reality” began appearing in 2020 and showed a gradual increase through 2025. The results of the word frequency over time provide an overview of changes in terminology usage from year to year. To gain a broader understanding, topic trend analysis was employed to track the evolution of research direction and focus over time. The trend-mapping topic is shown in Figure 10.

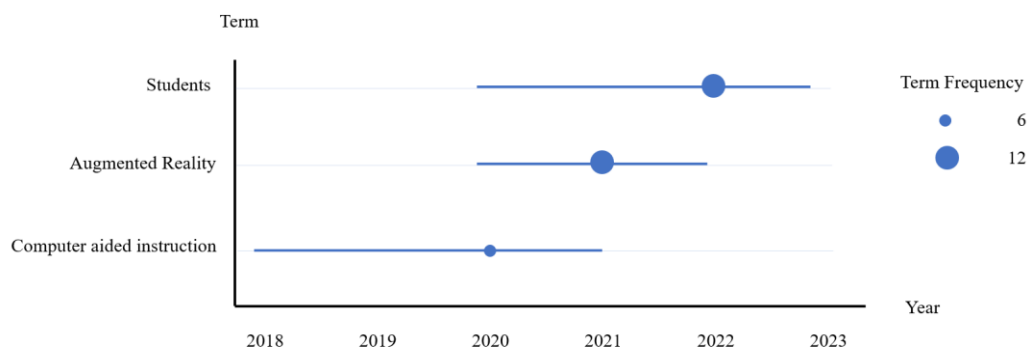


Figure 10 Keyword mapping has seen a significant increase in popularity (Trend Topics)

The data shows that “computer-aided instruction”, “augmented reality”, and “students” are all pretty frequent terms, but each has a distinct peak period. The term “computer-aided instruction” appears 6 times, indicating that this topic began to be widely discussed between 2018 and around 2021. This pattern suggests that interest in computer-aided learning emerged earlier than the other two terms. Meanwhile, “augmented reality” appears 12 times in the dataset and shows a peak research period, concentrated in the more recent period, from 2021 to 2022.

The term “students”, which has a similar total frequency to “Augmented Reality”, shows a slightly shifting pattern. Its peak activity began between 2020 and 2023. Although

“augmented reality” is the most frequently appearing keyword and one of the most discussed topics in this dataset, trend topic analysis indicates that Augmented reality research peaked in the 2020–2022 period. The trend topic method does not look at the entire timeframe, but rather highlights the years when publications reached their highest intensity. In other words, augmented reality remains a significant topic, but its research growth period was the most rapid in 2020–2022. Overall, this pattern demonstrates a shift in research focus from general learning technologies to immersive technologies and an increasingly student-centred research orientation. After mapping the evolution of research direction and focus over time, the thematic map is used to visualise the grouping of themes and the position of each topic within the research field, as shown in Figure 11.

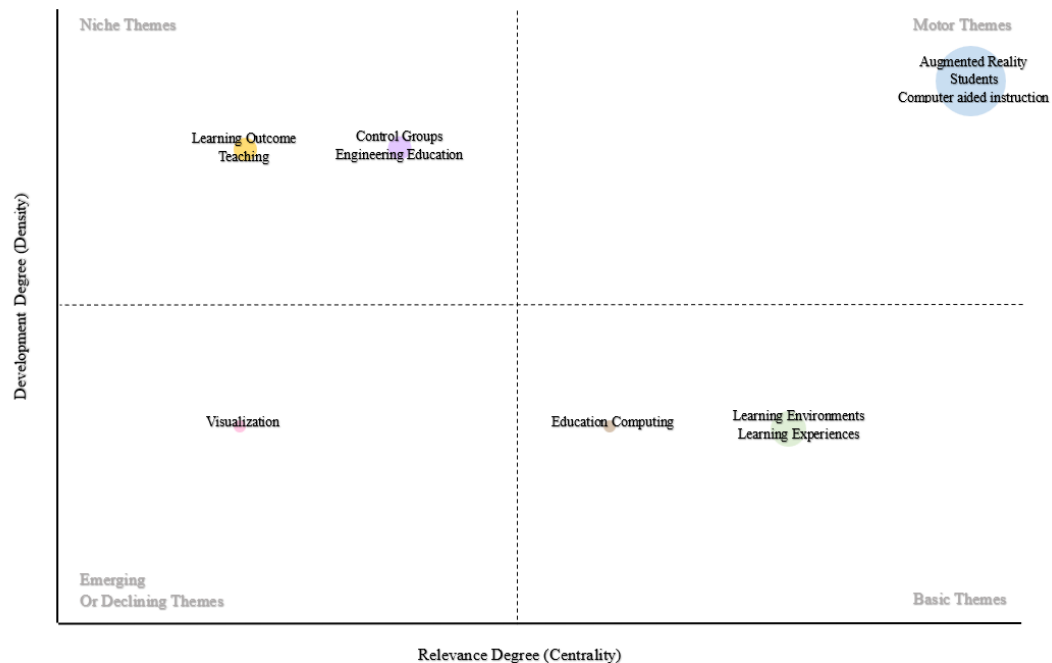


Figure 11 Quadrant map that positions research themes

From the thematic map presented in Figure 11, several key insights can be identified that may serve as a basis for exploring potential literature gaps. The map shows that the research themes are distributed across four main quadrants: niche, motor, basic, and emerging/declining themes. Niche themes such as “Learning Outcome”, “Teaching”, “Control Groups”, and “Engineering Education” show a high degree of development (density) but a low degree of relevance (centrality), suggesting that these niche themes have not been widely connected to motor themes such as “Augmented Reality”, “Students”, and “Computer-aided Instruction” and could present opportunities for further integration between these groups of themes.

Motor themes, consisting of “Augmented Reality”, “Students”, and “Computer-aided Instruction”, show a high degree of development and centrality, indicating that these topics occupy a central position in the literature. Within the basic themes, topics such as “Education Computing”, “Learning Environments”, and “Learning Experiences” show a high centrality but low density, indicating that these topics serve as a foundation for other research, although the development of these topics has not yet been extensively explored. This condition indicates the need for research directions that may contribute to the further development of these foundational themes. One potential direction involves the application of Augmented Reality (AR) in simulation, deep learning, and artificial intelligence. The integration of these technologies may help enrich learning environments and learning

experiences, while potentially strengthening underdeveloped basic themes and supporting the advancement of AR-based physics education ([Lampropoulos, 2025](#); [Prahani et al., 2022](#))

Finally, among the emerging or declining themes, the topic “visualization” shows a low level of development and relevance, indicating that it represents an emerging or declining theme and may constitute a potential area for future research. Based on this thematic classification, several potential research directions can be identified, including the integration of research themes between niche and motor themes, the development of basic themes toward technological innovation, the exploration of emerging themes, and an increased focus on students as part of a student-centered approach in technology-based education research. Most applications of AR in physics education still rely on experience-based learning approaches, while only a limited number of studies have examined its integration with higher-order inquiry-based, collaborative, or game-based learning models ([Lai & Cheong, 2022](#)). Augmented reality is conceptualized as a potentially promising technology in teaching and learning, as it may support the development of information and communication technology-related competences, facilitate inquiry-oriented and ubiquitous learning through immersive didactic resources, and support the representation of complex or abstract learning content ([Iatraki & Mikropoulos, 2025](#); [Jdaitawi & Kan'an, 2022](#)). Augmented reality has the potential to facilitate more natural and diverse interaction patterns that support inquiry-based learning ([Li et al., 2025](#)), which indicates implications for the design of instruction that emphasizes exploration, comparison, and iterative reasoning in physics education and contributes to the development of physics education research. Augmented reality offers an immersive and interactive learning experience by integrating digital elements into the physical environment, allowing three-dimensional visualizations to help students understand abstract concepts more concretely. Its high level of interactivity enables students to directly manipulate virtual objects, thereby increasing engagement and learning motivation, while also supporting collaborative learning through multi-user projects that strengthen contextual understanding and social skills ([Wibowo et al., 2026](#)).

In line with the third research question, the findings highlight the main research topics and their interrelationships within augmented reality research in physics education. Augmented reality and student-related aspects emerge as central themes, with connections to instructional approaches and learning environments. Analyses of keyword frequency and trend patterns indicate a gradual shift from general educational technologies toward more immersive, student-centered research orientations. Some foundational and niche themes appear distinct from central themes, indicating that they occupy different positions within physics education research.

Analyze Collaboration Patterns between Different Countries and Authors

Figure 12, which presents the results of the collaboration network map, shows that the authors are divided into 12 clusters, which represent research groups in the field of augmented reality in physics education. It is indicated that Cluster 1 is the largest group with actively collaborating authors. In contrast, the other clusters are smaller and relatively focused, indicating specific collaborations.

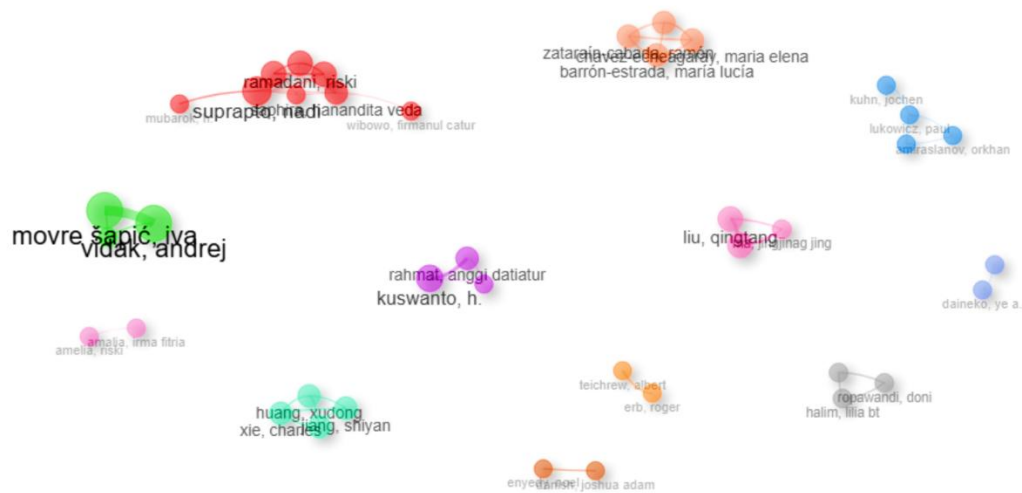


Figure 12 Collaboration network

In the context of network centrality, based on the betweenness metric in Table 2, Suprapto, Nadi, and Saphira, Hanandita Veda from Cluster 1, with a score of 6, and Lukowicz, Paul from Cluster 2, with a score of 2, act as key connecting nodes. Meanwhile, based on the closeness centrality data, a different pattern is observed. Erb, Roger, and Teichrew, Albert, from Cluster 5, Danish, Joshua Adam, and Enyedy, Noel, from Cluster 6, achieved a closeness value of 1, as the highest level of closeness to all nodes in the network through direct collaboration with other members in the cluster.

Table 2 Author collaboration network metrics

Node	Cluster	Betweenness	Closeness	PageRank
Suprapto, Nadi	1	6	0.125	0.033
Saphira, Hanandita Veda	1	6	0.125	0.003
Lukowicz, Paul	2	2	0.333	0.037
Erb, Roger	5	0	1	0.025
Teichrew, Albert	5	0	1	0.025
Danish, Joshua Adam	6	0	1	0.025
Enyedy, Noel	6	0	1	0.025

The dominance of high closeness scores but low betweenness scores indicates that collaboration in this field remains local and limited to small groups, with few connections across institutions or countries, which may further constrain the exchange and integration of knowledge in the field. After identifying collaboration patterns between authors, the level of collaboration between countries will be discussed using the country collaboration map shown in Figure 13.

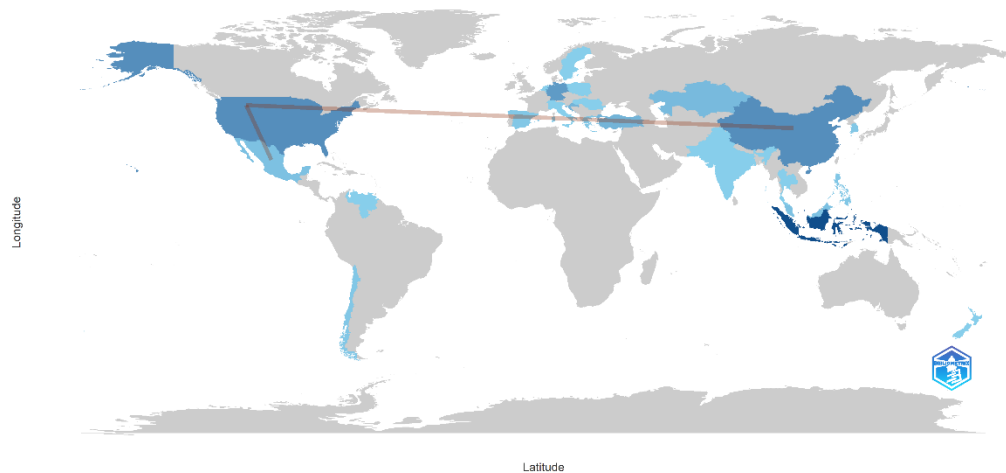


Figure 13 Country collaboration map

Based on the Country Collaboration Map in Figure 13, the countries with the highest publications on the topic of augmented reality in physics education are shown. The map only shows two main collaboration paths, indicating that most research is still conducted independently by each country. The most frequent collaborations were identified between the USA and Mexico and China and the USA. For more detailed data, the frequency of the Country Collaboration Map is presented in Table 3.

Table 3 Country collaboration map table

From	To	Frequency
CHINA	HONG KONG	1
CHINA	SINGAPORE	1
CHINA	USA	2
USA	KOREA	1
USA	MEXICO	2

From the Country Collaboration table in Table 3, it can be observed that international collaboration networks are relatively limited and have not yet formed a densely interconnected global network. The most frequent collaborations were identified between the USA and Mexico and China and the USA, each with a frequency of 2. This indicates that research collaboration remains fragmented by geographical lines, with few bridging ties between regions.

In line with the fourth research question, the findings highlight collaboration patterns among authors and countries in augmented reality research for physics education. Based on the finding that international collaboration networks remain relatively limited and have not yet formed a densely interconnected global network, this indicates an opportunity to develop a more integrated and globally connected research network in the future. In the context of physics education, strengthening international collaboration has the potential to encourage the exchange of diverse perspectives among researchers shaped by different learning environments. It may also contribute to the development of instructional innovations that are more globally relevant, thereby potentially supporting the future advancement of physics education research. In line with this, increasing visibility through international collaboration or targeting high-impact journals can help enhance the recognition and influence of research in the future ([Karaarslan et al., 2025](#); [Le et al., 2025](#)).

This fragmented collaboration structure. Such fragmentation may limit interaction and knowledge exchange across research groups, which can affect how knowledge is accumulated and integrated within the field. As a result, research development may remain localized within specific groups, potentially slowing the emergence of more comprehensive research frameworks that are applicable across broader educational contexts.

CONCLUSION

This research provides a comprehensive overview of the augmented reality research landscape in physics education, showing that augmented reality research in physics education has grown significantly since 2020. Thematic analysis reveals “augmented reality” and “students” as central topics, indicating that it has the potential to enhance the interactive physics learning experience. However, for its optimal utilization, more in-depth, cross-disciplinary, and sustainable research is needed to improve its quality and effectiveness in various contexts ([Koumpouros, 2024](#)). Several potential directions for future research can be pursued, including the enhancement of international collaboration, the exploration of integration between niche and motor themes, such as the development of adaptive and student-centered augmented reality designs, the conduct of longitudinal studies to evaluate the long-term impacts of augmented reality use, and the expansion of augmented reality implementation into diverse learning contexts. This study still has limitations: the data used is only sourced from one database, which causes the possibility of several relevant publications from other databases not being covered; the keyword matching and cluster analysis depend on technical parameters in the Biblioshiny software, so the results may have differences in data if using other devices at different time periods. Therefore, the findings in this study should be understood as a general overview rather than an absolute representation of the entire research. By considering these limitations, it is hoped that further research can conduct a more comprehensive and in-depth mapping of the topic and examine the integration of augmented reality technology with learning models to enrich the literature and improve the quality of physics learning.

CONFLICT OF INTEREST

The authors declare that the writing and publication of this article are free from any conflicts of interest.

AUTHOR CONTRIBUTION STATEMENT

All authors actively contributed to every stage of this research. SAW was responsible for conceptualizing the idea, collecting and analyzing the bibliometric data, and writing the initial draft of the manuscript; FCW, EB, and MAHB contributed to data validation, result visualization validation, and final editing of the manuscript.

AI DISCLOSURE

AI tools were used solely to assist in describing observed patterns in the data and in improving language quality. All interpretations, validations, and conclusions were conducted and verified by the authors, who take full responsibility for the final content of this manuscript.

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