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Global Research Trends on Augmented Reality in Science Education: A Bibliometric Analysis (2020–2025)

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Abstract: This study uses a bibliometric approach to analyze global research trends regarding the use of Augmented Reality (AR) in science education in the period 2020–2025. Data was obtained from the Scopus database as of July 16, 2025 using the keywords "augmented reality" and "science" searched for titles, abstracts, and author keywords, resulting in 223 initial documents. After going through a systematic screening process based on inclusion and exclusion criteria, including publication type, peer-review status, language, and time span, 102 articles were obtained that were worthy of further analysis. The analysis was carried out using VOSviewer through the stages of data extraction, cleaning, network construction, and visualization. The results of the study show that the study of AR in science education has increased significantly, especially in the 2020–2024 period with a peak in 2024. The largest contributions of publications come from Turkey, Indonesia, the United States, Malaysia, Taiwan, and China, reflecting the global spread of the field. The main journals that are the publication sites include Computers & Education, Education and Information Technologies, and Interactive Learning Environments. The co-word analysis revealed three dominant themes, namely: (1) the effectiveness of AR in improving student learning outcomes, (2) the challenges and development of AR implementation in education, and (3) the role of teachers, student involvement, and evaluation practices in AR-based learning. Meanwhile, the analysis of the co-authorship network showed that there were several clusters of cross-institutional and cross-country collaboration with a number of key authors acting as liaison. In conclusion, AR is not only seen as a technological innovation, but also as a pedagogical strategy that is able to increase motivation, understanding of concepts, and learning interactions in science education.

Keywords: Augmented Reality, Science Education, Bibliometric Analysis, VOSviewer, Research Trends.

Introduction

In the last five years, the use of AR in education has accelerated significantly due to its ability to deliver immersive, interactive, and contextual learning experiences (Babu, 2023; Che Dalim et al., 2020; García-Robles, 2024; R. Hayati et al., 2025; Nabil, 2024; Nirmala, 2024; Wang, 2023). AR allows students to understand abstract concepts through spatial visual integration with the real environment, which ultimately encourages increased motivation, engagement, and learning outcomes (Arici, 2024; Arymbekov, 2024; Fakih, 2023; Khowaja et al., 2020; Shin, 2023). The application of AR has been proven to be effective both in science learning at the elementary to tertiary education levels, as well as in medical education, with a positive impact on students' academic achievement, attitudes, and learning

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experiences (Bachrudin et al., 2023; Che Dalim et al., 2020; Haspolat, 2023; Kalemkuş, 2023; Su, 2024).

Bibliometric studies confirm that research on AR in education continues to increase rapidly, especially in the domains of STEM, experiential engagement, and immersion-based learning (Cheng, 2024; Flores, 2025; Maspiroh, 2025; Nabil, 2024; Scheffer, 2025; Tennessee, 2024; Washington, 2025; Zhang, 2024). Systematic research also shows that AR improves science literacy, scientific process skills, and student collaboration, although it is still faced with technical challenges, cognitive burden, and pedagogical integration (Bautista et al., 2025; Duncan, 2020; Kim, 2022; Lee, 2025; Queiruga-Dios, 2020; Sukatiman et al., 2020). In the context of science learning, the integration of AR with *Metaverse* or *Game-based learning* provide a more meaningful and empowering reflective learning experience *flow state* student (Czok, 2023; Hidayat, 2024b; Hou, 2021; Jääskä, 2022; Law, 2022; Sáiz-Manzanares, 2021).

On the other hand, various studies in Indonesia emphasize the importance of developing innovative learning models such as RADEC and Contextual Teaching and Learning (CTL) to strengthen higher-level thinking skills (*Higher order thinking skills*) and science literacy (Fitzgerald, 2024; N. Hayati, 2023; Jude, 2025; Queiruga-Dios, 2020; Roy, 2025; Silitonga et al., 2020; Utomo, 2022; Wulandari et al., 2021; C. Yan, 2024). These models encourage active student involvement in the learning process and are potentially more effective when combined with participatory and multimodal AR technology (Jiang, 2020; History, 2025; Uriarte-Portillo, 2023). Other studies have also highlighted that learning media are culturally and environmentally based, such as *Pop-up book*, flipbooks, and locally integrated textbooks, effective in strengthening science literacy and student learning motivation (Fatayan, 2024; Franco, 2023; Queiruga-Dios, 2020; Uriarte-Portillo, 2023; X. Yan, 2024).

Globally, recent research highlights the linkage between AR and the development of scientific process skills, creativity, and science literacy (Behnamnia, 2020; Ke, 2021; Mufit et al., 2023; Pears, 2025; Roy, 2025). AR has been proven to strengthen students' reflective thinking skills, problem-solving, and collaboration skills in the context of science learning (Fernández-Morante et al., 2022; Sukatiman et al., 2020). The application of AR is also starting to expand to various domains such as environmental literacy, health, and AR-based robotic interactions, which are expanding their relevance in 21st-century education (Srivastava, 2023; Subbiah, 2024). This emphasizes that AR is not just an auxiliary medium, but part of the digital transformation strategy of education towards adaptive, personalized, and inclusive learning (Khowaja et al., 2020).

Thus, the literature shows that there is a great opportunity to integrate AR technology with inquiry-based learning models, RADEC, and CTL in strengthening students' science literacy, HOTS, and scientific process skills. However, research gaps are still visible in aspects of sustainable pedagogical design, standardized evaluation, and the application of AR in the local context of Indonesia based on the Merdeka curriculum. Therefore, the future research agenda needs to be focused on developing AR-based learning models that are in harmony with the curriculum context, able to accommodate the diversity of students, and support the achievement of Pancasila student profiles holistically.

Method

This study uses a bibliometric approach to analyze publication trends, collaboration patterns, and research developments regarding AR in education (Avinç, 2025; Farokhah et al., 2023; Yu et al., 2020). Data was collected from the Scopus database on July 16, 2025 using the keyword "*Augmented reality*" and "*Science*" in the title, abstract, and keywords of the publication. An initial search yielded 223 documents that were then filtered using inclusion criteria: Scopus indexed journal articles, in English, discussing AR in an educational context, had gone through a process *Peer-review*, and published in the period 2020–2025. Documents in the form of *Preprints*, *Conference Abstracts*, editorial, and non-peer-reviewed publications are eliminated. After screening by year of publication, 149 papers remained, and after the selection of reputable journals, the final number of articles ready to be analyzed was 102. The next stage is the verification of the completeness of the metadata (author's name, affiliation, title, keyword, publication source, and year of publication) to guarantee the validity of the data and compatibility with bibliometric devices. Analysis is performed using VOSviewer through the process of extraction, data cleaning, network construction, and visualization. The results of the analysis include publication distribution, collaboration of authors and institutions, state contributions, journal sources, and keyword mapping to identify research hotspots (Gusteti et al., n.d., 2025; Kacmaz, 2024; Khowaja et al., 2020). With this methodology, the research ensures that only relevant and high-quality articles are analyzed, so as to be able to uncover the dynamics of global publications regarding the application of AR in education while providing direction for future research.

Search Procedure

The first step in this study is to search the literature through the Scopus database on July 16, 2025, using the keyword "Augmented Reality, science".

Bibliographic Screening

After all documents obtained from the Scopus database have been successfully collected, a screening stage is carried out using inclusion and exclusion criteria. This step aims to ensure that only articles that are academically viable, relevant to the research focus, and fit within a set time frame that will be further analyzed.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Articles published in the Scopus indexed journal	Publications that have not reached the final publication stage (e.g., *preprints* or *conference abstracts*)
Articles that have gone through *a peer-review process*	Articles that don't go through *the peer-review process*
Articles in English	Articles published in languages other than English
Articles that discuss *Augmented Reality*, *education*, *learning*, and *teaching*	Articles that are not relevant to the focus of the research
Articles published in the 2020–2025 time frame	Articles published before 2020 or after 2025

The selection of English-language articles is maintained because this language has become an international standard in scientific publications and dominates various bibliometric databases. Consequently, however, there may be relevant research in other languages that are not included. After a series of screenings, the number of documents used in the analysis shrank from 223 documents of the initial search results, to 149 documents after the application of the year filter, and finally 102 publications published between 2015 and 2025. This selection ensures that the documents analyzed are of high academic quality and truly fit the research objectives.

Bibliographic Completeness

This stage is done to ensure that each selected document has complete, consistent, and readable metadata. This process includes verification of key bibliographic elements such as the author's identity, institutional affiliation, article title, keywords, abstract, year of publication, and publication source. This examination is important so that all data can be processed optimally using bibliometric software, such as VOSviewer, resulting in accurate mapping and visualization of scientific networks. Documents that have incomplete, duplicate, or illegible metadata in standard format are excluded from the analysis stage to maintain the validity and reliability of the bibliometric study results.

Bibliometric Analysis

The bibliometric analysis is carried out after the document selection and verification process is completed. At this stage, clean and complete data is analyzed using bibliometric software such as VOSviewer to identify patterns of publication, collaboration, and research trends. The analysis includes various techniques, including *citation analysis* to see the influence and level of connectivity between articles, *co-authorship analysis* to map the collaborative network of authors and institutions, *co-word analysis* to reveal the main topics and connections between concepts, and *bibliographic coupling* to find documents with similar references.

The results of this analysis are then visualized in the form of network *visualization*, *density visualization*, and overlay visualization, so that they can provide a comprehensive overview of the knowledge structure in the field of study being studied. Through this stage, it is possible to identify the most productive authors or institutions, the most influential journals, and keywords that are the focus of the research. Thus, bibliometric analysis not only provides a map of research progress, but also reveals future research directions.

Research Process Flow Diagram

Figure 1 shows the stages of the document selection process in this study which consists of three main phases: *Scanning Phase*, *Eligibility Phase*, and *Analyzing Phase*. The process began with data collection from the Scopus database, which resulted in a total of 223 documents in the initial stages of screening. In *the Scanning Phase*, the implementation of inclusion and initial exclusion criteria was implemented, including restrictions on the field of study and relevant documents, so that 149 documents remained. Next, the document enters the *Eligibility Phase*, where further evaluation is carried out based on the type of publication, journal reputation, and topic relevance. From this stage, the number of eligible documents is reduced to 102 documents. The last stage, namely *the Analyzing Phase*, determines 102 documents that are considered the most relevant and meet the bibliographic completeness to be analyzed bibliometrically. These selected documents form the basis for mapping research trends, collaboration networks, and key topics that develop in the study.

Figure 1. Four-Stage Data Extraction and Filtration Process Flow Diagram (Vedula, 2024)

This process guarantees that only documents that match the inclusion criteria are included in the analysis, so that the results obtained are more valid, structured, and in accordance with the research objectives. This flow visualization also helps clarify the direction of research and study trends related to the use of AR in the context of education**.**

Result and Discussion

Number of Documents Found and Filtered

Initial searches yielded 223 documents that matched the research keyword. After the year of publication filter was carried out to ensure the up-to-date of the data, the number of documents shrunk to 149 documents. The next stage is screening based on reputable indexed journal sources, so that there are 102 remaining documents that are assessed to meet scientific quality and relevance standards. The depreciation of the number at each stage indicates the existence of literature that does not meet the criteria, either due to the factors of the year of publication, the type of publication, and the quality of the publisher. Therefore, these 102 final documents are used as the basis for bibliometric analysis, because they are considered the most representative for mapping trends, collaborations, and current research developments.

Analysis by Document Type

Figure 2 shows the distribution of publications by type of document indexed in Scopus. From the diagram, it can be seen that research articles are the most dominant type of document with a percentage of 87.3%, so it can be concluded that most publications focus on presenting empirical research results. The type of review document was in second place with a percentage of 8.8%, indicating that there was considerable attention to literature review and synthesis of previous research. Meanwhile, editorials and erratum each have a small portion, which is 2.0%. These findings show that scientific publications in the field of study analyzed are more in the form of original research articles, with relatively few contributions from reviews, editorials, and erratum.

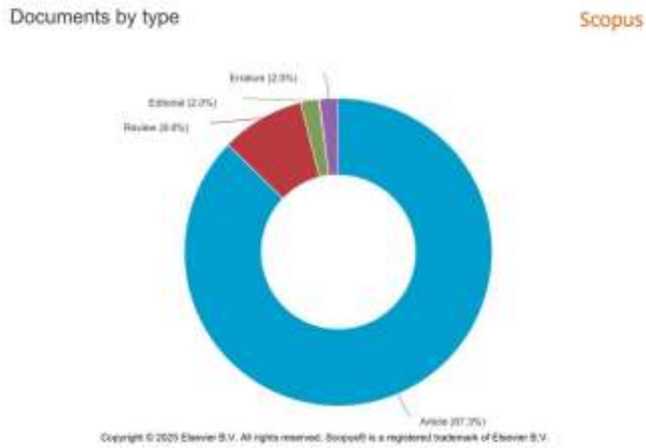

Figure 2. Document Type

Publication Trend Analysis per Year

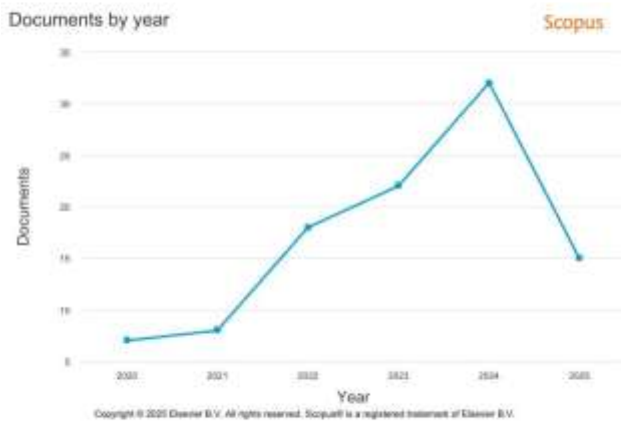

Figure 3. Publication Trends from 2020 to 2025

Figure 3 shows the trend of publications from 2020 to 2025 which has fluctuated quite significantly. In 2020 the number of publications was still relatively low, then increased slightly in 2021. A sharp increase was seen in

2022, followed by more stable growth in 2023. The peak in the number of publications occurred in 2024 with the highest number, reflecting the great attention and increased research interest in that year. However, in 2025 the number of publications will decrease quite drastically compared to the previous year. Overall, this trend shows a trend of increasing publications from 2020 to 2024 before finally declining in 2025.

Analysis Based on Journal Sources

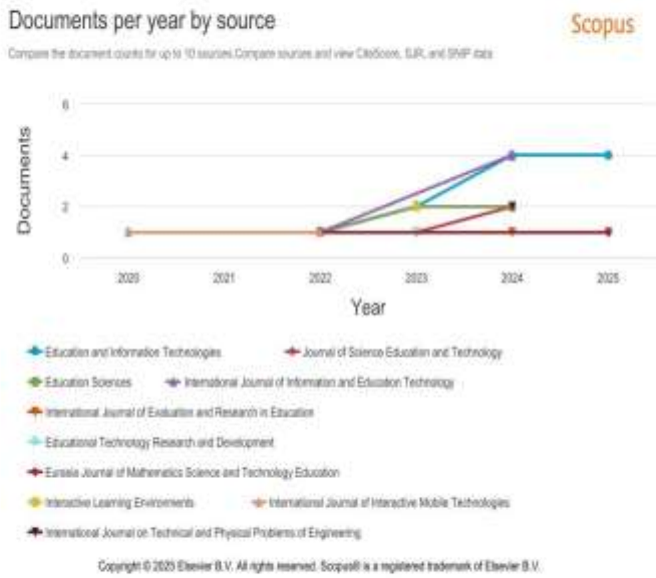

Figure 4. Analysis Based on Journal Sources

Figure 4 shows the distribution of publications by journal source from 2020 to 2025. Data shows that there are several journals that are consistently a place for publication, including *Education and Information Technologies* and *the International Journal of Information and Education Technology* which have experienced a significant increase since 2022 to reach the highest number of publications in 2024 with 4 documents. In addition, journals such as *Education Sciences* and *the International Journal of Evaluation and Research in Education* also show an upward trend in 2023–2024. Meanwhile, several other journals such as the *Journal of Science Education and Technology* and *the Eurasia Journal of Mathematics Science and Technology Education* appear to have a more limited contribution with a relatively small number of publications. Overall, it can be concluded that publications are more distributed in journals that focus on educational technology and information development, which confirms that the research themes analyzed have a high relevance to the field.

Subject-Based Analysis

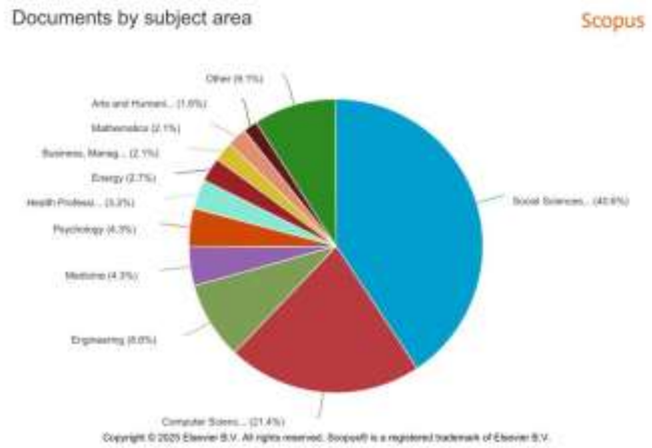

Figure 5. Distribution of Research Subjects

Figure 5 shows the distribution of publications by subject areas indexed in Scopus. Data shows that Social Sciences dominate with the largest percentage of 40.6%, indicating that research on the topics studied focuses the most on social science aspects. Furthermore, Computer Science ranks second with a contribution of 21.4%, followed by the Engineering sector of 8.6%. Some other fields that also contributed although with a smaller portion were Medicine (4.3%), Psychology (4.3%), Health Professions (3.2%), Energy (2.7%), as well as Business, Management and Accounting (2.1%) and Mathematics (2.1%). The Arts and Humanities sector was recorded with the smallest portion at 1.6%, while the Other category accounted for 9.1%. Overall, this distribution shows that publications are dominated by the fields of social and computer sciences, which shows a strong tendency for research on social aspects and the use of digital technology in the study themes analyzed.

Analysis by Institution

Figure 6 shows the distribution of publications by author's affiliated institutions indexed in Scopus. Data shows that Atatürk Üniversitesi is the institution with the highest number of publications, which is about 5 documents. The next position was occupied by Universiti Pendidikan Sultan Idris, Surabaya State University, and National Taichung University of Science and Technology which each produced 4 documents. Meanwhile, several other institutions such as Thurgau University of Teacher Education, Universiti Utara Malaysia, University of Western Macedonia, National Cheng Kung University, Pädagogische Hochschule Weingarten, and Universität Konstanz contributed with a relatively balanced number of publications, which was about 3 documents. Overall, this distribution shows that publications related to research in the field of study are not only concentrated in one country, but are spread across various international institutions, both in Asia, Europe, and the Middle East. This indicates a global collaboration and interest in the research topic being analyzed.

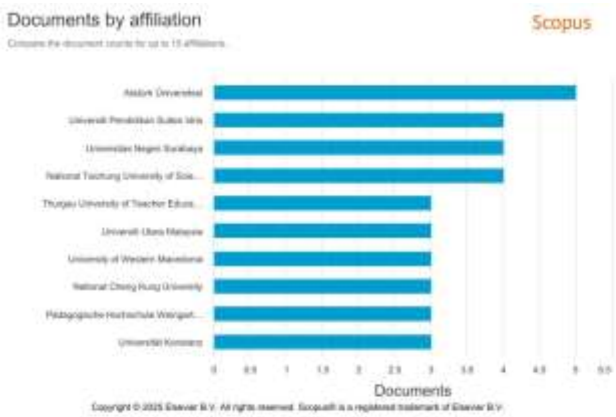

Figure 6. Analysis by Institution

Analysis by Country

Figure 7 shows the distribution of publications by country or territory indexed in Scopus. Data shows that Turkey is the country with the highest number of publications, which is around 17 documents. Indonesia occupies the second position with 14 documents, followed by the United States with 13 documents. Furthermore, Malaysia and Taiwan produced about 12 and 11 documents respectively, while China was recorded with 10 documents. Some other countries that also contributed although in smaller numbers were Germany and Saudi Arabia (7 documents each), the United Kingdom (5 documents), and Greece (4 documents). Overall, this distribution shows that publications related to research topics are not only concentrated in one region, but are spread across various countries, both in Asia, America, and Europe. The dominance of Turkey, Indonesia, and the United States indicates that the three countries have significant attention and contribution to the development of research in the field of study analyzed.

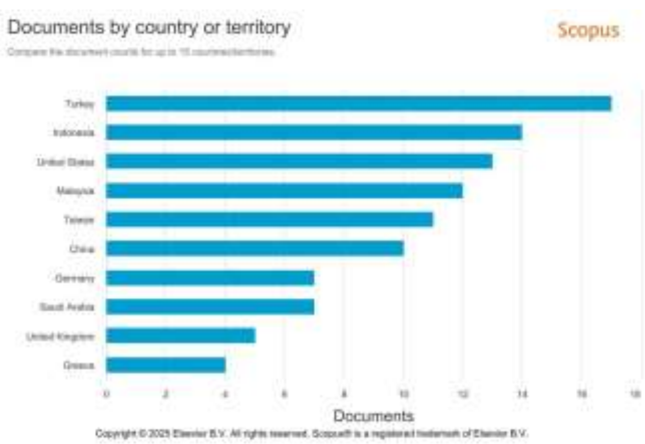

Figure 7. Document Distribution by Country

Analysis Based on Keywords

Figure 8 shows the results of *the co-word analysis* with the main keyword "science". From the visualization, it can be seen that this word is closely related to the terms "student", "education", and "learning" which are the center of the research network. This connection emphasizes that the study of *science* in the context of education is often associated with student learning experience, the effectiveness of methods, and the integration of learning technologies such as augmented reality technology. The green cluster focuses on *student*, *effect*, *group*, and *effectiveness*, which reflects experimental research related to the impact of *science learning* application on learning outcomes. The red cluster is related to *education*, *development*, *challenges*, and *fields*, indicating attention to the development of science education and obstacles to its implementation. Meanwhile, the blue cluster groups teachers, *questionnaires*, *engagement*, and *outcomes*, which highlight the role of teachers, measurement instruments, and student involvement in science learning. In general, this map illustrates that research on science focuses not only on students' academic achievements, but also on the dimensions of educational implementation, development challenges, and teacher and student involvement. This shows that *science* is a center of multidimensional studies that link learning effectiveness, technological innovation, and pedagogical strategies.

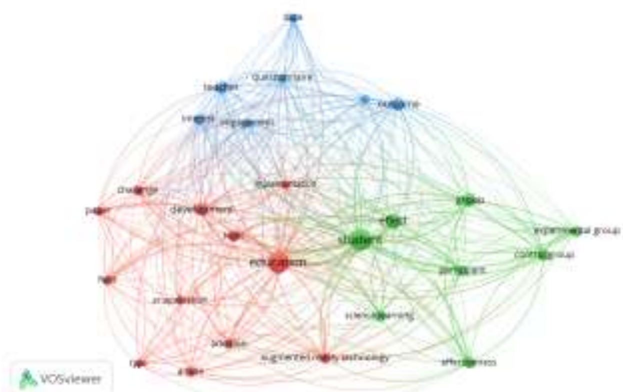

Figure 8. Keyword Visualization

Figure 9 shows the results of *a co-word analysis* that maps the relationship between keywords in publications related to science and augmented reality. The largest nodes such as *student*, *education*, and *science learning* emphasized that the main focus of research lies in students, learning processes, and the application of AR technology. The green cluster shows *the student*'s association with terms such as *effect*, *group*, *control group*, and *experimental group*, which represent experimental research to measure the effectiveness of AR in science learning. The red cluster is centered on *education* and *development* with connections to *challenges*, *topics*, and *fields*, indicating a research direction that highlights the implementation of AR and its development challenges in the context of education. Meanwhile, the blue cluster connects *teachers*, *questionnaires*, *engagement*, and *outcomes*, which emphasizes the role of teachers, evaluations, and student involvement factors in the learning process. Overall, this keyword map shows that research on AR in science focuses on three main aspects: the effectiveness of AR-based learning, challenges in educational development, and teacher and student engagement in more interactive learning experiences.

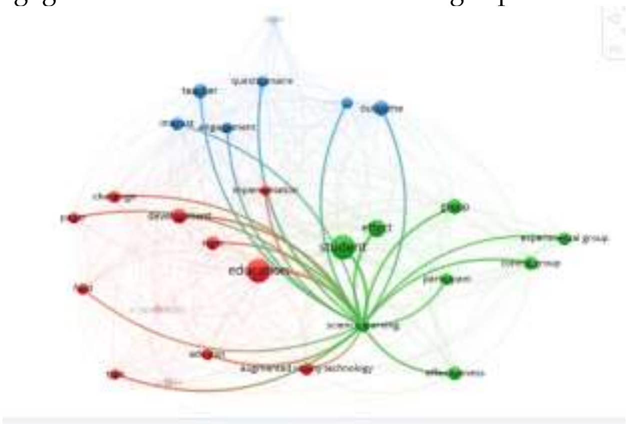

Figure 9. Keyword Visualization

Overall, Figure 8 provides a broad overview of research trends related to Augmented Reality (AR) publications in the field of science and education, including the development of the number of documents, country distribution, journal sources, and institutional contributions. Meanwhile, Figure 9 is more specific on keyword mapping that highlights the main focus of the research, namely the effectiveness of AR in science learning, implementation development challenges in education, and the role of teachers and student involvement in the interactive learning process.

Analysis of Collaboration Between Authors

Figure 10 shows an analysis of the co-authorship network that maps the cooperative relationship between researchers in publications related to the research topic. There are three main clusters, namely the blue cluster consisting of *imanda, r.*, *Setiawaty, S.*, and *Lukman, I.R.* with strong internal connections; the green cluster led by *Irwanto, I.*, *Bright, U.*, *suroso, j.*, and *sustainable, i.*; and red clusters containing *sekaringtyas, t.*, *Safitri, D.*, *Iskandar, R.*, *Suntari, y.*, *nafisa, s.*, *Marini, A.*, and *Sudrajat, a.*. From the entire network, *sustainable, i.* occupies a central position because it acts as a liaison between the blue and red clusters, so it has a strategic role in building cross-group collaboration. This visualization shows that the research is not only focused on one author, but is divided into several groups with fairly close collaboration within and between clusters.

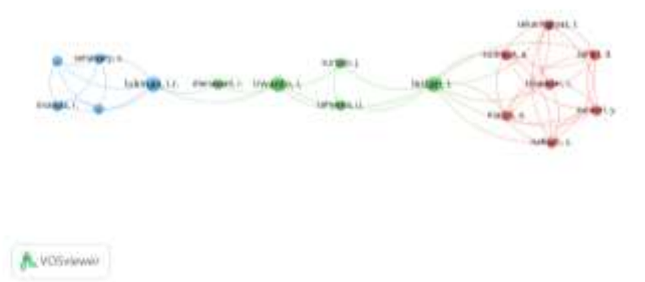

Figure 10. Author Collaboration.

Table 2. Most-Cited Articles on Augmented Reality in Science Education

Author(s)	Article title	Number of citations	Journal Name	Key Findings/Recommendations
Sahin, D., Yilmaz, R.M.	The effect of Augmented Reality Technology on middle school students' achievements and attitudes towards science education	291	Computers and Education	This quasi-experimental study with 100 seventh graders examined AR-based science learning ("Solar System and Beyond") versus traditional methods. Results showed the AR group achieved higher performance, developed more positive attitudes, felt no anxiety, and expressed willingness to continue using AR. A significant positive correlation was also found between achievement and attitudes.
Moro, C., Phelps, C., Redmond, P., Stromberga, Z.	HoloLens and mobile augmented reality in medical and health science education: A	154	British Journal of Educational Technology	This study compared AR-based anatomy and physiology lessons delivered via Microsoft HoloLens and mobile tablets to 38 pre-clinical students. Both modes effectively improved learning outcomes with no significant score differences. However, HoloLens use caused higher dizziness reports (25% more, p = .04),

Author(s)	Article title	Number of citations	Journal Name	Key Findings/Recommendations
	randomised controlled trial			while no other adverse effects were found. Overall, both delivery methods were effective, supporting AR's role in health sciences education (Moro et al., 2021).
López-Belmonte, J., Moreno-Guerrero, A.-J., López-Núñez, J.-A., Hinojo-Lucena, F.-J.	Augmented reality in education. A scientific mapping in Web of Science	71	Interactive Learning Environments	This bibliometric study analyzed 777 Web of Science publications on augmented reality (AR) in education using scientific mapping and co-word analysis. Results identified key trends in languages, knowledge areas, document types, institutions, authors, sources, countries, and most-cited works. Research themes highlighted AR's role in teaching effective use of the technology, its learning environments, educational applications, and addressing student diversity.
Chen, C.-H.	Impacts of augmented reality and a digital game on students' science learning with reflection prompts in multimedia learning	71	Educational Technology Research and Development	This study designed an AR game-based learning method combining AR technology, digital games, and reflection prompts in a mobile system for elementary science learning. A 2×2 experiment compared AR vs. non-AR and game vs. non-game approaches during a field trip. Results showed that both AR and games significantly enhanced learning motivation, but only games improved achievement and flow state. The study highlights the importance of flow in multimedia learning and emphasizes digital games' role in fostering affective-motivational states.
Salar, R., Arici, F., Caliklar, S., Yilmaz, R.M.	A Model for Augmented Reality Immersion Experiences of University Students Studying in Science Education	67	Journal of Science, Education and Technology	This article shows that AR-based immersive learning environments boost engagement, motivation, and understanding when grounded in strong usability principles. Usability tests highlight the value of 3D visuals, interactivity, and contextual learning in improving retention and comprehension. The authors recommend prioritizing user-centered design, accessibility, and iterative usability evaluations to develop effective AR educational tools aligned with learners' cognitive needs and preferences.
Marini, A., Nafisah, S., Sekaringtyas, T., ... Sudrajat, A., Iskandar, R.	Mobile Augmented Reality Learning Media with Metaverse to Improve Student Learning Outcomes in Science Class	66	International Journal of Interactive Mobile Technologies	This experimental study with 75 fifth-grade students tested mobile AR learning media integrated with the Metaverse in science classes. Using a pretest–posttest design, results showed significant improvement in learning outcomes. Students reported higher interest, easier understanding, and greater enjoyment when learning with the Metaverse AR application.
Hidayat, R., Wardat, Y.	A systematic review of Augmented Reality in Science, Technology, Engineering and Mathematics education	60	Education and Information Technologies	This article highlights both the benefits and challenges of AR in education. Advantages include boosting motivation, spatial understanding, collaboration, and interactive learning experiences. Challenges involve usability, cognitive overload, and technical limits. The study stresses that AR's success relies on careful pedagogical integration. It recommends user-friendly design, alignment with learning

Author(s)	Article title	Number of citations	Journal Name	Key Findings/Recommendations
				goals, and managing cognitive load, while urging educators and developers to conduct continuous evaluation and refinement of AR applications (Hidayat, 2024).
Zhao, X., Ren, Y., Cheah, K.S.L.	Leading Virtual Reality (VR) and Augmented Reality (AR) in Education: Bibliometric and Content Analysis From the Web of Science (2018–2022)	53	Sage Open	This article reviews rapid growth in VR and AR research in education, particularly in the past five years, with strong emphasis on STEM, immersive learning, and experiential engagement. Findings show AR/VR boost motivation, interactivity, and personalized learning but face challenges such as weak pedagogical integration, high development costs, and inconsistent evaluation. The authors recommend interdisciplinary collaboration, standardized assessment models, equitable technology access, and ethical awareness to maximize the effectiveness of immersive educational environments (Zhao, 2023).
Çetin, H., Türkan, A.	The Effect of Augmented Reality based applications on achievement and attitude towards science course in distance education process	51	Education and Information Technologies	This study with 15 third graders used AR-based applications in a distance science course on the "Electric Vehicles" theme via Zoom. Using a pretest–posttest design, results showed significant improvements in both students' achievement and attitudes toward science after 15 hours of AR-based learning.
Turan, Z., Atila, G.	Augmented reality technology in science education for students with specific learning difficulties: its effect on students' learning and views	49	Research in Science and Technological Education	This article emphasizes the potential of Augmented Reality (AR) to support students with specific learning difficulties, who often struggle with distraction and need additional learning support. By combining real and virtual elements, AR can capture attention, spark interest, and create more effective and engaging learning environments tailored to their needs.

Table 2 summarizes the ten most cited articles that discuss the use of AR in science education from various perspectives. The articles not only focus on improving student learning outcomes, but also highlight aspects of motivation, attitudes, engagement, and a more immersive learning experience through AR technology. For example, Sahin & Yilmaz's research that became the highest-cited article emphasized that the use of AR can improve academic achievement while shaping students' positive attitudes towards science subjects. Meanwhile, Moro et al. show the application of AR both through HoloLens and mobile devices in medical education and health sciences, confirming the flexibility of this technology at various levels of education and fields of study.

In addition, López-Belmonte et al. through a bibliometric approach provide a comprehensive overview of how AR develops in the world of education, while Chen's research blends AR with digital games to explore its influence on student motivation and achievement. Other studies, such as those conducted by Salar et al. and Marini et al., expand the understanding of immersive learning models with AR as well as the integration of the metaverse to improve elementary school student learning outcomes. These high-citation articles also highlight other important aspects, such as the implementation of AR in distance learning (Çetin &

Türkan), the role of AR in supporting students with special needs (Turan & Atila), to the analysis of global trends in AR research in education (Zhao et al.; Hidayat & Wardat).

Overall, the articles listed in Table 2 are important foundations in understanding how AR is applied in science education and the impact it has on the quality of learning. With a diverse scope ranging from experimental research, bibliometric studies, to systematic studies, this collection of articles not only represents a major contribution in the field of study, but also provides direction for future research development, both in the context of methodology, implementation strategies, and the use of AR to support more adaptive, interactive, and inclusive learning.

This study provides a comprehensive overview of the development of AR research in the field of science education during the period 2020–2025 through a bibliometric approach. From an initial search that yielded 223 documents after going through a rigorous screening process with inclusion and exclusion criteria, 102 relevant articles were obtained for further analysis. These findings show that the majority of AR-related publications in science education are published in the form of journal articles that have gone through *a peer-review* process and are indexed by Scopus, confirming the quality and credibility of the research used. Year-over-year publication trends show a significant increase, with a peak in 2024 before declining in 2025. This indicates that the topic of AR in education still has high appeal among academics and researchers, especially in the last five-year period. In terms of journal sources, publications are spread across a number of reputable international journals such as *Education and Information Technologies*, *Interactive Learning Environments*, and *the Journal of Science Education and Technology*, which are the main forum for the dissemination of research results related to technological innovations in education. Analysis based on the field of study shows that research on AR is most categorized in the field of *social sciences* (40.6%) and *computer science* (21.4%), with additional contributions from the fields of *engineering*, *medicine*, *psychology*, and *health professions*. This distribution shows that the application of AR in education is multidisciplinary, not only focusing on pedagogical aspects but also involving technical, health, and other applied science aspects. In terms of countries, the largest contributions came from Turkey, Indonesia, the United States, Malaysia, Taiwan, and China, illustrating that AR research in science education has developed globally with significant contributions from both developed and developing countries. The results of the keyword analysis (*co-word analysis*) show three main focuses in the research: (1) the effectiveness of AR in improving student learning outcomes, shown by the connection between the words *student*, *effect*, *science learning*, and *augmented reality technology*; (2) the challenges and development of AR implementation in education, reflected in the words *education*, *development*, *challenge*, and *field*; and (3) the role of teachers, evaluation, and student involvement in interactive learning, which is reflected in the interconnectedness of *the words teacher*, *questionnaire*, *engagement*, and *outcome*. This visualization confirms that AR research in education is not only focused on cognitive aspects, but also touches on motivational, implementive, and evaluative dimensions. In addition, *co-authorship analysis* shows the formation of several quite strong collaboration clusters. The red cluster shows a group of authors with a dense intensity of cooperation, the blue cluster contains a small but solid network, while the green cluster acts as a link between groups. Key figures such as *sustainability,* occupy a central position because they have a strategic role as a bridge for cross-cluster collaboration, strengthening integration in the research ecosystem. These findings confirm that AR research in education is collaborative and strongly influenced by a network of authors across institutions and countries. Overall, the results of this study conclude that AR has evolved into one of the important focuses in science education innovation, with increasing research trends, diverse topics, and increasingly strong collaboration networks. AR is not only seen as an innovative technology, but also as a pedagogical approach that is able to increase learning effectiveness, strengthen student motivation, and enrich interaction between teachers and students.

Conclusion

These findings provide a direction for future research to further emphasize aspects of long-term implementation, *evidence-based evaluation*, and cross-disciplinary and cross-country collaboration in optimizing the use of AR in the world of education. This study is limited to data from Scopus and English-language articles, so the potential for relevant publications from other databases as well as local studies in non-English languages has not been accommodated. In addition, the analysis emphasizes more on the quantitative aspect of metadata, so the depth of the content has not been fully explored. For this reason, further research is recommended to use multi-databases, involving cross-language articles, and combining bibliometrics with *systematic review* or *meta-analysis*. Future studies also need to emphasize the practical implementation of AR in the classroom through a longitudinal approach, as well as strengthen cross-disciplinary collaboration to produce more effective and contextual AR-based learning models.

Author Contributions

Conceptualization, R.J. and W.M.H; methodology, R.J; software, R.W.D; validation, R.J., and W.M.H; formal analysis, R.J; resources, W.M.H.; data curation, R.W.D; writing, R.J.; visualization, R.W.D; supervision, R.J Note: R.J. is the corresponding author. Initials: R.J. = Rahmiatul Jannah; W.M.H = Wahyuni Mulia Helmi; R.W.D = Rahmatia Wulan Dari.

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Conflicts of Interest

The authors declare no conflict of interest.

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