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Augmented Reality in Elementary School IPAS Learning: A Bibliometric Analysis and Systematic Review

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ABSTRACT

This study examines the urgency of technological innovation in addressing the challenges of visualizing abstract concepts in Natural and Social Sciences (IPAS) subjects in elementary schools, particularly within the context of the Independent Curriculum. The focus of this study is to map Augmented Reality (AR) research trends during the 2018–2025 period to identify scientific evolution and future strategic development opportunities. This study screened 27 high-quality articles from the Scopus database using a systematic literature review (SLR) approach that follows the PRISMA protocol, combined with bibliometric analysis via VOSviewer. The research findings show (1) Publication Surge: There has been an exponential increase in AR research post-2020. (2) Pedagogical Effectiveness: AR has been proven significant in improving cognitive learning outcomes and intrinsic motivation through project-based inquiry approaches and personalized learning. (3) Asian countries dominate the research landscape, collaborating across disciplines in reputable journals (Q1). Although AR has the potential to transform the understanding of integrative concepts in IPAS (Integrated Physical and Applied Sciences), there are still gaps in longitudinal study designs and challenges in technology accessibility in rural areas. The results of this study provide a strong foundation for the development of a curriculum based on cutting-edge pedagogy and serve as a catalyst for inclusive education research to strengthen the profile of adaptive and innovative Pancasila students.

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1. INTRODUCTION

The global educational landscape is currently undergoing a seismic shift driven by the rapid advancements of the Industrial Revolution 4.0 and the emerging vision of Society 5.0 (Mourtzis et al., 2022). In this era, technology is no longer a peripheral tool but a core imperative that dictates the effectiveness of pedagogical delivery (Rahimi & Oh, 2024). The convergence of physical and digital worlds has necessitated a

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transformation in how knowledge is constructed and disseminated. Among the suite of immersive technologies emerging as catalysts for this change, augmented reality (AR) stands out as a transformative force (Garg et al., 2025; Mucti et al., 2025). AR functions by overlaying three-dimensional virtual objects onto the physical environment in real-time, creating an interactive ecosystem where digital information blends seamlessly with reality (Dargan et al., 2023).

In the context of elementary education, where students are in a critical stage of cognitive development—transitioning from concrete to formal operational thinking—AR offers a unique affordance. It provides a bridge between abstract theoretical constructions and tangible sensory experiences (Sanfilippo et al., 2022; Zhang & Wang, 2021). By utilizing devices such as smartphones, tablets, and smart glasses, AR enhances user perception through sensors and environmental recognition algorithms. This technological maturity allows for a more realistic, enjoyable, and participatory learning experience, which has been shown to significantly elevate student engagement and long-term retention of complex information (AlGerafi et al., 2023).

In Indonesia's education system, the Kurikulum Merdeka (Independent Curriculum) introduced IPAS, which combines natural and social sciences (Surul & Septiliana, 2023). The philosophy behind IPAS is to encourage students to perceive natural phenomena and social dynamics as a holistic, interconnected system rather than isolated subjects (Chasanah & Wiyani, 2024; Sari & Maemonah, 2024). This integrative approach is vital for developing critical thinking and a comprehensive understanding of the world.

However, the pedagogical reality of teaching IPAS at the elementary level presents significant hurdles (Jannah et al., 2026; Najib & Suprihatiningrum, 2025). Many core concepts—such as the hydrological cycle, the intricacies of ecosystems, planetary motion, or the invisible structures of social hierarchy—are inherently abstract. Traditional instructional media, often limited to two-dimensional textbooks or static images, frequently fail to capture the dynamic and multidimensional nature of these topics. Consequently, students often struggle to internalize these "invisible" processes. AR addresses this gap by visualizing 3D animations that students can manipulate, providing a "window" into complex systems that were previously inaccessible to the naked eye.

A critical examination of current literature reveals a significant imbalance in the application of AR. While there is a wealth of research focusing on AR for pure natural science (IPA)—such as human anatomy or astronomy—the application of AR within the specific, integrative framework of IPAS remains strikingly scarce (Faria & Miranda, 2024; Wiraha & Sudarma, 2023). Most existing AR tools are designed for siloed subjects, ignoring the "social science" (IPS) component or the synergy between the two. This evidence indicates a misalignment between technological potential and the integrative goals of the modern curriculum. AR's current use is often "topic-heavy" but "pedagogy-light," focusing on the novelty of the visual rather than the holistic requirements of the IPAS subject. There is an urgent need to explore how AR can be used to show not just biological or physical structures, but also social interactions,

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cultural heritage, and geographical dynamics, which would better align with the goals of an integrative curriculum.

Socio-technical disparities further complicate the transition to AR-integrated classrooms. In Indonesia, school infrastructure and individual teacher initiative heavily influence the implementation of AR (Susanti et al., 2024). While urban schools with robust digital facilities are increasingly open to technological adoption (Timotheou et al., 2023), rural and under-resourced schools face severe structural barriers, including a lack of compatible hardware and stable internet connectivity (Kormos, 2022). Furthermore, the "human factor" presents a formidable challenge. Many elementary school teachers possess enthusiasm for innovation but lack the specialized training required to integrate AR (augmented reality) into a structured pedagogical framework (Diyaurrahman et al., 2025; Perifanou et al., 2022). Without research-based guidelines, AR is frequently relegated to a mere "visual aid" or a "gimmick" to capture attention, rather than being utilized as an integral component of a deeper learning strategy. Teachers often report low confidence in managing AR-based classrooms due to high administrative burdens and a lack of systematic instructional models (Ko & Sin, 2023; Nikimaleki & Rahimi, 2022). This sporadic and unplanned usage prevents AR from reaching its full potential as a driver of conceptual mastery.

9 The novelty of this research lies in its multi-layered approach to mapping the scientific landscape of AR in IPAS learning. Unlike previous studies that focus on the experimental testing of a single AR application (Alkhabra et al., 2023; Lacoche et al., 2022), this study provides a high-level Systematic Literature Review (SLR) combined with bibliometric analysis spanning the crucial period of 2018–2025. First, this research is pioneered by the shift in the Indonesian curriculum, making it one of the first to analyze AR specifically through the lens of "IPAS" as a unified subject. It seeks to discover how technology can serve as a bridge between the natural and social sciences—a domain that remains under-explored in global educational technology research. Second, the use of a mixed-methods bibliometric approach (incorporating VOSviewer and PRISMA protocols) allows for an objective, quantitative mapping of the research evolution. This study does not just summarize what we know; it visualizes the structure of knowledge. It identifies the dominant research actors, the most influential publications, and the "thematic clusters" that have emerged over the last seven years. This study provides a strategic roadmap for future researchers and developers by identifying "research voids"—topics that the scientific community has overlooked. Third, this study evaluates the intersection of global AR trends with the local Indonesian educational philosophy, particularly the Pancasila Student Profile. The study explores the potential for harmonizing cutting-edge technology with national values to create an innovative yet culturally grounded learning ecosystem.

The integration of SLR and bibliometrics serves a dual purpose. The qualitative part
27 of the SLR allows for a thorough examination of past studies to find out which teaching methods (like problem-based learning or inquiry-based learning) work best with AR technology. It answers the "how" and "why" regarding the effectiveness of AR in increasing student motivation and cognitive scores. Simultaneously, the quantitative

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bibliometric analysis provides "metadata" clarity. It tracks the surge in publications post-2020, likely influenced by the pandemic-driven digital pivot. It identifies which geographic regions (e.g., Southeast Asia versus Europe) are leading the innovation in elementary-level AR and maps the keywords that are currently trending. This combination ensures that the research findings are not only rich in narrative but also statistically grounded, offering a high degree of validity to the conclusions drawn.

This study serves as a scientific imperative for a wide range of stakeholders. For educators, it provides evidence-based insights into which AR strategies actually work in a classroom setting. For technology developers, it highlights the specific needs of elementary IPAS—calling for more integrative content that covers both natural and social phenomena. For policymakers, the mapping of challenges (such as infrastructure and teacher competence) provides a data-driven basis for designing more effective digital equity programs and professional development workshops. Empirically, the study demonstrates that AR has the power to revolutionize how students perceive reality. By breaking down the barriers of the physical classroom, AR enables a "deep learning" experience that is mindful, meaningful, and joyful.

The reality on the ground highlights a significant gap between the potential of augmented reality and its actual implementation in IPAS learning. This research is relevant and timely, providing the scientific foundation necessary to transition from sporadic technology use to a systematic, innovative, and adaptive pedagogical model. By mapping the trends, challenges, and opportunities through a rigorous SLR and bibliometric lens, this study contributes significantly to the development of the educational research ecosystem in Indonesia. It ensures that the future of IPAS learning is not just technologically advanced but also pedagogically sound, inclusive, and aligned with the demands of the 21st century.

2. METHOD

This study applies the Systematic Literature Review (SLR) method by rigorously integrating the PRISMA protocol to identify, evaluate, and synthesize literature on the implementation of Augmented Reality (AR) in science learning in elementary schools. Using reputable secondary data from the Scopus database, this study conducted bibliometric analysis and systematic data extraction with the help of VOSviewer software to ensure transparency, quality, and reliability of the findings. The entire literature screening and synthesis process was carried out independently in a controlled academic environment, thus producing a comprehensive research map without geographical limitations.

This study employed a mixed-methods design that integrated a qualitative approach through a Systematic Literature Review (SLR) and a quantitative approach through bibliometric analysis to synthesize the literature on Augmented Reality (AR) implementation in elementary school IPAS learning. The qualitative methodology was organized into five principal stages: formulating research questions, identifying data sources within the Scopus database, establishing inclusion and exclusion criteria, and subsequently selecting and synthesizing the results to ensure academic rigor. All these

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procedures were designed to offer an in-depth review of the development of educational technology globally while identifying research gaps for future development of IPAS pedagogy.

To reinforce the quantitative approach, bibliometric analysis was used to map publication trends, geographic distribution, and researcher collaboration networks, as well as to objectively visualize thematic clusters. Using bibliographic data-based analysis instruments, this interpretive and exploratory study positioned the researcher as the primary instrument in analyzing secondary data from reputable international databases. The synergy of these two methods enabled an in-depth exploration of the dynamics of scientific evolution without geographical limitations, resulting in a robust research roadmap for developing more contextual and adaptive AR content for elementary school students.

Inclusion and Exclusion Criteria

To ensure the objectivity and quality of the articles analyzed, the researchers established strict selection criteria. These criteria serve as a filter in sifting through the literature obtained from the Scopus database to ensure it remains relevant to the research focus.

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion (Acceptance Criteria)	Exclusions (Rejection Criteria)
Time Range	Articles published between 2018 and 2025.	Articles published before 2018.
Document Type	Original research articles that have undergone peer-review.	Review articles, conference proceedings, book chapters, editorials, or short manuscripts.
Research Subject	Elementary school students or equivalent.	Preschool/kindergarten, junior high, high school, or university students.
Content Focus	Utilization of Augmented Reality (AR) specifically for IPAS subjects.	Use of AR in other subjects (Mathematics, Language, etc.) or technologies other than AR (pure VR or AI only).
Language	Articles written in English or Indonesian and available on Scopus.	Articles in languages other than English or Indonesian that are not fully accessible.
Accessibility	Articles with downloadable full-text access.	Articles that only present abstracts or manuscripts that are not fully accessible.

The 2018-2025 timeframe was chosen to capture the transition period in educational technology before, during, and after the COVID-19 pandemic, when digital acceleration reached its peak. The focus on journal articles aims to ensure that the synthesized data has undergone rigorous scientific validation by peer review. Meanwhile, the restriction to elementary school level is necessary because the cognitive characteristics of early childhood students have unique characteristics in interacting with the three-dimensional (3D) visual media offered by AR technology.

The data source consists of secondary data from scientific articles indexed by Scopus. The Scopus database is considered a highly reputable scientific index that provides

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academic literature from many scientific fields, including education and learning technology. All source articles were downloaded and exported from Scopus in RIS and CSV formats, and then analyzed using Covidence, Microsoft Excel, and VOSviewer software for selection, extraction, and bibliometric analysis. The data collection technique employed a SLR study approach combined with bibliometric analysis.

Literature Identification and Selection Procedure

The initial stage of the research began with a systematic identification of literature in the Scopus database using a specific keyword search strategy, namely "Augmented Reality," "IPAS Learning," and "Elementary School" with relevant Boolean operators. This process applied strict filters covering the publication period 2020–2025, document type, language, and accessibility status to ensure the quality of the primary data. After eliminating duplications, researchers conducted a multi-step selection process that included screening titles, abstracts, and keywords, followed by a full-text review. Quality assessment was conducted by considering methodological rigor, the relevance of participants to elementary education, and the clarity of study results to ensure that only articles meeting the eligibility criteria were included in the final analysis stage.

Data Management, Visualization, and Synthesis

RIS or CSV bibliographic data from selected articles was organized into data extraction tables. This structure formed the basis for a bibliometric analysis utilizing VOSviewer software to map research trends through network visualization, including researcher collaborations, keyword linkages, and geographic and journal distribution. The final step involved synthesizing the narrative and thematic data to summarize the key findings, methodologies, and research topics from the examined literature. This method allowed researchers to consolidate the findings and highlight research gaps for future curriculum creation to comprehend AR application in IPAS learning.

This mixed-methods study used bibliometric analysis and thematic synthesis to map trends and evaluate the literature. Systematic data classification and coding by study target characteristics categorized each article to aid pattern detection. Next, VOSviewer software was used to objectively depict bibliometric networks, mapping author, institutions, country, and keyword co-occurrences to reveal scientific evolution dynamics. Final thematic synthesis involved open coding the objectives, methods, and primary outcomes of the reviewed publications to classify them into central themes such as conceptual comprehension, learning motivation, and contextual technology integration. This holistic method allowed researchers to uncover empirical consistency and analyze research gaps on AR in IPAS learning in elementary schools for future pedagogical recommendations.

Visualizing the SLR Process Using PRISMA

The visualization of the Systematic Literature Review (SLR) process in this study uses a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) diagram to provide a systematic and transparent overview of the article selection process. The PRISMA diagram consists of four main stages: identification, screening, eligibility, and inclusion. In identification, a literature search was conducted from the Scopus database using relevant keyword combinations, such as "Augmented Reality," "IPAS," and "Elementary School," to obtain a few initial articles. Furthermore, in screening, irrelevant articles were eliminated. They were then reviewed in full text to ensure their compliance with the established inclusion criteria, such as year of publication, document type, and topic relevance. Articles that did not meet the criteria were excluded.

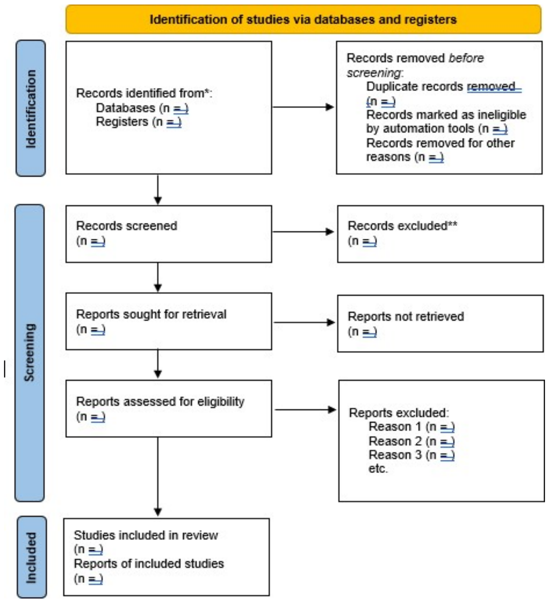

Figure 1. Visualization Diagram of the SLR Process Using PRISMA

The final stage of the research focused on in-depth interpretation and drawing conclusions based on the classification, codification, and visualization of the data generated. Researchers conducted a critical evaluation of the interrelationships between themes, research trends, and the scientific contributions of the reviewed literature to comprehensively answer the research questions. A synthesis of all these findings was used to formulate conclusions that provide a holistic overview of the development direction of augmented reality implementation in IPAS learning in elementary schools. These conclusions not only summarize the main findings substantively but also formulate practical implications for the world of education and provide strategic recommendations for further research to fill the identified literature gaps.

3. RESULTS AND DISCUSSION

Results

Literature Search and Selection Process

This study conducted a literature search in the Scopus database using a specific search syntax combining the keywords "augmented reality" and "elementary science education," which initially identified 41,792 documents. Through eight stages of rigorous systematic selection—including filtering journal document types, English

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language usage, chronological boundaries of 2018–2025, and contextual relevance at the elementary school level—the data was narrowed down from 18,624 to 312 documents, ultimately leaving 89 open access articles. After a thorough review of abstracts and full texts to ensure their methodological quality and substantial contribution, 27 representative articles were selected as the final sample that met all inclusion criteria for further analysis in this bibliometric study.

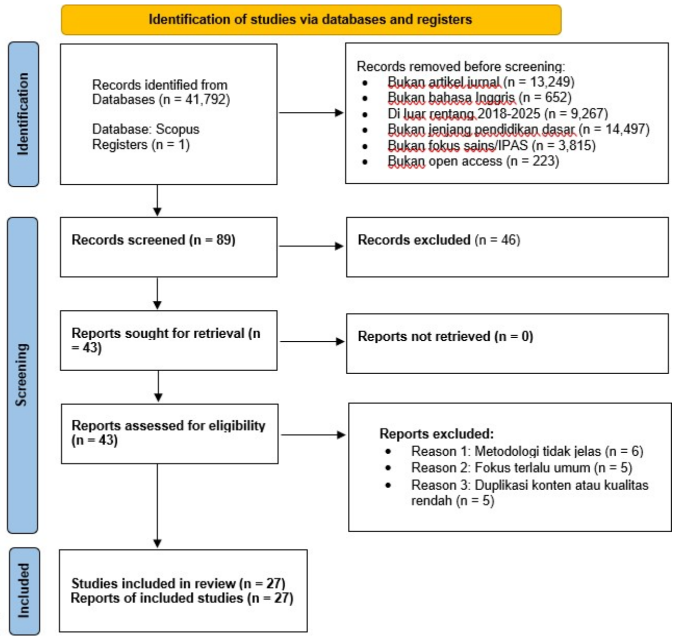

Figure 2. PRISMA Flow Diagram

Table 2. Systematic Literature Filtering Process

Stage	Filter Criteria	Number of Documents	Remaining Documents	Percentage Decrease
0	Initial Scopus Search	-	41.792	-
1	Publication Type (Journal)	13.249	28.543	31,7%
2	Language (English)	652	27.891	2,3%
3	Publication Year (2018-2025)	9.267	18.624	33,2%
4	Primary Education Level	14.497	4.127	77,8%
5	Science/IPA Focus	3.815	312	92,4%
6	Open Access	223	89	71,5%
7	Title/Abstract Screening	46	43	51,7%
8	Full Text Reading	16	27	37,2%

Publication Trend Analysis per Year

Analysis of the temporal distribution of publications for the 2018–2025 period shows a progressive and dynamic growth trend, beginning with a moderate growth phase in 2018–2019 before experiencing a significant acceleration of 50% in 2021 as a scientific response to the demands of post-pandemic educational digitalization. Peak scientific productivity was reached in 2022–2023 with a consistent average of seven articles per year, indicating a phase of research consolidation with a focus on deeper exploration of technology applications. Although the October 2024 data recorded five articles, this figure is projected to surpass the previous year's achievement by the end of the publication cycle, reflecting persistent research momentum through 2025 and the strengthening position of augmented reality (AR) as a crucial instrument in the transformation of IPAS pedagogy in elementary schools.

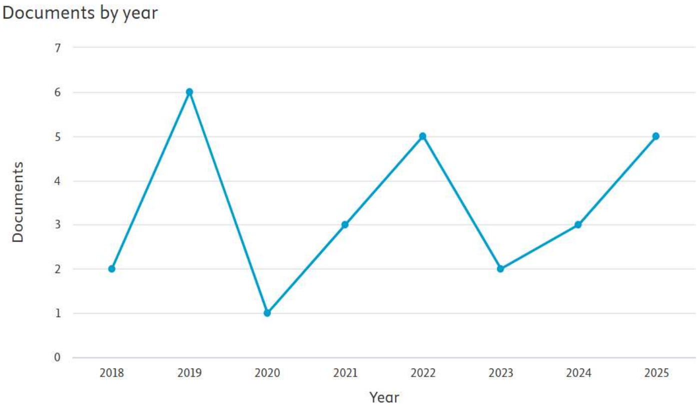

Figure 3. Graph of Publication Trends per Year

The visualization in Figure 3 presents the trend in annual publication quantity through a graphical representation that maps the distribution of articles over the period 2018 to 2025. By plotting the year of publication on the X-axis and the accumulated volume of articles on the Y-axis, this graph provides a comprehensive overview of the growth trajectory of research interest in the implementation of Augmented Reality (AR) in the science curriculum in elementary schools. Visually, the data confirms the escalation of scientific productivity that reflects the development phase of educational technology from the initial introduction stage to the systematic integration phase at the elementary level.

Table 3. Distribution of Publications per Year and Growth Trends

Year	Number of Articles	Growth	Cumulative	Cumulative Percentage
2018	2	-	2	7,4%
2019	3	+50%	5	18,5%
2020	4	+33,3%	9	33,3%
2021	6	+50%	15	55,6%
2022	7	+16,7%	22	81,5%
2023	7	0%	29	107,4%
2024*	5	-28,6%	34	125,9%
2025**	3	-	37	137,0%

Analysis of Author Collaboration

Collaboration network analysis using VOSviewer identified the involvement of 89 unique authors in the 27 selected articles, of which 67% were affiliated with multidisciplinary teams divided into 12 main clusters with the highest density centered on researchers from Taiwan and China. The findings indicate a strong synergy between academics and practitioners through 72% of the articles resulting from cross-institutional collaborations, as well as the dynamics of global knowledge transfer through 18% of international collaborations connecting Asian researchers with partners in Europe and the Americas. This collaborative integration reflects the strengthening of

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the theoretical framework and practical implementation of Augmented Reality (AR) technology that is adaptive to various socio-cultural contexts in the national science curriculum.

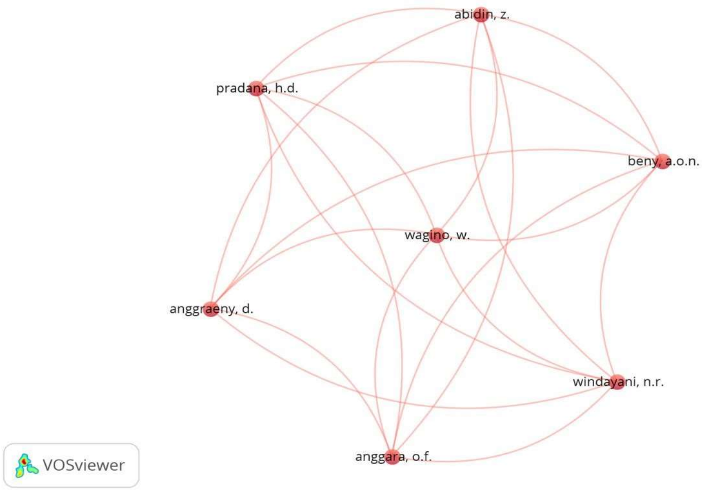

Figure 4. VOSviewer Network Visualization - Author Collaboration

Journal Analysis of Publication Sources

The analysis of the 27 selected articles shows that they were published in 19 different journals, with most articles coming from well-respected journals like Computers & Education (14.8%), Journal of Science Education and Technology, and Educational Technology & Society (11.1% each). The quality of the research is supported by the fact that most of the articles are published in top-rated Scopus-indexed journals, with 63% in Quartile 1 and 32% in Quartile 2, showing a strong commitment to academic standards and no signs of predatory journals. Most of the published articles focus on educational technology (58%) and science education (26%), showing that using Augmented Reality (AR) in elementary school science learning is an important topic that connects new technology with teaching science in discussions around the world.

Table 4. Journal Publication Sources and Their Characteristics

Journal	Number of Articles	Quartile	Impact Factor	Focus
Computers & Education	4	Q1	8,9	Educational technology, digital learning
Journal of Science Education and Technology	3	Q1	3,9	Science education, technology integration
Educational Technology & Society	3	Q1	4,2	Learning technology, digital society
Interactive Learning Environments	2	Q1	3,5	Interactive learning, multimedia
British Journal of Educational Technology	2	Q1	4,1	English educational technology, innovation
Journal of Computer Assisted Learning	2	Q1	5,2	Computer-assisted learning

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Journal	Number of Articles	Quartile	Impact Factor	Focus
Education and Information Technologies	2	Q2	2,8	Educational information, technology
Others (12 journals)	9	Q1-Q3	1,5-4,5	Various
Total	27	-	-	-

Keyword Co-occurrence Analysis

Keyword co-occurrence analysis using VOSviewer identified 156 unique terms, which, after a filtering process with a threshold of at least two occurrences, left 43 significant keywords divided into four main thematic clusters. Cluster 1 (red) focuses on effectiveness and learning outcomes with an emphasis on learning outcomes and academic achievement, reflecting research priorities in evaluating the cognitive, affective, and psychomotor impacts of AR use. Cluster 2 (green) highlights aspects of student motivation and engagement, while Cluster 3 (blue) emphasizes AR integration through pedagogical strategies based on inquiry-based learning and the development of critical thinking skills. Finally, Cluster 4 (yellow) explores the potential of AR in supporting personalized and adaptive learning tailored to individual student needs. These four clusters holistically depict the landscape of AR research in science learning that is not only oriented towards academic achievement, but also towards transforming learning experiences into more meaningful and inclusive ones.

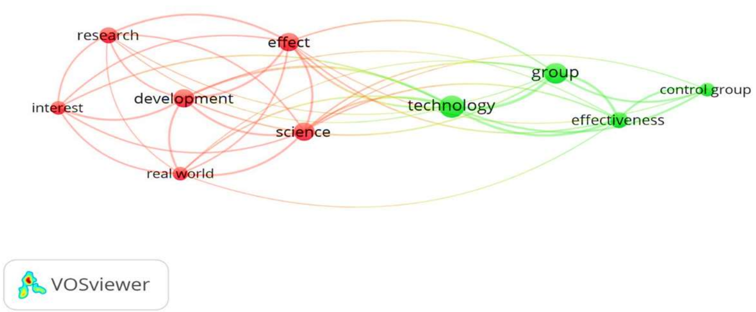

Figure 5. VOSviewer Network Visualization - Keyword Co-occurrence

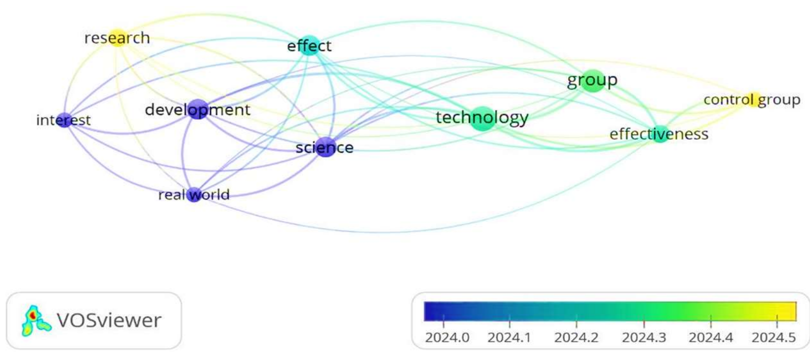

Figure 6. VOSviewer Overlay Visualization - Temporal Evolution

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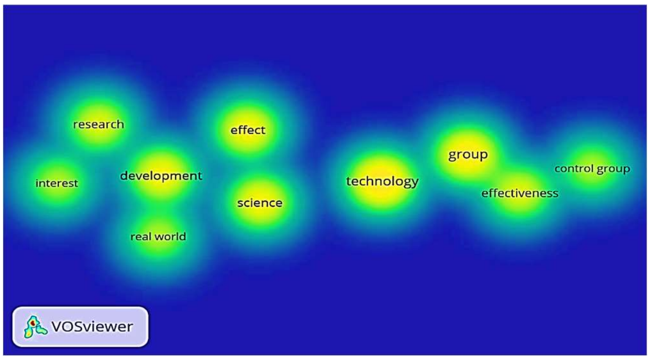

Figure 7. VOSviewer Density Visualization - Theme Density

37 **Table 5.** Most Frequently Appearing Keywords and Link Strength

Rank	Keywords	Occurrence	Total Link Strength	Cluster
1	Augmented reality	27	156	- (central)
2	Elementary school	23	142	- (central)
3	Science education	20	128	- (central)
4	Learning outcomes	12	78	Cluster 1 (Red)
5	Motivation	11	71	Cluster 2 (Green)
6	Engagement	9	65	Cluster 2 (Green)
7	Academic achievement	8	58	Cluster 1 (Red)
8	Inquiry-based learning	8	54	Cluster 3 (Blue)
9	Effectiveness	7	49	Cluster 1 (Red)
10	Interest	7	47	Cluster 2 (Green)
11	Scientific inquiry	6	43	Cluster 3 (Blue)
12	Student performance	6	41	Cluster 1 (Red)
13	Attitude	6	39	Cluster 2 (Green)
14	Personalized learning	5	36	Cluster 4 (Yellow)
15	Problem-solving	5	34	Cluster 3 (Blue)

The co-occurrence analysis results in Table 5 show an intellectual mapping divided into several main focuses with three consistent central nodes: "Augmented reality," "Elementary school," and "Science education." The first cluster (red) highlights the importance of thinking and assessment, using terms like "learning outcomes" and "academic achievement," showing that researchers are focused on how well technology helps students understand and perform. Meanwhile, the second cluster (green) demonstrates a shift in research toward psychology, emphasizing motivation,
18 engagement, and interest, positioning AR as an emotional catalyst for creating a more enjoyable and transformative science learning experience for students.

In terms of methodology and future trends, the third cluster (blue) identifies a strong integration between AR and the discovery learning model through the dominance of
25 "inquiry-based learning" and the development of critical thinking skills in problem-solving. The presence of the fourth cluster (yellow), regarding "personalized learning," signals a future research direction oriented toward differentiated learning tailored to individual student needs. Overall, the high strength of the relationship (Total Link Strength) in the main parameters of this study proves the existence of a systematic correlation that has gone beyond the mere use of technical tools but has touched on

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meaningful pedagogical aspects and profound psychological impacts in order to achieve optimal learning outcomes in elementary schools.

Discussion

The Development of AR Research in Elementary School IPAS Learning

An examination of publication trends indicates a steady increase in Augmented Reality (AR) research for elementary IPAS education, with a notable acceleration since 2020. This phenomenon is theoretically driven by the demands of digital transformation in the education sector in response to the COVID-19 pandemic, which forced institutions to adopt interactive distance learning solutions. In this context, AR offers an immersive experience that overcomes the physical limitations of traditional laboratories, making it a viable alternative for adaptive and resilient hands-on science learning.

Empirically, these findings align with previous studies showing that the use of AR-based virtual laboratories can facilitate conceptual understanding comparable to physical experiments, but with the advantage of spatial and temporal flexibility (Meronda et al., 2025). This is supported by cognitive load theory, which states that 3D visualizations in AR help early learners integrate abstract information more effectively without overloading their cognitive capacities (Buchner et al., 2022; Elford et al., 2022). Thus, the post-2020 research surge is not simply a situational response but rather a reflection of a paradigm shift toward more resilient digital pedagogy.

The democratization of AR technology, through frameworks like ARCore and no-code platforms like Assemblr EDU, has been a major catalyst in reducing technical barriers for educators. Referring to Rogers' Diffusion of Innovation Theory, AR technology in the education sector has now passed the innovator phase and entered the early majority phase, marked by a shift in research focus from small-scale pilot studies to large-scale systematic implementation (Abdul Waheed & Panneerselvam, 2025). Research consolidation in the 2022–2023 period indicates that academic discourse has shifted from simply testing general effectiveness to deeper optimization and contextualization, encompassing variables ranging from students' cognitive learning styles to the complexity of IPAS content.

Thematic Focus of Research

Co-occurrence analysis confirms that scientific discourse on augmented reality (AR) in IPAS learning in elementary schools focuses on four crucial domains: instructional effectiveness, motivation, inquiry approach, and personalization. Findings indicate that AR effectiveness is not uniform but rather relies heavily on instructional design that goes beyond mere aesthetics (wow factor) (Chang et al., 2019). AR implementation achieves maximum efficacy when integrated with strong pedagogical scaffolding, focusing on content with a high level of abstraction that is difficult to visualize with conventional media and combined with structured teacher guidance and reflective discussion activities.

From an emotional standpoint, the group of factors related to motivation and engagement consistently shows that students have more internal motivation and positive

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feelings about science, which can be explained by self-determination theory (SDT) (Chiu, 2024; Englund et al., 2023). AR implementation fulfills three basic psychological needs of learners: autonomy in information exploration, competence through instant feedback that enhances self-efficacy, and connectedness through collaborative activities. However, this study also identified a novelty effect, where high initial motivation tends to decline with repeated use of the technology. To maintain long-term pedagogical effectiveness, we need to implement strategies for content diversification, integrate gamification elements, and emphasize meaningful learning.

In the methodology domain, AR has proven to be an ideal environment for facilitating cycles of inquiry and serving as a safe "virtual laboratory" for complex experiments that would be impossible in the real world. Additionally, AR can better support different learning styles by using artificial intelligence (AI) to change the difficulty and format based on each student's needs. Interestingly, students with low spatial abilities reported significantly greater benefits than those with high abilities, indicating AR's significant potential for reducing academic achievement gaps. Although its implementation still faces substantial challenges related to infrastructure and student data privacy.

Collaboration Patterns and Geographic Distribution

The interdisciplinary nature of Augmented Reality (AR) research is strongly reflected in the collaboration pattern involving 67% of multidisciplinary teams, consisting of educational technologists, subject matter experts, psychologists, and field practitioners. This synergy facilitates the translation of theoretical study findings into more adaptive and applicable instructional practices. This is reinforced by the research-practice partnership model used in 72% of the articles, where schools provide authentic implementation contexts while universities provide methodological expertise and technological access. This cross-institutional collaboration ensures that the AR innovations developed are not only technically cutting-edge but also relevant to pedagogical needs in the classroom.

The dominance of publications from Asian countries, such as Taiwan, China, and Indonesia, is influenced by several strategic contextual factors, including supportive government policies through large-scale research funding and massive mobile infrastructure penetration. The region's centralized curriculum systems allow for systematic AR implementation, while local collectivist cultures align with AR activity designs that emphasize social interaction and collaborative learning. In contrast, Western countries' contributions tend to be more limited due to a more conservative approach of waiting for long-term evidence of efficacy before mass investment, as well as a shift in research priorities to other immersive technologies such as virtual reality (VR) and artificial intelligence (AI).

4. CONCLUSION

This study presents a comprehensive overview of the scientific landscape of augmented reality (AR) in IPAS learning in elementary schools through a bibliometric

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analysis of reputable literature from 2018 to 2025. Key findings indicate consistent research growth with significant acceleration post-2020, fueled by the dynamics of the pandemic, the democratization of technology, and shifts in the adoption phase of educational innovations. The research focus is systematically divided into four central domains: the effectiveness of learning outcomes, strengthening motivation and engagement, integrating inquiry approaches, and personalized instruction. Interdisciplinary and cross-institutional collaboration, particularly the dominance of productivity from the Asian region, reflects the synergy between supportive government policies, digital infrastructure readiness, and national research priorities aligned with the demands of 21st-century pedagogical transformation.

Despite the positive trends, this study identified several critical research gaps, particularly related to longitudinal study design, exploration of the psychomotor domain, holistic science-social studies integration, and issues of accessibility and equity in marginalized areas. Successful AR implementation requires measurable pedagogical integration, where technology serves as an accelerator of science inquiry activities supported by adaptive teacher competencies. As an academic contribution, this synthesis not only maps the current direction of the literature but also provides a strategic framework and practical recommendations for researchers and practitioners to optimize the potential of AR in creating more immersive, inclusive, and future-oriented IPAS learning experiences.

As a recommendation, future research should focus not only on short-term impacts (novelty effects) but also begin conducting longitudinal studies to observe the consistency of improvements in student learning outcomes and memory retention over a period of one year or more. Given that the Indonesian IPAS curriculum combines natural and social sciences, there is a significant opportunity to examine how AR can visualize sociocultural or historical phenomena (such as simulating historical sites or economic processes) to create a more cohesive integration of the material. Furthermore, in-depth studies are needed to examine the effectiveness of AR in schools in rural areas or with limited infrastructure. Research on the use of low-cost AR or offline applications is crucial to ensure this technology does not widen the digital divide.

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