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Research Trend on Augmented Reality (AR) in Education Using Bibliometric Analysis with VOSviewer

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ABSTRACT

The rapid penetration of Augmented Reality (AR) technology in various crucial sectors demands a comprehensive mapping of emerging research trends, particularly in the educational context. This study aims to identify and visualize key clusters and shifts in the focus of AR research in education through bibliometric analysis. The research method used was descriptive qualitative, analyzing 1,832 articles from the ScienceDirect database for the 2022–2026 period using VOSviewer software. The analysis revealed three dominant clusters encompassing technical aspects, pedagogical implementation, and user psychology, with the keywords "student" and "system" having the highest centrality. These findings indicate a significant transition from system foundation development in 2023 to more rigorous experimental and simulation methodologies in mid-2024. While the education sector remains a key laboratory for AR testing, the emergence of new nodes such as "patient" suggests potential future diversification into the medical field. Based on these findings, it is recommended that further research further integrate technical reliability with user psychology to create an inclusive digital ecosystem. Multidisciplinary collaboration between engineers, educators, and behavioral experts is key to driving the sustainable mass adoption of this immersive technology.

Keywords: Augmented Reality, Bibliometrics, VOSviewer, Research Trends, Education.

INTRODUCTION

The educational landscape has undergone a fundamental transformation over the past two decades thanks to the rapid advancement of digital technology. A meta-analysis of thousands of research papers shows that the introduction of mobile devices such as smartphones has triggered a major shift toward more interactive, mobile, and media-rich learning (Sengul et al., 2026; Wiesing et al., 2026; Yuan et al., 2026). Amidst this change, many laboratories in higher education face pressure to provide authentic, hands-on experiences that remain safe, equitable, and cost-effective (Taz & Rao, 2026). This situation has driven the need for new technological approaches that maintain the pedagogical benefits of physical laboratories while reducing barriers to access for learners (Grigore & Octavian Turcu, 2026). Augmented Reality (AR) has emerged as a promising technology capable of presenting digital content in real time within the user's physical worldview. Unlike fully immersive virtual reality (VR), AR can run on commodity mobile devices and support situated learning by adding labels, animations, and procedural instructions to real-world artifacts (Samsudin et al., 2026). From a process design perspective, AR has the key advantage of making abstract phenomena, such as airflow fields or thermodynamic forces, more visible, and providing timely scaffolding for complex procedures (Y. Liu et al., 2026). Based on bibliometric analysis using the Scopus database (2018–2025), research on AR integration in science education shows a significant global growth trend with an annual growth rate of 57.46% (De Bruyne et al., 2026; De Witte et al., 2026). This sharp increase is particularly evident post-COVID-19 pandemic, where the need for immersive and adaptive digital learning solutions has become a top priority for educational institutions worldwide. International publications in this field are dominated by contributions from countries with significant research capacity, such as China, India, and the United Kingdom (Collins et al., 2026). Network mapping using bibliometric software such as VOSviewer identifies three main intellectual clusters in the current literature: scientific literacy, AI-AR integration-based learning, and strengthening scientific reasoning in digital environments. Keyword co-occurrence analysis shows that augmented reality occupies a central position as a bridge connecting various domains, from engineering education to health literacy (Chan et al., 2026). This reflects the development of AR research into a multidisciplinary field involving cognitive psychology and human-computer interaction design (Salvia et al., 2026).

The application of AR in engineering and science education offers a tangible solution to time constraints and expensive physical laboratory access (Khandia et al., 2026). For example, the development of AR Tunnel into a digital twin of a university wind tunnel allows students to practice procedures and visualize airflow before face-to-face sessions. The integration of AR into thermodynamics has also been shown to enhance students' critical thinking skills through interactive visualizations that bridge the gap between symbolic equations and physical reality phenomena. In addition to conceptual mastery, the integration of AR with ethnoscience elements (such as the local tradition of Karapan Sapi in physics) has been shown to significantly enhance students' creativity and motivation to learn. Through culturally relevant virtual simulations, students can explore Newton's laws in a more meaningful and authentic way. AR-based experiential learning approaches (such as the EDMV-AR model) have also demonstrated advantages in improving academic performance and learner autonomy compared to traditional teaching methods. However, bibliometric analysis also reveals several technical and pedagogical challenges that must be overcome, including the uneven distribution of digital infrastructure and the high cost of devices. Positioning (GPS) accuracy issues and visual impairments are frequently reported as major barriers to the use of location-based AR outdoors. Furthermore, the "novelty effect" raises concerns that student interest may be fleeting and not based on sustainable educational value. In conclusion, the systematic integration of hybrid AI, AR, and scientific literacy is crucial for achieving the Sustainable Development Goals (SDGs), particularly in providing quality education. While AR technology offers significant potential for enhancing engagement and conceptual understanding, its long-term value depends largely on how well it aligns with established pedagogical practices. Cross-disciplinary collaboration between technology developers and educators is necessary to build an inclusive, safe, and transformative learning ecosystem for the future.

Bibliometric analysis has several benefits. One of these is the ability to identify research topics that are constantly evolving (Manning et al., 2026). Despite this, researchers may identify businesses that have a lot of potential for growth. Bibliografi can also help prevent duplication of research (J. Li et al., 2026). This is very important for increasing research efficiency. In addition, the use of bibliometrics makes it possible to identify researchers or organisations with significant impact. This data can be used for collaborative research. As a result, bibliometric analysis becomes strategic (Bayus et al., 2026). This is especially true in industries like data mining that are seeing rapid growth. Bibliometric analysis analysis, a tool that can effectively analyse and visualise data is required (Botchwey et al., 2026). VOSviewer is a widely used program for creating and visualising bibliometric networks. This program may provide visual aids that illustrate the relationship between writing, language, and publication. This visualisation facilitates the interpretation of complex data (Zhang et al., 2026). Additionally, VOSviewer has the ability to group research topics. This makes it possible to identify the main topics in the current bidang. As a result, VOSviewer is an extremely useful tool for bibliometric research and graph mapping in Augmented Reality (AR) research.

RESEARCH METHOD

This research uses descriptive qualitative research with a bibliometric approach to convey the results of review of journal articles. The data search method was carried out using PoP software with the main Sciencedirect database and analyzed using the VOSviewer application (Yustiarini et al., 2025). A systematic literature review on was conducted in January 2022 - April 2026 using the keywords “Data Mining”. The process involved five key stages. First, keyword determination was carried out using Google Scholar, supported by PoP software, to search for journal articles published between Januari 2022 - April 2026, yielding 1,832 articles stored in RIS format, containing essential bibliographic information. Second, the initial search results were refined by filtering data based on study topics and ensuring only journal articles were included, which were then transferred to Mendeley for enhancement (Kiani et al., 2026; Orús et al., 2026; Sekhri et al., 2026; Sharma et al., 2026). Third, a thorough validation process was conducted to check the completeness and quality of the articles, ensuring the inclusion of relevant and high-quality literature, resulting in a final dataset of 1,832 articles. Fourth, statistical data compilation was performed in Mendeley to ensure all bibliographic details, such as publication year, volume, and page numbers, were complete and accurate. Finally, bibliometric network analysis and visualization were conducted using VOSviewer software, enabling the creation of network maps that revealed literature clusters, historical connections, and potential research opportunities within the field. This structured approach ensured a focused and reliable analysis of the topic (Yang et al., 2026). Data collection used a purposive method; the data were selected based on the special characteristics determined by the researcher (Hidajat, 2026) so that data relevant to the research topic was obtained. This research was adapted from (Utami & Astutik, 2025) through 5 stages. The process of data analysis for bibliometric analysis in research uses co-occurrence analysis as a description of the conceptual structure or knowledge from the literature and analysis based on keywords to see the development of research and the development of visualized data(Huang et al., 2026). Bibliometric data analysis techniques can be seen in the following flowchart in Figure 1.

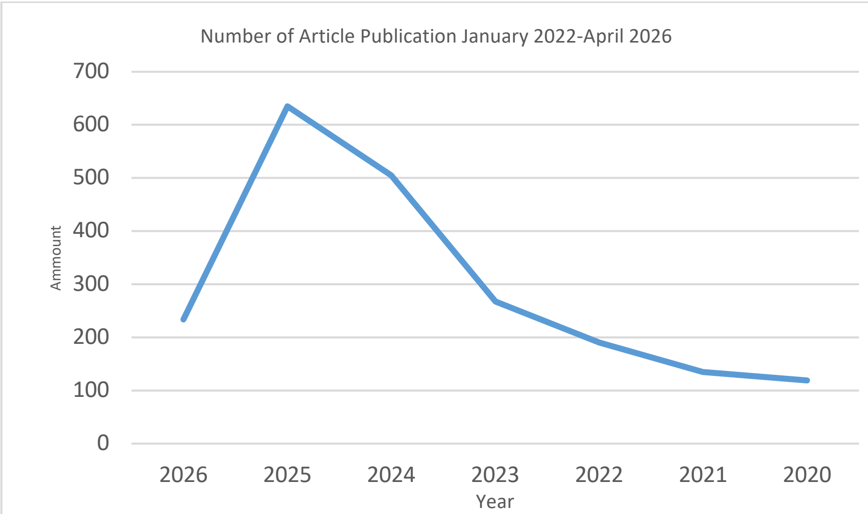

Figure 1. Article publication data Jan 2022-April 2026

RESULTS AND DISCUSSION

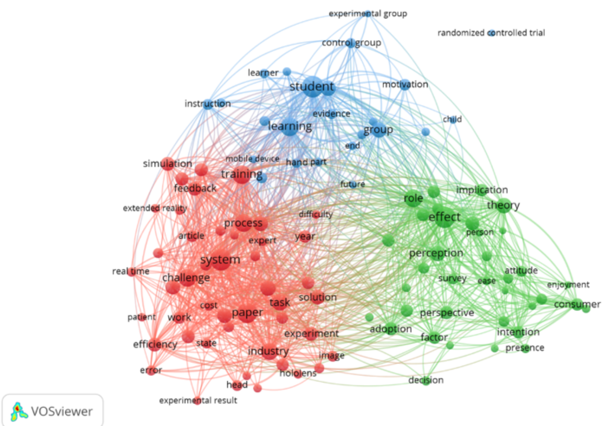

Figure 2. Visualization topic area using VOSviewer using network visualization

Based on the network visualization generated using VOSviewer software, three main clusters dominate the Augmented Reality (AR) research map (Emma, 2026). The first cluster, marked in red, is the largest group, focusing on technical aspects, systems, and industrial implementation (Al-Hamad & Gilányi, 2026). Within this cluster, keywords such as "system," "process," and "training" emerge as significant nodes, indicating that AR infrastructure development remains a primary concern for researchers. Furthermore, there is a strong emphasis on the use of AR for simulation purposes and work efficiency across various industrial sectors (Arya, 2026). The relationships between nodes in this red cluster are very close, reflecting the close integration between development systems and functional feedback. Research in this group is also beginning to explore the concept of extended reality and the use of specific hardware such as HoloLens. Overall, the red cluster illustrates the technical and operational background that supports the sustainability of AR technology in the field. The second cluster, represented in blue, specifically highlights the application of Augmented Reality in education and learning contexts. Dominant nodes such as "student," "learning," and "motivation" indicate that researchers' primary focus is on how AR can improve pedagogical quality (Messina et al., 2026). Many studies in this cluster use a quantitative approach, as evidenced by the terms "experimental group," "control group," and "randomized controlled trial." This indicates a systematic effort to prove the effectiveness of AR as a processing tool through empirical testing. In addition to focusing on learning outcomes, the blue cluster also considers students' psychological factors, particularly their motivational drive during interactions with digital content. The link between the "instruction" and "learner" nodes emphasizes that AR is viewed not merely as a visual aid but as a comprehensive learning strategy (Busse et al., 2026). Thus, the blue cluster represents the humanities and human resource development aspects of the AR ecosystem (Su et al., 2026).

The third cluster, green, focuses on the psychological dimensions of users, perceptions, and technology adoption theories. Nodes such as "effect," "perception," and "role" are central to the discussion, linking user experience to behavioral theories. Researchers in this cluster frequently explore how "consumers," or end-users, perceive AR technology based on factors such as "enjoyment" and "presence." Technology use theories are often used to analyze users' intentions or "intentions" in adopting AR devices in everyday life. Furthermore, attitude is a crucial variable in determining the success of AR implementations outside of academic settings. The relationship between the green and red clusters suggests that the success of a technical system depends heavily on how people perceive its ease of use and benefits. This cluster effectively bridges the gap between technological capabilities and subjective user experience. Further analysis of node density reveals that the keywords "system" and "student" have high centrality in this research network. This indicates that current discussions about Augmented Reality remain divided between technological refinement and its application in the classroom. Despite the differences in cluster color, the connecting lines or links between them indicate strong multidisciplinary integration. For example, the "training" node in the red cluster frequently connects with the "learning" node in the blue cluster, signifying the intersection between industrial training and formal education. The challenges or "challenges" emerging at the center of the research map also serve as a meeting point for all clusters to find innovative solutions. This map demonstrates that AR is no longer a standalone technology, but rather an ecosystem involving technicians, educators, and behavioral experts. This integration is key to AR's future development, ensuring it remains relevant to market and user needs.

Interestingly, several smaller nodes are beginning to emerge on the periphery of the network, such as "patient" and "image," indicating AR's expansion into the medical field.

While not yet independent clusters, the emergence of these terms suggests the potential for future diversification of AR research. The focus on "efficiency" and "error" within the technical cluster also signals that researchers are shifting from simply creating technology to optimizing performance. The issue of cost, which appears near the red cluster, also serves as a reminder of the economic barriers that still need to be overcome in urban centers. Methodologically, the use of questionnaires or "surveys" remains a popular data collection tool for evaluating AR impact. Thus, this visualization not only presents current trends but also maps out the wide-open research opportunities for future researchers. In conclusion, the VOSviewer results demonstrate that the Augmented Reality research roadmap is highly dynamic and encompasses a very broad spectrum. The dominance of the education cluster indicates that schools and universities are the primary laboratories for testing this technology before its mass adoption. On the other hand, the emphasis on the industry cluster reminds us of the importance of system reliability and precise simulation capabilities (Stålberg et al., 2026; Walkington et al., 2026). User behavior in the green cluster serves as a critical filter that determines whether an AR innovation will be sustainable or merely a passing fad. The synergy between system development, learning effectiveness, and user acceptance will continue to be a key focus in the scientific literature on AR. Going forward, it is hoped that more research will emerge that can integrate these three dimensions in a balanced manner to create a more inclusive digital ecosystem.

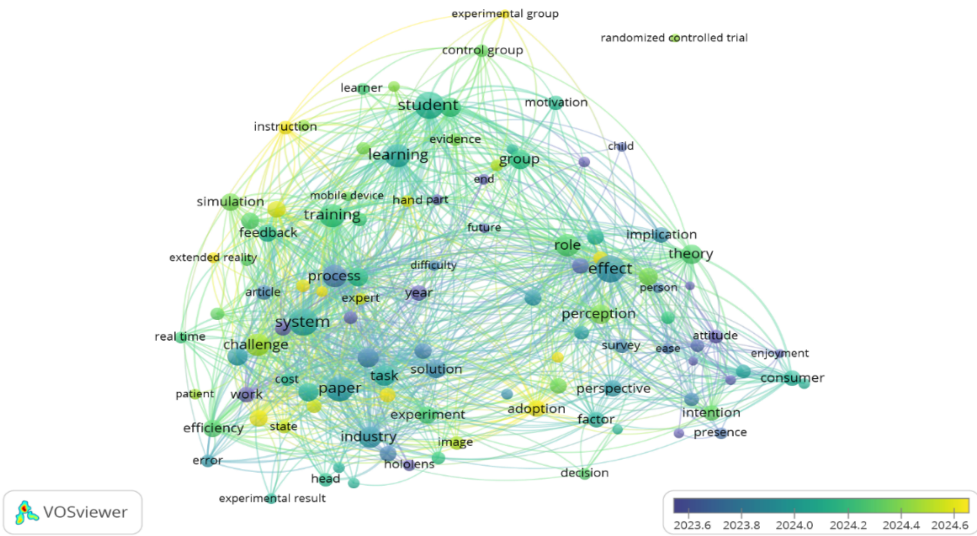

Figure 3. Visualization topic area using VOSviewer using overlay visualization

The VOSviewer overlay visualization shows a significant shift in Augmented Reality (AR) research trends from 2023 to mid-2024 (Ding et al., 2026). Initially, research focused primarily on system foundations and basic processes, represented by dark purple nodes. Over time, the research focus shifted toward practical applications and user evaluation, characterized by the dominant green color (Komolafe et al., 2026). Recent trends emerging in mid-2024 show a strong focus on advanced experimental and simulation methodologies (Longo et al., 2026). The bright yellow color on the map indicates that topics such as extended reality and system feedback are currently trending (Z. Liu et al., 2026). This indicates that AR technology has moved beyond mere technical concepts to more scalable and applicable implementations (Jain et al., 2026). Researchers are now more interested in exploring the effectiveness of AR use in various real-life scenarios in depth. Overall, this map depicts a highly dynamic research ecosystem that continues to evolve toward higher scientific maturity (Eom et al., 2026). The education sector has emerged as a key pillar in the AR literature, with significantly large "student" and "learning" nodes. Although this topic has been researched since its inception, its intensity remained high, reaching a peak in 2024. The primary focus in this cluster is how AR can increase student motivation and engagement in classroom learning (Mansoor et al., 2026). The emergence of the keyword "instruction" in yellow indicates new innovations in more interactive digital content delivery strategies. Educational research now looks not only at learning outcomes but also at the instructional process supported by immersive technology. The relationship between the "student" and "group" nodes indicates that AR-based collaborative learning is a rising trend (Gül et al., 2026). Mobile devices remain the primary means of accessing AR content in academic settings, demonstrating that AR has significant potential to transform traditional education into a more engaging learning experience (Böhmer et al., 2026; Park et al., 2026).

One of the most striking findings in the latest visualization is the strengthening of rigorous experimental research methodology (Kim, 2026). Keywords such as "experimental group" and "control group" dominate the bright yellow spectrum at the top of the network map (Atoum et al., 2026). This trend indicates that the research community is striving to prove the validity of AR through more objective scientific testing (Bai et al., 2026). The use of randomized controlled trials (RCTs) signals that AR research standards are now on par with those in medicine or other pure sciences (Amadita et al., 2026). Researchers no longer simply report qualitative descriptions but instead seek robust empirical evidence through comparisons between groups of subjects (Movassaghi et al., 2026). A focus on gathering "evidence" has become the core of recent publications published throughout 2024. This shift is crucial for increasing stakeholder confidence in the broad efficacy of AR technology across various sectors of life (Wibowo et al., 2026). Thus, the quality of current AR literature demonstrates a much higher level of methodological maturity than in previous years. In industry, the research focus has shifted from "system" development to the more specific concepts of "training" and simulation (Rodrigo et al., 2026). The yellowish-green "training" node indicates that AR-based workforce training is a highly relevant and pressing topic (Roodposhti & Esmaeelbeigi, 2026). Simulation implementation is widely used to minimize work errors, or "errors," that frequently occur in complex manual procedures (Zaragoza et al., 2026). The presence of a "feedback" node demonstrates the importance of real-time feedback for users in improving their operational efficiency and accuracy (Anđić et al., 2026). The use of sophisticated devices like HoloLens is increasingly being discussed in the literature as a dominant primary tool in the industrial sector (Xu, 2026). The association between "industry" and "safety" suggests that occupational safety is a primary motivation behind the use of this AR technology (Haryadi et al., 2026). This technology is considered capable of simplifying complex tasks through intuitive holographic guidance for workers. Research in this area continues to develop, seeking solutions to the cost and technical complexity challenges still encountered in the field (Jita & Shambare, 2026; Rikard et al., 2026).

The psychological dimension of users remains an integral part of AR research, particularly regarding perceptions and intentions use of the technology (Cascone et al., 2026). The "perception," "attitude," and "intention" nodes form the bridge between technological capabilities and the level of human acceptance in society at large (Nan et al., 2026). The "enjoyment" factor has been found to be a key variable determining whether consumers will continue to use AR applications in the long term (Srivastava et al., 2026). Research on the sense of presence in virtual worlds is an important foundation for developing more authentic user experiences (Guo et al., 2026). Consumers are now seen as active subjects in assessing the utility and ease of use of AR technology in their daily lives (Ortova et al., 2026). Technology adoption theory continues to be used by researchers to analyze user behavior towards various emerging digital innovations (Chen et al., 2026). The challenges in adopting this technology have also emerged as a point of concern that is often discussed in depth by experts (O'Nascimento et al., 2026). Understanding this humanistic side is crucial for the development of technical systems to remain aligned with human psychological needs, comfort, and expectations (Rodriguez-Florido et al., 2026). Looking ahead, this visualization signals a convergence towards the concept of Extended Reality (XR), which combines various immersive technologies simultaneously (Ortega et al., 2026). The emergence of the "patient" node indicates that the healthcare sector is beginning to see the great potential of AR for therapy and certain medical procedures (Y. Li & Sahari, 2026). Despite its relatively small size, this health topic shows a very promising direction for future research diversification. Integrating physical and digital elements in real time will continue to be both a technical challenge and a research opportunity (Belfadel et al., 2026). Researchers are also beginning to pay attention to the long-term impact of AR use on specific groups, such as children, in social contexts (Alex et al., 2026). This map shows that AR is no longer an isolated technology, but rather part of a larger global digital revolution. Aligning technical developments with robust research methodologies will accelerate the mass adoption of this technology across various fields (Çiçek & Özoğlu, 2026). The results of this VOSviewer analysis provide strategic guidance for researchers in selecting topics that still possess a high degree of novelty (Khoury et al., 2026; W. Liu et al., 2026).

Figure 4. Visualization topic area using VOSviewer using overlay visualization

The density visualization shows the concentration of the most researched key topics in the field of Augmented Reality (AR). Bright yellow indicates areas of high density, meaning these terms appear highly frequently in the scientific literature. Three main centers of gravity shape the global AR research map in this dataset. The keywords "student," "system," and "effect" stand out as the main hotspots with the brightest light. Green areas surrounding these centers indicate supporting topics that complement the main discussion in each cluster. Conversely, areas of blue or dark purple indicate topics that are still rarely explored or have weak connections. This map effectively illustrates the balance between technical research, education, and psychological impact on users. This density structure reflects the scientific community's priorities in developing AR technology over the past few years. The education cluster at the top of the map demonstrates AR's massive impact in academia. The terms "student" and "learning" are the central focus, surrounded by supporting topics such as "instruction" and "learner." The high density in this area demonstrates that AR-based learning experiments are the most established research trend. Researchers are exploring how this immersive technology can enhance students' understanding of abstract concepts. Despite its strong focus, the terms "motivation" and "child" have a slightly lower density at the periphery of the cluster. This suggests that research is still dominated by general learning effectiveness rather than specific psychological variables. The relationship between "learning" and "evidence" also appears quite dense, indicating a strong effort to validate results. Education remains a primary laboratory for testing AR prototypes before large-scale commercial implementation.

In the bottom left, a technical cluster focuses on system development, processes, and industrial implementation. The keywords "system" and "challenge" emerge as dense points, indicating intense discussion of technical challenges. The term "training" also shines brightly, indicating that the use of AR for job training is of high interest in industry. Researchers appear to be grappling with how to integrate AR systems into existing professional workflows. Around this area, the terms "paper" and "work" also appear, indicating that many publications address the operational side. However, topics like "efficiency" and "error" are in the greener areas, indicating that research in this area is not as dense as that of the underlying system. Technical challenges include hardware and software, as well as cost, which remains a barrier. The focus on "process" suggests that AR integration requires fundamental changes in how tasks are completed manually. The cluster on the right side of the map is dominated by the keywords "effect" and "perception," representing the human side of technology. The density in this area is highly concentrated on how humans perceive and react to the use of AR technology. The terms "role" and "theory" surround the center of this cluster, indicating a strong theoretical framework in impact analysis. Research on "adoption" or technology adoption also emerged as an important area, although its density is slightly lower than the education cluster. End-users, or "consumers," are the primary subjects studied through various methods such as surveys or questionnaires. The focus on "enjoyment" and "presence" suggests that the user experience aspect is key to the success of AR applications. Scientists are trying to understand whether the feeling of being "present" in a virtual world significantly influences users' intention to reuse it. This cluster effectively balances the dominance of technical research with in-depth behavioral and social psychology perspectives.

While the map is filled with hotspots, there are several terms on the periphery that indicate future research opportunities. The terms "randomized controlled trial" and "experimental group" appear at the very top with very low density. This indicates that while experimental methods are beginning to be used, they are not yet as frequently used as descriptive research or systems development. Similarly, the term "patient" on the left side indicates that AR medical applications remain an underdeveloped field. "HoloLens" as a specific device is also beginning to emerge. However, it has not yet formed a dominant hotspot. This density gap provides clues for new researchers to fill the remaining gaps in the literature map. The large green areas between clusters indicate that multidisciplinary integration still has much potential to be explored. Each gap between the bright spots represents the possibility of new innovations that can connect technology with human needs. Overall, this VOSviewer density visualization provides a comprehensive overview of the current Augmented Reality research roadmap. The dominance of yellow dots in the education and basic systems sectors indicates that AR is still in the maturation stage of infrastructure and pedagogy. However, the significant density in the impact cluster indicates that attention to user experience is starting to become a top priority. Researchers are now focusing not only on how AR works but also on how the technology affects human behavior. This map shows that AR research has developed into a very mature field with clearly defined clusters. The existence of these hotspots can guide policymaking or future digital product development. The synergy between system reliability and user convenience will be key in driving mass adoption of AR technology. By looking at this density, we can predict that the direction of research will increasingly move towards experimental validation and industrial specialization.

CONCLUSION

Research on the integration of Augmented Reality (AR) in science education shows a rapid global growth trend with an annual increase rate of 57.46%. Bibliometric analysis using VOSviewer identified three main research clusters that dominate the current literature: scientific literacy, AI-AR integration-based learning, and strengthening scientific reasoning in digital environments. Empirically, the implementation of AR technology has been shown to significantly improve students' objective knowledge scores, creativity, and learning motivation compared to traditional teaching methods. AR successfully bridges the gap between abstract theory and physical reality by visualizing invisible phenomena, such as air flow in wind tunnels, the laws of thermodynamics, and interactions between species in ecosystems. Furthermore, the use of location-based AR has been found to increase students' physical activity and the intensity of nature exploration, although these results do not always correlate directly with permanent affective changes towards the environment. These findings have strategic implications for achieving the Sustainable Development Goals (SDGs), particularly in supporting the provision of inclusive and transformative quality education. In the context of engineering and science education, AR serves as an efficient preparation tool, allowing time in physical laboratories to be optimized for hypothesis testing and reflective analysis rather than simply tool orientation. However, the development of this technology still faces several technical and methodological limitations, such as uneven digital infrastructure, low GPS accuracy in outdoor applications, and high hardware procurement costs. There is also the risk of a "novelty effect," where students' interest is feared to be temporary due to the allure of the technology rather than its ongoing educational value. Furthermore, many existing studies rely on small sample sizes and self-reported data, which is susceptible to subjective bias. Looking ahead, it is recommended to strengthen interdisciplinary collaboration between engineers, educators, and behavioral scientists to build a more inclusive and safe digital ecosystem. Future research should focus more on longitudinal studies to measure long-term knowledge retention and begin implementing randomized controlled trials (RCTs) to improve scientific validity standards. With the emergence of new indicators such as "patients" in bibliometric maps, AR research also has significant potential to expand into the medical field and specific industrial training. Overall, aligning technical innovation with established pedagogical practices is key to AR technology making a real and sustainable contribution to education.

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