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Publication Trends and Knowledge Structure of Augmented Reality Research in Sports and Basketball: A Scopus-Based Bibliometric Analysis (2010–2026)

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A B S T R A C T

Augmented Reality (AR) has become an emerging technology for enhancing sports training, performance evaluation, and interactive learning. This study examines publication trends and the knowledge structure of AR research in sports, with particular attention to basketball-related studies. A bibliometric analysis was conducted using 1,040 Scopus-indexed publications (2010–2026) and visualized with VOSviewer. The findings reveal a significant increase in publications after 2021, with Computer Science as the dominant subject area and China and the United States as the leading contributors. Keyword mapping identifies AR as the central research theme, strongly connected with virtual reality, artificial intelligence, and sports performance. However, basketball remains underrepresented, highlighting opportunities for future research on AR-based basketball training and performance systems

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INTRODUCTION

The continuous advancement of digital technologies has substantially transformed the field of sports by introducing innovative approaches to athlete training, performance evaluation, and sports education (Cossich et al., 2023). Among these technological innovations, augmented reality (AR) has emerged as one of the most promising tools because it enables the integration of virtual information with real-world environments, allowing users to interact with digital content in real time (Syed et al, 2022). Unlike conventional training approaches, AR provides immersive learning experiences, immediate visual feedback, and interactive simulations that facilitate skill acquisition, motor learning, tactical understanding, and performance enhancement across various sporting disciplines. Consequently, AR has become an increasingly important component of technology-assisted sports training and athlete development (AlGerafi et al, 2023). Recent developments in artificial intelligence, computer vision, wearable technologies, motion tracking, and human–computer interaction have further accelerated the application of AR in sports. These technological advancements have expanded the utilization of AR beyond simple visualization into more sophisticated applications, including movement analysis, tactical simulation, rehabilitation, injury prevention, coaching assistance, and performance monitoring (Dargan et.al, 2023). The integration of multiple digital technologies has also promoted interdisciplinary collaboration among researchers in sport sciences, computer science, engineering, medicine, psychology, and education, resulting in a rapidly growing body of scientific literature that reflects the expanding role of AR within modern sports ecosystems (Kim et al, 2017; Arena et al, 2022).

The increasing volume of publications demonstrates that AR research has evolved into a multidisciplinary research domain characterized by diverse scientific perspectives and application contexts (Cipresso et al, 2018 ; Wei et al, 2019). Studies have investigated AR implementation in physical education, athlete training, rehabilitation programs, sports medicine, motor learning, and decision-support systems, while emerging technologies such as virtual reality, mixed reality, machine learning, deep learning, and metaverse environments have become increasingly interconnected with AR-based research (Yeung et al, 2021; Kayaalp et al, 2025). Although this diversity has enriched scientific knowledge, it has simultaneously created challenges in understanding the overall development of the field, identifying dominant research themes, and recognizing emerging research directions. Without a systematic evaluation of the existing literature, it remains difficult to obtain a comprehensive understanding of how this research area has evolved over time and where future investigations should be directed. A comprehensive understanding of research development is particularly important because scientific publications have increased considerably during the last decade, accompanied by broader international collaboration and multidisciplinary contributions. The rapid expansion of the literature has produced increasingly complex knowledge networks involving authors, institutions, countries, and research themes. Consequently, researchers require systematic approaches capable of synthesizing large volumes of

bibliographic information while revealing the intellectual structure, collaboration patterns, thematic evolution, and emerging research hotspots that characterize this research field.

Bibliometric analysis has become one of the most effective quantitative approaches for evaluating the development of scientific knowledge through the analysis of publication metadata (Gan et al, 2022; Kumar, 2025). By examining publication growth, subject categories, document characteristics, geographical contributions, collaboration networks, and keyword relationships, bibliometric analysis provides a comprehensive overview of research performance and scientific evolution (Marlés-Sáenz, et al, 2025). Furthermore, science mapping techniques supported by visualization software such as VOSviewer enable researchers to identify thematic clusters, intellectual relationships, and research frontiers that may not be apparent through traditional narrative literature reviews. Therefore, bibliometric analysis represents a robust methodological approach for investigating the development and knowledge structure of AR research within the sports domain (Passas, 2024). Although previous studies have discussed the implementation and effectiveness of augmented reality in specific sports contexts, comprehensive bibliometric investigations that systematically map the global research landscape of AR in sports remain relatively limited (Zhao et al, 2022; Gazali et al, 2026). Existing reviews generally emphasize technological applications or experimental findings, whereas studies examining publication trends, knowledge structures, international collaboration, and thematic evolution across the broader research field are still scarce. Considering the rapid growth of scientific publications over recent years, an updated bibliometric assessment is needed to provide a clearer understanding of the current state of research and to identify future opportunities for scientific development.

Therefore, this study aims to examine the publication trends and knowledge structure of augmented reality research in sports through a bibliometric analysis of Scopus-indexed publications published between 2010 and 2026. Specifically, this study analyzes publication growth, subject area distribution, document types, country contributions, and keyword co-occurrence networks to reveal the intellectual landscape and thematic evolution of AR research in sports. The findings are expected to provide valuable insights into dominant research topics, emerging themes, global research collaboration, and potential research gaps that may serve as a foundation for future investigations and the continued development of technology-assisted sports research.

LITERATURE REVIEW

Augmented Reality in Sports

Augmented Reality (AR) is an interactive technology that integrates computer-generated virtual objects with the real-world environment, enabling users to perceive and interact with digital information without completely disconnecting from their physical surroundings (Dargan et al, 2023). Unlike Virtual Reality (VR), which immerses users in a fully virtual environment, AR enhances real-world experiences by superimposing digital elements such as

three-dimensional objects, text, animations, and visual cues onto the user's field of view (Balushi et al, 2024; Wang et al, 2024). This capability has positioned AR as one of the most influential technologies within the broader spectrum of immersive technologies, particularly in domains requiring real-time interaction and contextual information delivery. In the field of sports, AR has evolved from a visualization tool into an intelligent platform capable of supporting athlete development, coaching, rehabilitation, and performance evaluation (Debarba et al, 2018). Modern AR systems provide real-time movement visualization, biomechanical feedback, tactical simulations, and interactive training scenarios that facilitate motor learning and improve athletes' cognitive and technical skills. By combining digital information with actual sporting environments, AR enables coaches and athletes to evaluate performance more accurately while creating engaging and personalized training experiences (Borgohainet al, 2022; Zhao et al, 2022).

The integration of AR with complementary technologies, including artificial intelligence, computer vision, wearable sensors, motion capture, and Internet of Things (IoT) devices, has further expanded its application across various sports disciplines. Consequently, research concerning AR in sports has become increasingly multidisciplinary, involving contributions from sport science, computer science, engineering, medicine, psychology, education, and rehabilitation sciences (Gazali et al, 2026). The rapid expansion of these interdisciplinary studies has generated an increasingly complex body of scientific knowledge that requires systematic evaluation to understand its development, thematic evolution, and future research opportunities.

Bibliometric Analysis

Bibliometric analysis is a quantitative research approach that evaluates scientific literature through the statistical analysis of bibliographic metadata, including publication records, citations, authorship, affiliations, and keywords (Kumar, 2025). Unlike traditional literature reviews, which primarily synthesize research findings qualitatively, bibliometric analysis provides objective measurements of scientific productivity, collaboration patterns, research impact, and knowledge development within a specific research domain (Passas, 2024). The growing availability of large bibliographic databases such as Scopus and Web of Science has significantly increased the application of bibliometric methods across various scientific disciplines (Gan et al, 2022). Through bibliometric indicators, researchers can examine publication growth, identify influential authors and institutions, determine geographical research distributions, evaluate collaborative relationships, and detect emerging research themes (Marlés-Sáenz et al, 2025). Consequently, bibliometric analysis has become an essential methodological approach for understanding the evolution of scientific knowledge and supporting evidence-based research planning.

Recent developments in science mapping have further enhanced bibliometric analysis by enabling visual exploration of relationships among publications, authors, institutions, countries, and research topics. These visualization techniques facilitate a deeper understanding of intellectual structures and thematic evolution beyond conventional descriptive statistics.

Therefore, bibliometric analysis provides an appropriate framework for investigating the development of augmented reality research in sports over time while revealing the dynamics of global scientific collaboration and thematic expansion (Borgohain et al, 2022).

Knowledge Structure and Science Mapping

Knowledge structure refers to the intellectual organization of scientific knowledge within a particular research field and reflects how concepts, topics, and research communities are interconnected over time (Petrovich, 2021). Rather than examining individual publications independently, knowledge structure analysis investigates the relationships among research themes to reveal dominant topics, emerging areas of investigation, and conceptual linkages that collectively shape the evolution of scientific disciplines (Sharifi et al, 2021). Science mapping is one of the principal approaches used to visualize and interpret knowledge structures (Chen, 2017). By analyzing relationships among keywords, citations, authors, institutions, or countries, science mapping transforms large bibliographic datasets into graphical representations that illustrate the organization and development of scientific knowledge. These visual networks allow researchers to identify thematic clusters, intellectual foundations, collaboration patterns, and emerging research frontiers that may not be readily observable through conventional review methods.

Among the various science mapping techniques, keyword co-occurrence analysis is widely employed to explore conceptual relationships within a research field. Frequently co-occurring keywords indicate common research interests and often form thematic clusters representing distinct scientific domains. As research evolves, changes in keyword networks reflect shifts in scientific attention, technological innovation, and interdisciplinary integration. Consequently, knowledge structure analysis has become an indispensable component of contemporary bibliometric studies seeking to understand research evolution comprehensively.

VOS-viewer for Bibliometric Visualization

VOSviewer is one of the most widely used software applications for constructing and visualizing bibliometric networks (Kirby, 2023). Developed specifically for science mapping, the software enables researchers to analyze relationships among publications, authors, institutions, countries, journals, citations, and keywords through intuitive graphical representations (Moral-Munoz et al, 2019). Its capability to process large bibliographic datasets efficiently has made VOSviewer a standard analytical tool in contemporary bibliometric research. One of the principal strengths of VOSviewer lies in its ability to generate multiple visualization modes, including network visualization, overlay visualization, and density visualization (Bukar et al, 2023). Network visualization illustrates the relationships among research entities through interconnected nodes and links, allowing researchers to identify collaborative networks and thematic clusters (Smyrnova-Trybulska et al 2018). Overlay visualization highlights the temporal evolution of research topics, while density visualization reveals areas of high research concentration and thematic prominence. Together,

these visualization techniques provide comprehensive insights into the intellectual organization and development of a scientific field.

In addition to visual representation, VOSviewer supports several bibliometric analytical techniques, including co-authorship analysis, co-occurrence analysis, citation analysis, bibliographic coupling, and co-citation analysis. In the present study, VOSviewer is employed primarily to perform keyword co-occurrence analysis and country collaboration mapping. These analyses facilitate the identification of dominant research themes, conceptual relationships, and international collaboration patterns within augmented reality research in sports, thereby providing a comprehensive understanding of the field's knowledge structure and research evolution.

Research Framework

Since this study adopts a descriptive bibliometric approach, it does not test causal relationships among variables or formulate statistical hypotheses. Instead, the study is guided by a conceptual research framework that describes the sequential stages of bibliometric analysis, beginning with literature retrieval and ending with knowledge mapping and interpretation.

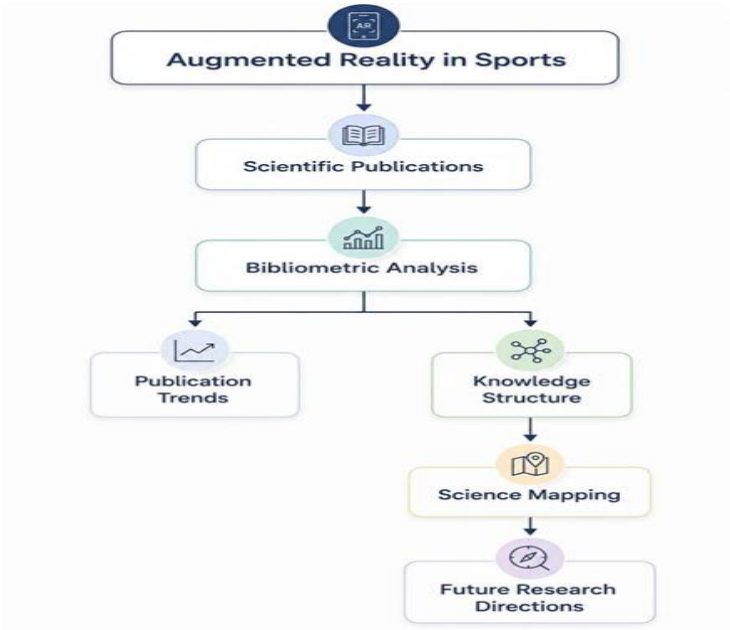

Figure 1. Research Framework

METHODOLOGY

This study employed a bibliometric approach to systematically examine the publication trends and knowledge structure of augmented reality (AR) research in sports during the period 2010–2026. Bibliometric analysis is widely recognized as an effective quantitative method for evaluating the development of scientific knowledge through the analysis of publication metadata, enabling researchers to identify research growth, thematic evolution, collaboration networks, and emerging research topics (Marlés-Sáenz et al, 2025). The analysis was conducted using the Scopus database because of its broad coverage of peer-reviewed international publications across multiple disciplines, standardized

indexing system, and comprehensive bibliographic metadata suitable for science mapping and bibliometric investigations.

The literature search was conducted directly in the Scopus database using a structured search strategy based on the principal concepts investigated in this study. The search employed the following keywords:

"Augmented Reality" AND "Sport" AND "Basketball" AND "Performance System"

The search strategy was designed to retrieve publications addressing the application of augmented reality within sports-related contexts while maintaining relevance to athlete performance, sports training, and performance-support technologies. The selected keywords represent the primary concepts of this study and were determined after preliminary exploration of the Scopus database to ensure adequate coverage and relevance of the retrieved literature. The search process was completed in April 2026. To ensure the quality and relevance of the bibliometric dataset, a document screening procedure was conducted following predefined inclusion and exclusion criteria. The initial search identified 1,054 publications. Subsequently, document types considered unsuitable for bibliometric mapping, including retracted documents, short surveys, and editorials, were excluded from the analysis. Following the screening process, a final dataset comprising 1,040 publications was retained for subsequent bibliometric analysis. The document selection procedure is illustrated in the figure 2.

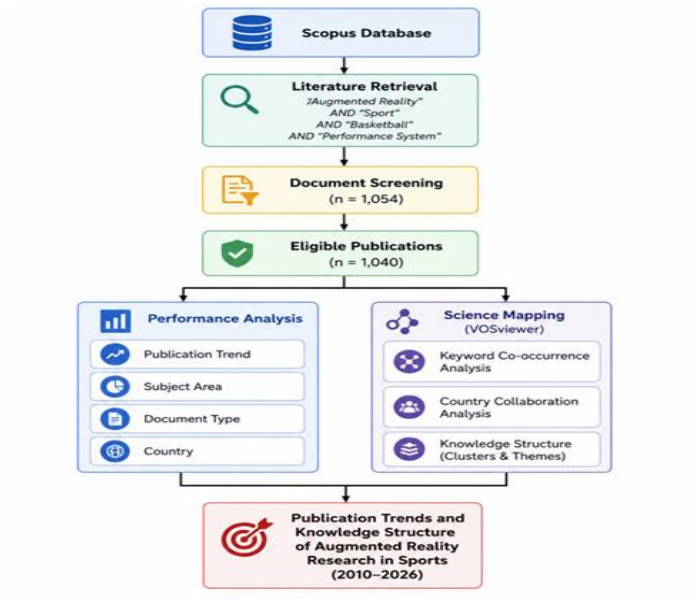

Figure 2. Study Workflow

The bibliometric analysis focused on several publication characteristics to provide a comprehensive overview of the research landscape. Descriptive analyses were performed to examine annual publication trends, subject area distribution, document types, and country or regional contributions. These analyses provide insights into the growth and disciplinary characteristics of AR research in sports while highlighting geographical patterns of scientific

productivity. To explore the intellectual structure of the research field, science mapping analysis was conducted using VOSviewer. Keyword co-occurrence analysis was employed to identify dominant research themes, thematic clusters, and conceptual relationships among research topics. In addition, country collaboration analysis was performed to visualize international research networks and scientific cooperation patterns. The resulting network, overlay, and density visualizations facilitated the identification of influential research topics, emerging themes, and collaborative structures within the global AR-in-sports research landscape. The overall methodological framework of this study consisted of four sequential stages:

- literature retrieval from the Scopus database;
- document screening based on predefined inclusion and exclusion criteria;
- bibliometric performance analysis, and
- science mapping using VOSviewer.

This workflow ensures the transparency, reproducibility, and reliability of the bibliometric analysis while providing a comprehensive understanding of publication trends and the knowledge structure of augmented reality research in sports.

RESULTS AND DISCUSSION

The following section presents the findings of the bibliometric analysis, providing a comprehensive overview of the publication trends, disciplinary distribution, document characteristics, geographical contributions, and knowledge structure of augmented reality (AR) research in sports. Furthermore, science mapping analysis using VOSviewer is employed to reveal thematic relationships, international collaboration patterns, and emerging research topics, thereby offering deeper insights into the evolution and future directions of this research field.

Document by Subject Are

The distribution of subject areas provides an overview of the disciplinary composition of research on augmented reality (AR) in sports. As illustrated in Figure 3, the 1,040 publications included in this bibliometric analysis are distributed across 25 subject areas, indicating that AR research has evolved into a highly interdisciplinary field spanning technology, health sciences, education, and social sciences.

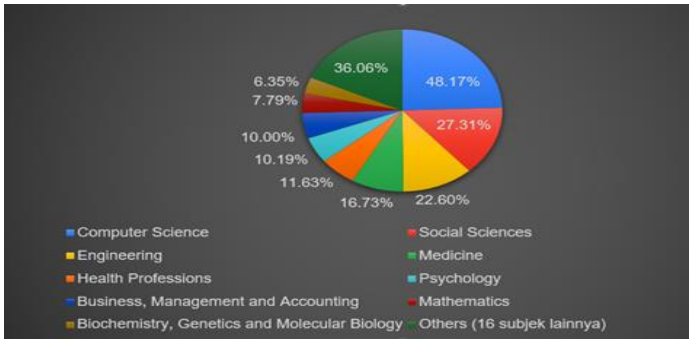

Figure 3. Publication Trends by document subject area.
Source: Scopus Analysis.

Among all disciplines, Computer Science constitutes the largest research domain, accounting for 501 publications (48.17%), followed by Social Sciences with 284 publications (27.31%), Engineering with 235 publications (22.60%), and Medicine with 174 publications (16.73%). Other major subject areas include Health Professions (121 publications; 11.63%), Psychology (106; 10.19%), Business, Management and Accounting (104; 10.00%), Mathematics (81; 7.79%), and Biochemistry, Genetics and Molecular Biology (66; 6.35%). Lower contributions were observed in Neuroscience (51; 4.90%), Physics and Astronomy (49; 4.71%), Materials Science (48; 4.62%), Arts and Humanities (44; 4.23%), Multidisciplinary (40; 3.85%), and Economics, Econometrics and Finance (38; 3.65%). Several disciplines, including Environmental Science and Decision Sciences, each contributed 28 publications (2.69%), while Energy (23; 2.21%), Chemistry (19; 1.83%), and Chemical Engineering (18; 1.73%) represented relatively smaller research contributions. The remaining subject areas, including Nursing, Agricultural and Biological Sciences, Immunology and Microbiology, Pharmacology, Toxicology and Pharmaceutics, and Earth and Planetary Sciences, each contributed less than 1% of the total publications.

The predominance of Computer Science (48.17%) indicates that the development of AR research in sports is primarily driven by advances in computational technologies, including computer vision, human–computer interaction, artificial intelligence, visualization techniques, and interactive software development. This finding reflects the technological nature of AR systems, which require sophisticated algorithms and real-time processing to integrate digital information into physical sporting environments. Meanwhile, the substantial contribution of Engineering (22.60%) highlights the importance of hardware development, wearable devices, sensor technologies, and motion-tracking systems that support AR implementation in sports training and performance analysis. Interestingly, the significant representation of Medicine (16.73%) and Health Professions (11.63%) demonstrates that AR research has expanded beyond technological innovation into clinical and sports-health applications (Amirouche & Patel, 2025). These studies commonly investigate rehabilitation programs, injury prevention, motor recovery, biomechanical assessment, and athlete health monitoring, emphasizing the growing role of AR in evidence-based sports medicine. Furthermore, the considerable proportion of publications within Social Sciences (27.31%) and Psychology (10.19%) suggests increasing attention toward learning processes, coaching strategies, technology adoption, user experience, and behavioral aspects associated with AR-assisted sports training.

Overall, the subject area distribution demonstrates that augmented reality research in sports has evolved into a multidisciplinary scientific field characterized by strong integration between technological innovation and applied sport sciences (Bădescu et al, 2022). The combination of expertise from computer science, engineering, medicine, education, and behavioral sciences has facilitated the development of increasingly intelligent, interactive, and data-driven sports training systems (Mateus et al, 2024). This interdisciplinary landscape also indicates substantial opportunities for future research involving

artificial intelligence, wearable technologies, immersive learning environments, and personalized athlete performance optimization (Cossich et al, 2023).

Subject Area Distribution

The distribution of document types provides insights into the preferred publication formats used to disseminate research on augmented reality (AR) in sports. As presented in Figure 4, the 1,040 publications analyzed in this study are distributed across various document categories, reflecting differences in research maturity, dissemination practices, and scholarly communication within this multidisciplinary field.

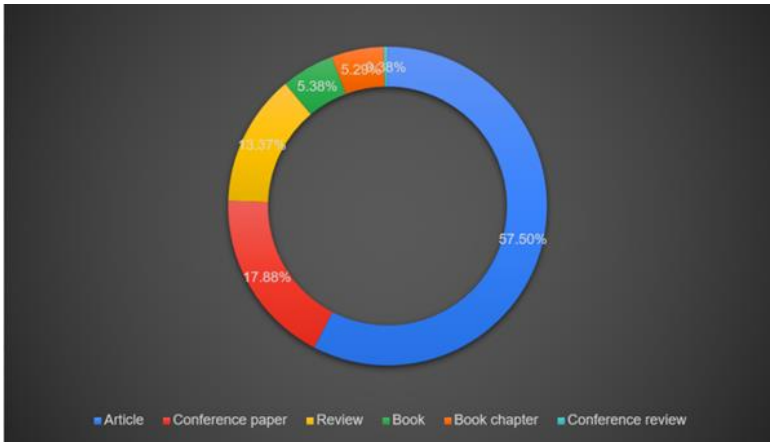

Figure 4. Publication Trends by Subject Area Distribution.
Source: Scopus Analysis.

Among the identified document types, articles constituted the largest proportion, with 598 publications (57.50%), indicating that peer-reviewed journal articles remain the primary medium for disseminating scientific findings related to AR in sports. The second-largest category was conference papers, comprising 186 publications (17.88%), followed by review articles with 139 publications (13.37%). Meanwhile, books and book chapters contributed 56 publications (5.38%) and 55 publications (5.29%), respectively, whereas conference reviews represented only 4 publications (0.38%), making them the least common document type within the dataset. The predominance of journal articles (57.50%) suggests that augmented reality research in sports has reached a relatively mature stage of scientific development (Noury et al, 2023). Publications in peer-reviewed journals generally present comprehensive research designs, rigorous methodological approaches, and validated findings, thereby serving as the primary source of scientific evidence. The substantial number of journal articles also reflects the increasing academic recognition of AR as a significant research topic within sport sciences and related disciplines (Dertli et al, 2025; Calabuig-Moreno et al, 2020).

The considerable proportion of conference papers (17.88%) demonstrates the strong technological orientation of this research field. In disciplines such as computer science and engineering, conferences frequently serve as venues for presenting novel algorithms, software architectures, wearable systems, and prototype applications before they are further refined for journal publication.

This publication pattern highlights the rapid pace of technological innovation associated with AR and emphasizes the importance of scientific meetings in facilitating the early dissemination of emerging research (Iatsyshyn et al, 2020). In addition, the presence of 139 review articles (13.37%) indicates a growing effort to synthesize existing knowledge and evaluate the current state of AR research in sports. Review papers generally become more prevalent as a research field matures, reflecting increasing scholarly interest in consolidating empirical evidence, identifying research trends, and proposing future research directions. The contributions of books (5.38%) and book chapters (5.29%) further demonstrate that AR research has expanded beyond journal-based dissemination to support academic teaching, professional training, and broader scientific communication.

Overall, the distribution of document types indicates that research on augmented reality in sports has developed into a well-established scientific field characterized by a balance between technological innovation and academic rigor (Cipresso et al, 2018; Iatsyshyn et al, 2020; Miah et al, 2023). While conference publications continue to facilitate the rapid exchange of emerging ideas, the dominance of peer-reviewed journal articles underscores the increasing emphasis on methodological quality, empirical validation, and long-term scientific contributions. This publication profile reflects the continued evolution of AR research toward a mature and multidisciplinary area of inquiry with growing relevance to sports science, engineering, health sciences, and educational technology.

Publication Trends by Country

The analysis of publication trends by country or region was conducted to identify the geographical distribution of research on Augmented Reality (AR), sport, basketball, and performance systems based on authors' affiliated countries in the Scopus database. This analysis provides insights into the global research landscape and highlights the countries that contribute most actively to this field.

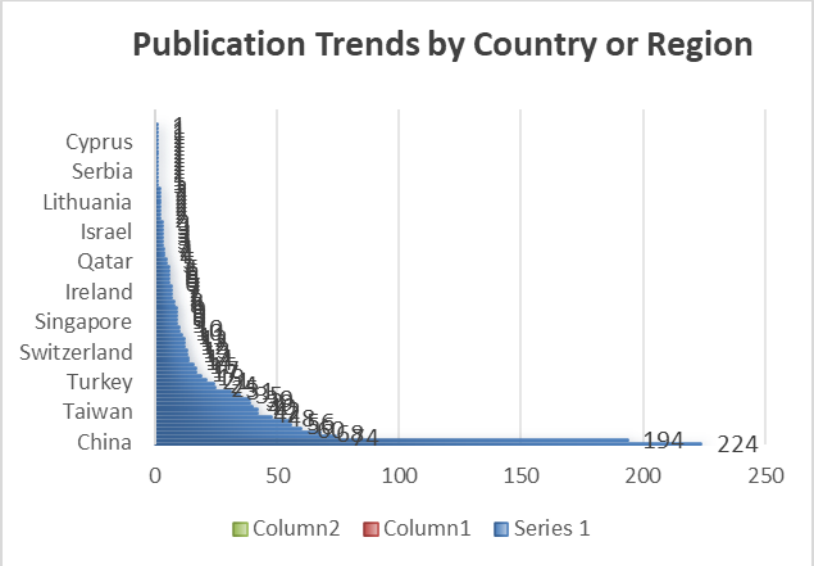

Figure 5. Publication trends by country.
Source: Scopus Analysis.

As presented in Figure 5, a total of 1,040 publications were distributed across 86 countries and regions, indicating widespread international interest in the application of augmented reality in sports. China emerged as the leading contributor with 224 publications, followed by the United States with 194 publications. The United Kingdom ranked third with 74 publications, while Germany and Australia contributed 68 and 60 publications, respectively. The dominance of these countries reflects their strong research capacity, technological development, and sustained investment in digital innovation within sports science and human-computer interaction. Asian countries demonstrated substantial research productivity in this domain. In addition to China, Indonesia and India each produced 56 publications, followed by South Korea (48), Taiwan (42), Malaysia (40), and Japan (39). These findings suggest that Asia has become one of the major research hubs for augmented reality applications, particularly in technology-enhanced learning, sports training, and performance analysis (Wong et al, 2024; Gazali et al, 2026).

European countries also made significant contributions, with the United Kingdom, Germany, Spain (42 publications), Italy (35), France (31), the Netherlands (25), and Turkey (24) demonstrating consistent research output. Together with contributions from North America and Oceania, these results indicate that research on augmented reality in sports has evolved into a globally distributed field rather than being concentrated in a single geographical region (Zhao et al, 2022; Borgohain et al, 2022). Notably, Indonesia ranked sixth in terms of publication output, matching India and surpassing several countries with well-established research ecosystems, such as Japan, Canada, and France. This finding highlights the increasing contribution of Indonesian researchers to the global development of augmented reality research. However, further examination of the bibliometric mapping suggests that most existing studies focus on general applications of augmented reality in sports and education, whereas studies specifically addressing basketball performance systems remain relatively limited (Janssen et al, 2023; Chan et al, 2024). Overall, the geographical distribution of publications indicates that research on augmented reality in sports is primarily driven by countries with advanced technological infrastructure and strong research ecosystems. At the same time, the relatively limited number of studies focusing specifically on basketball performance systems reveals a promising research opportunity for future investigations, particularly in developing innovative AR-based training and performance evaluation systems for basketball.

Publications by Year

The analysis of publication trends by year was conducted to examine the temporal development of research on Augmented Reality (AR), sport, basketball, and performance systems. This analysis provides insights into the evolution of scholarly interest in the field and identifies periods of significant research growth.

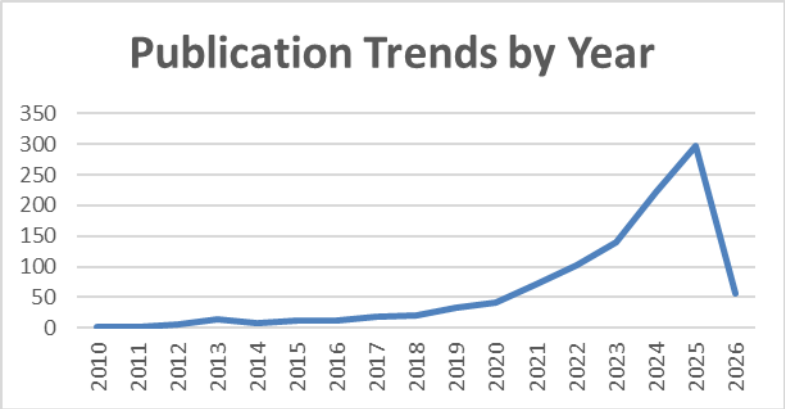

Figure 6. Publication by Year.
Source: Scopus Analisys

As illustrated in Figure 6, publications on this topic have increased substantially over the past decade. Between 2010 and 2016, research output remained relatively low, with annual publications ranging from 1 to 15 documents. During this early stage, augmented reality technologies were still emerging, and their applications in sports were primarily explored through conceptual studies and preliminary technological developments (Cossich et al, 2023; Mateus et al, 2024). A gradual increase in publication output became evident from 2017 to 2020, rising from 18 publications in 2017 to 41 publications in 2020. This upward trend reflects the growing adoption of immersive technologies in sports science, particularly for athlete training, motor skill development, performance monitoring, and interactive learning environments. Advances in computer vision, wearable technologies, and mobile computing further accelerated research in this period (Bădescu et al, 2022; Amirouche & Patel, 2025).

Research productivity experienced a remarkable surge after 2021, increasing from 70 publications in 2021 to 103 in 2022, 139 in 2023, and 222 in 2024. The highest publication output was recorded in 2025, with 298 documents, representing the peak of research activity within the study period. This rapid growth indicates an expanding global interest in integrating augmented reality with artificial intelligence, machine learning, motion analysis, and performance evaluation systems to improve sports training and athletic performance. Although only 55 publications were recorded for 2026, this lower number should be interpreted cautiously, as the Scopus database had not yet indexed publications for the complete year when the data were collected. Consequently, the publication count for 2026 is expected to increase as additional documents are indexed. Overall, the annual publication trend demonstrates sustained and accelerating growth in research related to augmented reality in sports. The sharp increase observed after 2021 suggests that AR has evolved from an emerging technology into an established research area with broad applications in sports performance analysis, athlete training, education, and digital learning environments. This continuous upward trajectory also indicates that research on AR-based sports performance systems remains an active and expanding field,

offering considerable opportunities for future investigation, particularly in sport-specific applications such as basketball.

Country Network Analysis

To examine international research collaboration, a country co-authorship network analysis was performed using VOSviewer. This analysis visualizes collaborative relationships among countries based on co-authored publications and identifies the major contributors within the global research network. The size of each node represents the publication productivity of a country, while the links between nodes indicate the strength of collaborative relationships. Countries with larger nodes and more connecting lines generally have higher research output and stronger international collaboration.

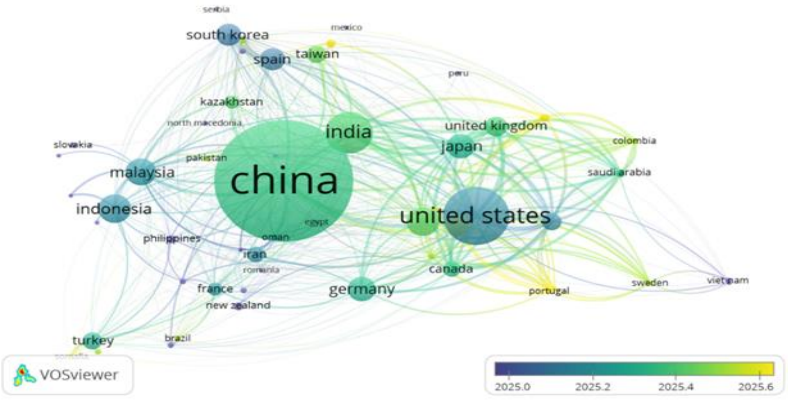

Figure 7. Country Network Analysis.
Source: Scopus Analisys

As illustrated in Figure 7, China occupies the most prominent position within the collaboration network, as indicated by its relatively large node and extensive connections with other countries. This finding suggests that China has become one of the leading contributors to research on augmented reality applications in sports and maintains broad international research collaborations (Zhao et al, 2022). The country's central position also indicates its significant influence on the development and dissemination of knowledge within this research field. The United States also represents a major hub in the collaboration network, exhibiting numerous collaborative links with countries across Europe, Asia, and Oceania. Its extensive international partnerships reflect the multidisciplinary nature of augmented reality research, which integrates expertise from computer science, sports science, engineering, artificial intelligence, and educational technology. Similarly, countries such as the United Kingdom, Germany, and Australia occupy important positions within the network, demonstrating active participation in global scientific collaboration.

The collaboration map further reveals that research on augmented reality in sports is characterized by a highly interconnected international network rather than isolated national research activities (Mendoza-Ramírez, etal, 2023). Strong collaboration among technologically advanced countries facilitates knowledge exchange, accelerates technological innovation, and promotes the development

of more comprehensive applications of augmented reality for athlete training, performance analysis, and sports education (Calabuig-Moreno, et al, 2020). Although Indonesia contributes a considerable number of publications, its position within the collaboration network is less central than that of leading countries such as China and the United States. This observation suggests that while Indonesia has demonstrated growing research productivity, there remains substantial opportunity to strengthen international collaborations with leading research institutions (Dertli et al, 2025). Expanding such partnerships may enhance research quality, increase scientific visibility, and facilitate the development of more advanced augmented reality applications in sports. Overall, the country collaboration network demonstrates that international cooperation plays a crucial role in advancing augmented reality research. The dominant positions of China and the United States highlight their leadership in shaping the global research landscape, while the increasing participation of other countries reflects the expanding international interest in applying immersive technologies to sports performance, training, and education.

Overlay Visualization of Country Collaboration

To complement the co-authorship network analysis, an overlay visualization was generated using VOSviewer to illustrate the temporal distribution of country contributions within the research field. In this visualization, node colors represent the relative publication period, allowing the identification of countries with earlier and more recent research activities. Brighter-colored nodes indicate more recent contributions, whereas darker-colored nodes represent countries whose publications were predominantly produced during earlier periods.

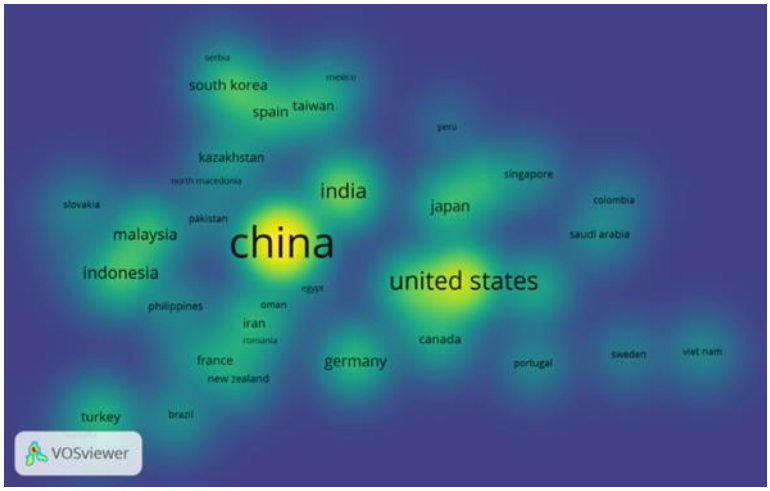

Figure 8. Overlay Visualization of Country Collaboration

As shown in Figure 8, China appears as one of the brightest and most prominent nodes in the network, indicating not only a high volume of publications but also sustained research activity in recent years. This finding suggests that China continues to play a leading role in advancing research on augmented reality applications in sports, consistently contributing new knowledge and technological innovations to the field.

Other major contributors, including the United States, the United Kingdom, Germany, and Australia, also exhibit relatively bright nodes, reflecting their continuous involvement in the development of augmented reality research. The temporal distribution suggests that these countries have maintained active publication output over time and continue to influence emerging research directions through sustained scientific productivity and international collaboration. The overlay visualization further demonstrates that research activity has gradually expanded to a broader range of countries. Several Asian and developing countries, including Indonesia, India, and Malaysia, are increasingly represented within the network, indicating growing research engagement in immersive technologies and sports-related applications. This trend reflects the global diffusion of augmented reality research beyond traditional scientific leaders and highlights the increasing accessibility of digital technologies for research and innovation. Overall, the overlay visualization reveals that augmented reality research in sports remains an active and rapidly evolving field. The concentration of recent publications among leading research countries indicates that innovation continues to accelerate, driven by advances in artificial intelligence, computer vision, wearable technologies, and digital training systems. At the same time, the growing participation of emerging research countries suggests that the field is becoming increasingly collaborative and globally distributed, providing opportunities for broader international partnerships and future technological development.

Keyword Co-occurrence Analysis

To identify the conceptual structure of the research field, a keyword co-occurrence analysis was conducted using VOSviewer. This analysis examines the frequency with which author keywords appear together within the same publications, thereby revealing the major research themes and their interrelationships. In the network visualization, the size of each node represents the frequency of keyword occurrence, while the connecting lines indicate the strength of co-occurrence between keywords. Keywords that are grouped within the same cluster represent closely related research topics.

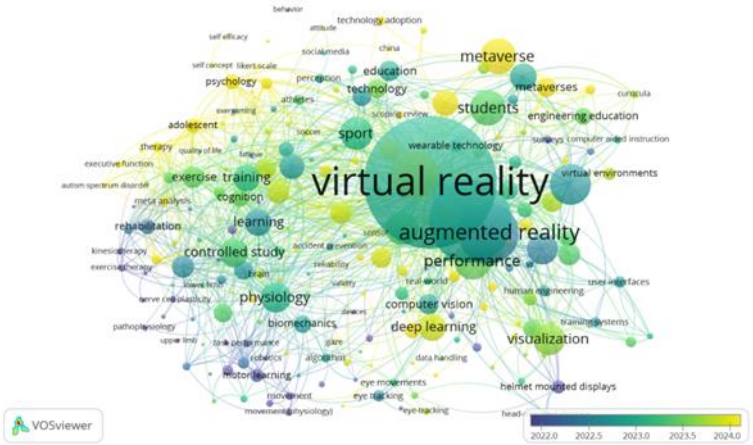

Figure 9. Co-occurrence Analysis.
Source: Scopus Analisys

As illustrated in Figure 9, Augmented Reality (AR) occupies a central position within the network and appears as one of the largest nodes, indicating that it is the dominant research topic across the analyzed publications. Its central location and extensive connections with other keywords demonstrate that augmented reality serves as the core technology linking multiple research domains, including sports science, education, visualization, computer vision, and artificial intelligence. A particularly strong relationship is observed between Augmented Reality and Virtual Reality, suggesting that immersive technologies are frequently investigated together rather than independently. This close association reflects the growing integration of AR and VR in developing interactive training environments, simulation systems, and performance evaluation platforms that enhance both technical and cognitive aspects of athletic performance. The network further highlights the close connections between augmented reality and sports-related concepts, including sport, physical activity, training, motor performance, and athletic performance. These relationships indicate that current research primarily focuses on applying AR technologies to improve athlete training, facilitate motor skill acquisition, optimize coaching strategies, and provide real-time performance feedback. The prominence of these keywords demonstrates the increasing adoption of immersive technologies within sports performance enhancement and athlete development.

Another important cluster is associated with advanced computational technologies, including computer vision, deep learning, machine learning, visualization, and artificial intelligence. The strong connections among these keywords suggest that recent studies increasingly integrate AR with intelligent analytical methods to automate motion tracking, biomechanical analysis, and performance evaluation. Such technological integration enables more accurate movement detection, objective performance assessment, and personalized training interventions. Educational applications also represent a significant research theme within the network. Keywords such as learning, teaching, students, and e-learning are closely linked to augmented reality, indicating that AR has been widely adopted to support interactive learning, motor skill development, and technology-enhanced education. This finding underscores the multidisciplinary nature of augmented reality research, extending beyond sports performance into broader educational and training contexts.

Although basketball appears within the network, its node is relatively smaller than broader concepts such as sport, training, and performance. This finding suggests that existing studies predominantly investigate augmented reality from a general sports perspective, whereas sport-specific applications, particularly in basketball, remain comparatively underexplored. Consequently, the development of AR-based systems specifically designed for basketball training, tactical decision-making, and performance evaluation represents an important direction for future research. Overall, the keyword co-occurrence network demonstrates that research on augmented reality has evolved into a multidisciplinary domain that integrates sports science, educational technology, artificial intelligence, computer vision, and human–computer interaction. The central role of augmented reality within the network confirms its position as the

primary technological platform driving innovation in sports training, performance analysis, and digital learning environments.

Keyword Focus on Basketball

To obtain a more detailed understanding of the role of basketball within the research landscape, the VOSviewer network was further examined by focusing specifically on the basketball keyword. This visualization highlights the direct relationships between basketball and other research topics, providing a clearer picture of its prominence within the broader augmented reality literature.

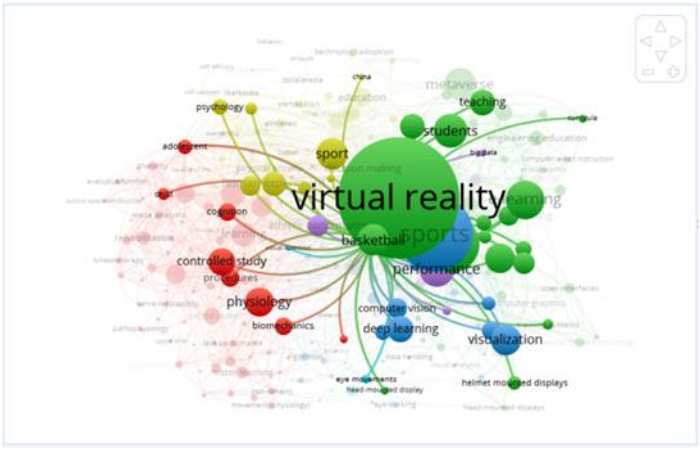

Figure 10. Keyword Focus on Basketball.
Source: Scopus Analisys

As presented in Figure 10, the basketball keyword occupies a relatively peripheral position in the network and is represented by a smaller node compared with major keywords such as Augmented Reality, Virtual Reality, Sport, and Performance. The relatively small node size indicates that basketball-specific studies constitute only a limited proportion of the overall research on augmented reality in sports. Despite its lower frequency, the basketball keyword remains connected to several important research themes, particularly those related to sports training, performance evaluation, motor learning, and interactive technologies. These connections suggest that existing studies have recognized the potential of augmented reality to support basketball training through skill development, movement analysis, and real-time performance feedback (Lin et al, 2021; Li, et al, 2025). However, the limited number of publications indicates that these applications have not yet been extensively explored. The visualization also reveals that most augmented reality research has concentrated on general sports applications rather than on individual sports disciplines (Noury et al, 2022). As a result, basketball has received considerably less attention than broader topics such as immersive learning environments, virtual reality, and sports performance enhancement. This imbalance suggests that sport-specific implementation of augmented reality remains an emerging area of investigation.

The limited representation of basketball within the keyword network highlights a significant research opportunity. Future studies may focus on developing and evaluating AR-based systems specifically designed for

basketball, including applications for shooting mechanics, dribbling techniques, tactical decision-making, player positioning, and real-time performance analytics. Integrating augmented reality with artificial intelligence, computer vision, and motion-tracking technologies may further improve the effectiveness of basketball training and performance assessment. Overall, the keyword-focused analysis confirms that while augmented reality has become an established research topic within sports science, its application to basketball remains relatively underdeveloped. This finding supports the existence of a clear research gap and underscores the need for further investigation into basketball-specific augmented reality applications, particularly those aimed at enhancing athletic performance and evidence-based coaching practices.

CONCLUSIONS AND RECOMMENDATIONS

This study provides a comprehensive bibliometric overview of Augmented Reality (AR) research in sports based on 1,040 Scopus-indexed publications published between 2010 and 2026. The findings demonstrate that AR has become an increasingly important multidisciplinary research area, as evidenced by the substantial growth in publications, particularly after 2021. Computer Science emerged as the dominant subject area, while journal articles represented the primary channel for scientific dissemination. Geographically, China and the United States were identified as the leading contributors and central actors in international research collaboration. The VOSviewer analysis further revealed that AR occupies a central position within the knowledge structure and is strongly associated with virtual reality, artificial intelligence, computer vision, training, and sports performance. These findings indicate that current research has increasingly focused on integrating immersive and intelligent technologies to enhance athlete training, performance monitoring, and interactive learning. However, the keyword analysis also showed that basketball remains relatively underrepresented compared with broader sports-related topics, suggesting that sport-specific AR applications have not yet been extensively investigated. Overall, this study demonstrates that AR research in sports continues to evolve rapidly and offers considerable opportunities for future innovation, particularly through the integration of emerging digital technologies and the development of sport-specific applications.

Recommendations

Based on these findings, future research should expand beyond general sports applications by developing and evaluating AR-based solutions for specific sports, particularly basketball. Further studies are encouraged to integrate AR with artificial intelligence, computer vision, motion tracking, wearable sensors, and data analytics to improve athlete performance assessment and decision-making. Strengthening international research collaboration, especially among emerging research countries, may also facilitate knowledge exchange and accelerate technological innovation. In addition, future bibliometric studies may incorporate multiple databases, such as Web of Science and Dimensions, and employ complementary analytical techniques, including citation, co-citation, and

bibliographic coupling analyses, to provide a more comprehensive understanding of the evolution of AR research in sports.

FURTHER STUDY

Despite providing a comprehensive overview of augmented reality research in sports, this study has several limitations. First, the bibliometric analysis was based exclusively on the Scopus database, which may have excluded relevant publications indexed in other databases such as Web of Science, Dimensions, PubMed, or IEEE Xplore. Second, the analysis relied on a specific search strategy using the keywords "Augmented Reality," "Sport," "Basketball," and "Performance System." Consequently, studies employing alternative terminology or closely related concepts may not have been captured. Third, this study primarily employed descriptive bibliometric indicators and science mapping techniques without conducting citation-based analyses, such as co-citation, bibliographic coupling, or citation network analysis, which could provide deeper insights into the intellectual foundations of the field.

Future research should integrate multiple bibliographic databases and broader search strategies to improve dataset coverage and reduce potential selection bias. In addition, incorporating advanced bibliometric techniques, including citation analysis, thematic evolution, and longitudinal trend analysis, would provide a more comprehensive understanding of the evolution of augmented reality research. Given the limited representation of basketball identified in this study, future investigations are also encouraged to examine sport-specific applications of augmented reality, particularly those integrating artificial intelligence, computer vision, wearable technologies, and real-time performance analytics to support athlete training and performance optimization.

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