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A Comprehensive Analysis using RStudio: Augmented Reality in Microbiology Mapping

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Abstract

Augmented Reality (AR) is an emerging technology with significant potential across various domains, including microbiology. However, despite increasing interest, the research landscape at the intersection of AR and microbiology remains underexplored. This study conducts a bibliometric analysis to map the current state of research on AR in microbiology, identifying key trends, contributors, and thematic developments. Using RStudio and the bibliometric R-package, the researchers analysed publications indexed in the Scopus database from the past five years, employing performance analysis (e.g., publication growth, country productivity, and leading sources) and science mapping techniques such as co-word analysis and thematic mapping. The study focused on the keywords "augmented reality" and "microbiology" to identify relevant literature, resulting in 10 documents. The findings reveal a gradual increase in publications, especially in recent years, with the United States emerging as the leading contributor. Keyword co-occurrence analysis identified "augmented reality", "microbiology", and "human" as central themes. The thematic analysis highlighted key areas such as the design and evaluation of AR tools for microbiology education, their effects on student learning outcomes, and the challenges of integrating AR into instructional practices. These insights offer a foundation for advancing research and practical applications of AR in microbiology education. Future studies should continue to explore how AR can enhance learning experiences and outcomes in this field.

Keywords: AR; Artificial Intelligence; Microbiology; Microbiology Literacy; RStudio

Introduction

Augmented reality (AR) has emerged as a promising technology in various fields, including education (Alnajdi, 2022; Pathania et al., 2021; YAPICI & KARAKOYUN, 2021), with the potential to enhance learning experiences (Faith Marcel, 2019; Jung et al., 2021) through the visualisation of abstract concepts (Buchner et al., 2021; Nuanmeesri, 2018; Uriarte-Portillo et al., 2022). In the context of microbiology literacy, AR enables students to better understand microorganisms and their crucial roles in health and disease (Ingrassia et al., 2020). Research on the application of AR in microbiology education has grown rapidly in recent years, as evidenced by the increasing number of scientific publications in this field.

Microbiology literacy is not a newly developed concept; rather, it has re-emerged as a focal point, coinciding with the recent surge in publications within this field (Fidiastuti et al., 2025; Rachman et al., 2024; Timmis, 2023; Timmis et al., 2019, 2020). The microbiological context is not only related to the role of microorganisms alone, but also the green economy (Lorek & Spangenberg, 2014; Luo & Cheng, 2022; Vandegrift et al., 2017), sustainability (Obaideen et al., 2022; Tom et al., 2021), bioremediation and biodegradation (Fidiastuti et al., 2020b, 2020a; Rozana et al., 2023) as well as other essential roles.

Recent trends in AR-related publications in the Scopus database show significant growth (Buchner et al., 2021; Pathania et al., 2021). However, most prior studies have been small-scale and conducted in controlled settings, limiting understanding of AR's broader educational potential. Additionally, comprehensive bibliometric reviews on AR research in microbiology literacy are lacking, leaving gaps in knowledge about its long-term impact and application in diverse educational contexts.

This study addresses these gaps by conducting a bibliometric analysis of AR-related publications in microbiology literacy from 2020 to 2024. The analysis examines publication trends, research collaborations, and key themes in the literature. The findings aim to provide valuable insights for researchers, educators, and policymakers while identifying unexplored research opportunities to enhance AR's application in microbiology education.

Methodology

Research design

This study employs a quantitative bibliometric approach to systematically examine the research landscape at the intersection of augmented reality and microbiology. Bibliometric analysis enables the identification of trends, influential contributors, research dynamics, and thematic developments of trends, influential contributors, research dynamics, and thematic developments in this emerging interdisciplinary domain. The analysis was conducted using the bibliometric R-package in RStudio, which supports a range of performance and science mapping techniques, including publication growth analysis, co-authorship networks, keyword co-occurrence mapping, and thematic evolution.

Data Source

The data were sourced from the Scopus database, selected for its extensive coverage of peer-reviewed literature and consistent indexing standards. Scopus provides high-quality bibliographic data, including citation and authorship metadata, which is crucial for bibliometric assessment. All retrieved records were exported in BibTeX format to ensure compatibility with the analysis tools.

Inclusion and Exclusion Criteria

To ensure relevance and quality, the following inclusion criteria were applied:

a. Peer-reviewed publications from 2020 to 2024

b. documents containing the keywords "augmented reality" and "microbiology" or related terms in the title, abstract, or keywords

c. Publications with full-text availability for contextual validation

d. Articles are written in English to ensure consistency in keyword interpretation and analysis.

e. Documents such as conference summaries, editorial notes, and non-scholarly commentaries were excluded to maintain the focus on research-based literature.

Data Collection

The data collection process involved a structured search within Scopus using controlled keyword combinations. After the initial retrieval, duplicate entries and non-relevant documents were manually screened.

A final dataset of 10 relevant publications was selected for in-depth analysis. Extracted bibliographic metadata included titles, authorship, affiliations, publication sources, years, abstracts, and author keywords. An extended review of abstracts and available full texts was conducted to validate the contextual relevance of each article.

Data Analysis

The collected data were analysed using the bibliometric software package in the RStudio environment. Bibliometric analysis involves various techniques, including:

a. Descriptive analysis

   Calculating the number of publications, annual growth rate, average document age, average citations per document, and the number of references

b. Context analysis

   Identifying frequently occurring keywords, including those provided by authors and those generated automatically

c. Author analysis

   Identifying prolific and influential authors, as well as collaboration patterns among them

d. Document type analysis

   Classifying documents based on their type, such as articles, conference papers, reviews, and notes. However, due to the limited number of documents found, further categorisation was not performed, as only articles and conference papers were identified.

Additionally, keyword co-occurrence analysis and co-citation analysis were conducted to identify relationships between key concepts and influential authors in the field.

Results and Discussion

Annual Science Production

Figure 1 shows a decline in publications on AR and microbiology from 2020 to 2024. After a peak of 6 publications in 2020, there were none in 2021, 2 in 2022, and only 1 each in 2023 and 2024, indicating a reduced interest in this research area. However, this five-year period may not fully capture long-term trends, and further study is needed to explore the factors driving these publication patterns.

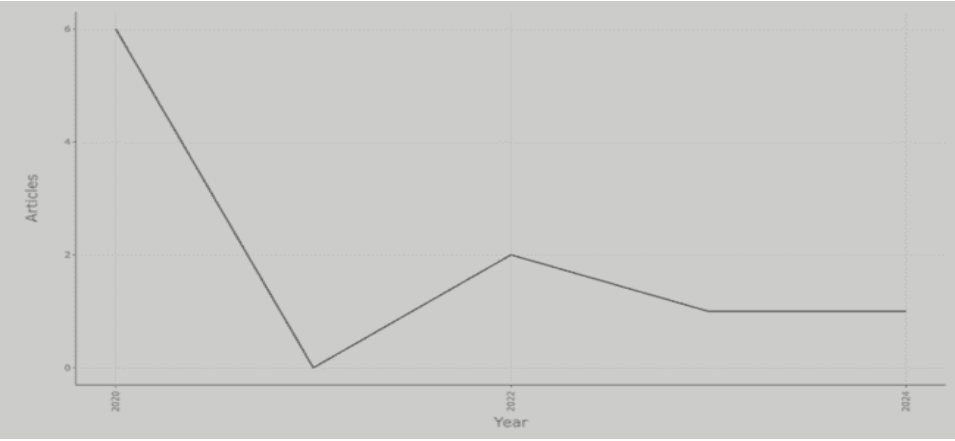

Figure 1. Annual Science Production (Source: RStudio)

Average Citations Per Year

Figure 2 shows a decline in the annual citations of research articles on AR and microbiology from 2020 to 2023, with a peak in 2020 followed by a sharp drop, reaching its lowest point in 2023. Several factors may explain this trend:

1. Declining Research Interest: Interest in AR and microbiology may have diminished due to shifts in focus, limited

funding, or the effects of the COVID-19 pandemic

2. Topic Saturation: Research in this intersection may have reached a saturation point, with key questions already extensively explored
3. Evolving Trends: Shifts in focus within AR and microbiology, such as moving from microbial identification to disease diagnosis, could have led to fewer citations for older topics.

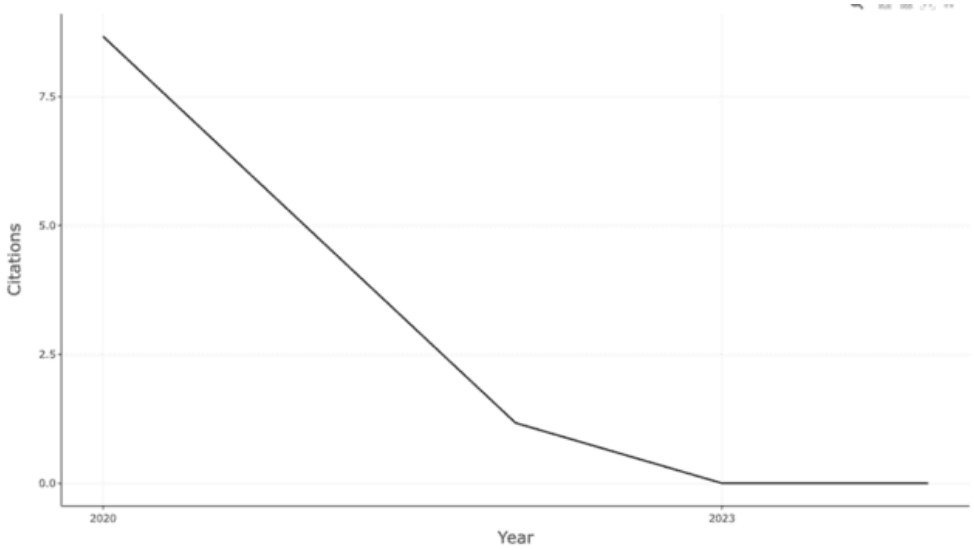

Figure 2. Average Citations Per Year (Source: RStudio)

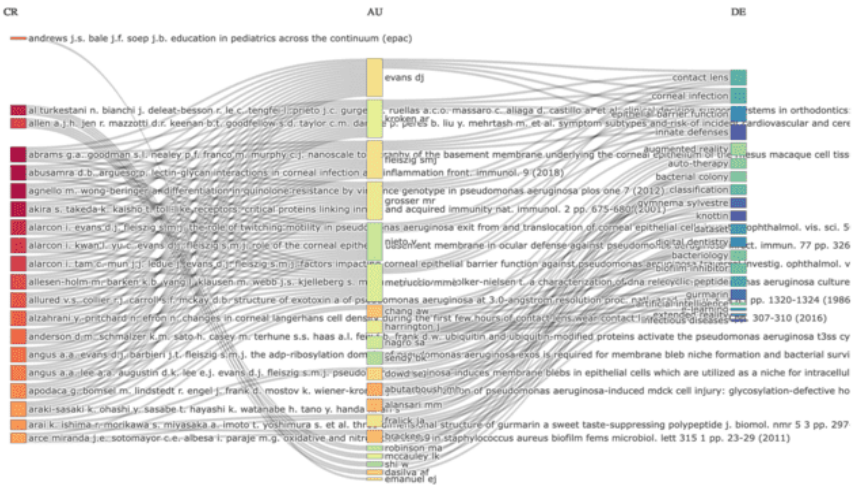

Figure 3. Three-Field Plot (Source: RStudio)

Three-Field Plot

Based on the bibliometric analysis in Figure 3, a notable correlation exists between AR and microbiology, particularly in research on corneal infections and epithelial defence. Fleiszig et al.'s work demonstrates the potential of AR in studying infections caused by Pseudomonas aeruginosa, focusing on bacterial motility, biofilm formation, and interactions with corneal epithelial cells (Fleiszig et al., 2020). Though the combination of AR and microbiology remains underexplored, the analysis suggests promising opportunities for future research. AR could play a pivotal role in advancing the

understanding of infection mechanisms, developing innovative therapies, and enhancing microbiology education and training.

Most Relevant Sources

Figure 4 presents a bibliometric analysis of publications at the intersection of AR and microbiology, sourced from a range of reputable journals. The analysis revealed a small but expanding body of literature on AR's integration into microbiology. The Journal of Physics: Conference Series emerged as the most prolific source, with four publications, indicating a strong focus on AR research in microbiology, especially in conferences related to instrumentation or microorganism visualisation.

Other key journals included the 3rd International Conference on Computing, Frontiers in Cellular and Infection Microbiology, Journal of American Medical Association, JDR Clinical and Translational Research, Medical Science Educator, and Progress in Retinal and Eye Research. These publications demonstrate the diverse applications of AR in fields such as basic research, clinical practice, education, and ophthalmology. Overall, while the intersection of AR and microbiology remains underexplored, the growing interest across various disciplines suggests significant potential for future research to advance AR's role further in microbiology.

Authors' Production Over Time

The visualisation in Figure 5 reveals a gap in document publication in 2021, with a clustering of publications in 2020 and 2022. Authors Abutarboush MH and Alansari MM are notably represented with two publications each in 2022, contrasting with the single publication from each of the following authors: Brackee G.; Chang AW.; DaSilva AF.; Dowd SE.; Emanuel EJ.; Evans DJ.; Fleiszig SMJ.; and Fralick JA within the analysed period.

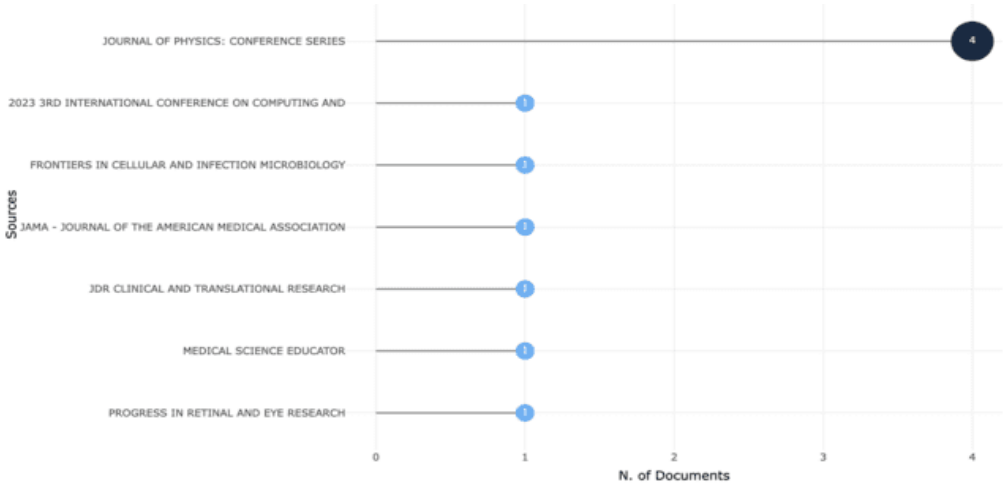

Figure 4. Most Relevant Sources (Source: RStudio)

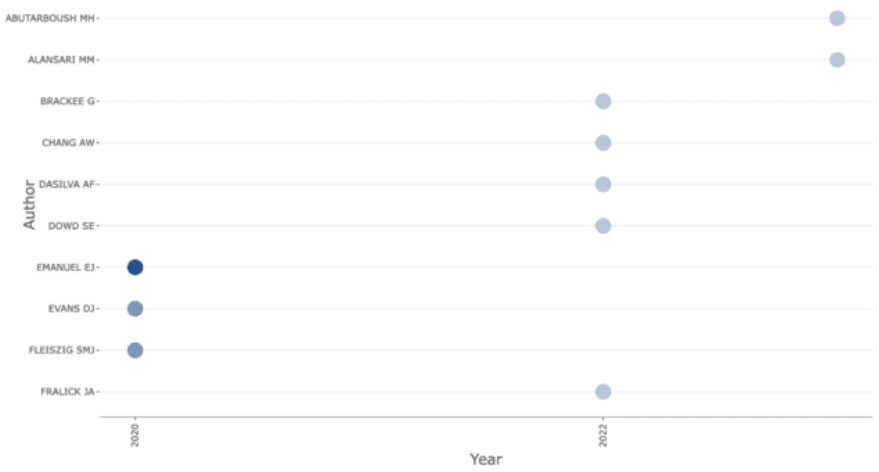

Figure 5. Authors Production Over Time (Source: RStudio)

Most Relevant Affiliations

The primary goal of this analysis is to identify the leading institutions contributing to AR research in microbiology, as indicated by citation frequency. Figure 6 highlights the institutional landscape in this field. The University of California stands out as the top contributor, with seven publications. Other notable institutions, each producing two publications, include the Institute of Wellness and Preventive Medicine, Kansas State University, Saudi Electronic University, Texas Tech University Health Science Center, and the University of Michigan School of Dentistry. Additionally, institutions such as Molecular Research DNA, Rocky Vista University, The Forsyth Institute, and The University of Alabama at Birmingham School of Dentistry contributed one cited document each. This overview provides insight into the distribution of research contributions across various academic and research institutions.

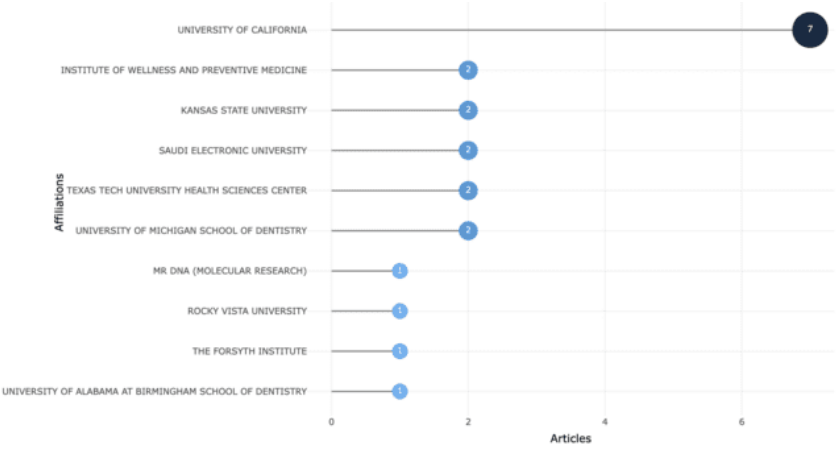

Figure 6. Most Relevant Affiliations (Source: RStudio)

Most Cited Countries

The citation analysis in Figure 7 reveals a notable disparity between the United States and Saudi Arabia in AR microbiology research. The United States received 267 citations, indicating a significant global impact, while Saudi Arabia received none. This suggests that U.S. research in this field has had a more substantial influence. However, it is important to recognise that this analysis is based on only 10 identified documents, and a broader analysis, including data from other databases, might uncover further contributions from Saudi Arabia.

Most Global Cited Documents

The document authored by Emanuel demonstrated the highest global citation impact, with 184 citations (Figure 8). This high citation count reflects the considerable influence of Emanuel's work and its standing as a key reference in the field. The limited body of literature on this topic likely contributes to the disproportionately high citation rate for this study.

Reference Spectroscopy

A significant rise in citations from publications spanning 1980 to 2022 suggests that earlier research likely laid the theoretical foundations for the development of AR in microbiology. The peak in citations occurred in 2022, establishing it as a landmark year for AR research in this field. As shown in Figure 9, the number of references published has followed a steady upward trend, reflecting the growing body of work.

However, there is a notable disparity between the number of published references and the annual citations received, indicating that AR research in microbiology heavily relies on earlier studies, which boosts its citation potential. Despite this, the quality of publications remains a key factor influencing how frequently they are cited.

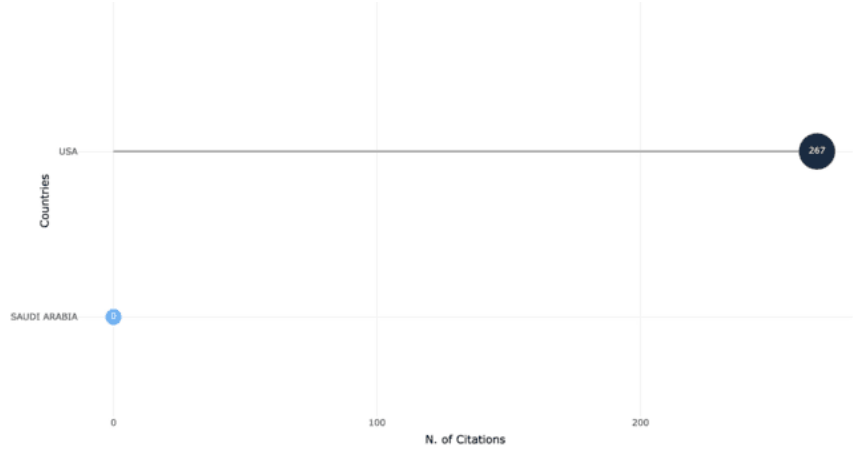

Figure 7. Most Cited Countries

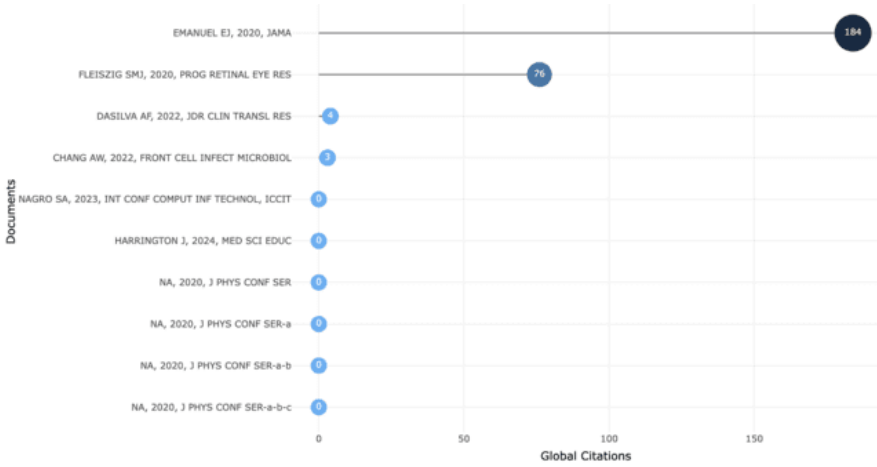

Figure 8. Most Global Cited Documents (Source: RStudio)

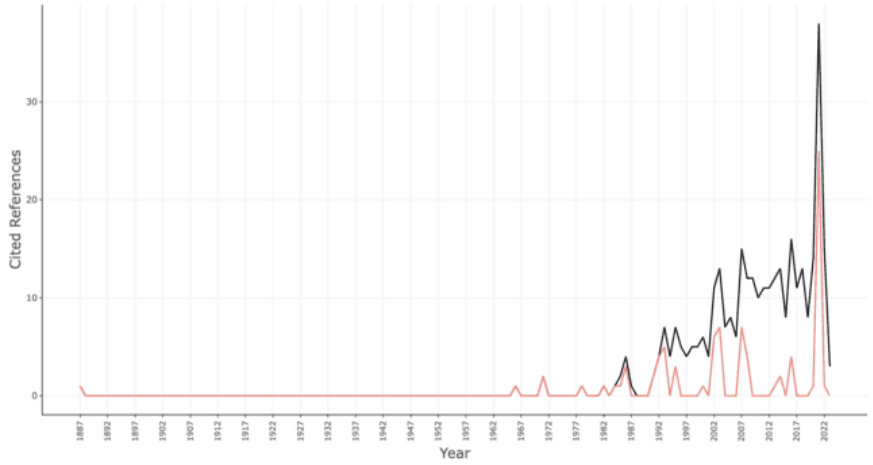

Figure 9. Reference Spectroscopy (Source: RStudio)

Most Frequent Words

Figure 10 underscores the central role of human-related concepts in AR research within microbiology. The keywords "augmented reality" and "human" appeared most frequently, each cited four times. This highlights the primary focus on human-centred applications of AR in this field. The keyword analysis offers a detailed perspective on the specific areas where AR technologies are being applied, particularly in developmental and practical applications within microbiology.

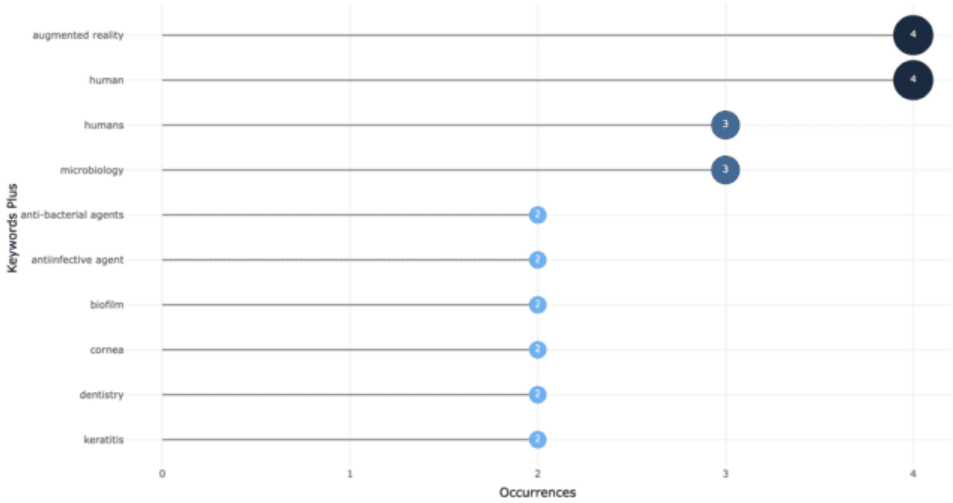

Figure 10. Most Frequent Words

Word Cloud

The word cloud visualisation (Figure 11) offers a comprehensive overview of the research landscape within the domain of AR in microbiology. Key findings from the analysis include:

1. Primary Focus

   The predominant terms within the word cloud are "augmented reality", "microbiology", and "human", indicating a concentrated focus on human-centric applications of AR technologies within the field of microbiology.

2. Medical Applications

   The appearance of keywords such as "antibacterial agents", "antibiotic resistance", "sepsis", "keratitis", "cornea", "dentistry", and "medical education" suggests a significant interest in utilising AR for medical applications,

particularly in diagnosis, treatment, and education related to microbiology.

3. Bacterial Focus

   The frequent occurrence of terms like "bacterial microbiome", "bacterial virulence", "bacterial classifications", "bacterium isolate", "bacterial eye infection", "bacterial colonies", and "Staphylococcus aureus" demonstrates a substantial focus on bacteria and their interactions with humans within the context of AR research.

4. AI as A Supporting Technology

   The presence of the term "artificial intelligence" indicates the pivotal role of artificial intelligence in the development and application of AR technologies within microbiology.

5. Broader Implications

   The appearance of terms such as "cultural competence", "collaborative learning", "communication", "skill", "classification of information", and "commercial phenomena" suggests a broader scope of research, encompassing social, economic, and educational dimensions.

Figure 11. Word Cloud (Source: RStudio)

The data analysed was sourced from the Scopus database, encompassing publications from seven different sources between 2020 and 2024. A total of 10 publications were included in this study. The annual growth rate analysis revealed a 36.11% decrease in the number of annual publications during the analysed period. The average document age was 2.9 years, indicating that most of the research was recent and relevant to current developments. Each document was cited an average of 26.7 times, suggesting a significant impact and recognition within the scientific community. All publications collectively referenced 337 documents demonstrating a strong theoretical foundation in augmented reality research related to microbiology.

A total of 131 keywords were identified from all analysed documents, indicating specific research topics. Authors employed an average of 39 unique keywords per document, reflecting the diversity of research field in this field. Twenty-two authors contributed to the analysed documents, with only two publishing individually. Each document had an average of 2.2 co-authors, suggesting a prevalent collaborative research culture in AR and microbiology. However, no international collaborations were identified, indicating a localised research scale. This presents an opportunity for future development.

The document types included articles, conference papers, conference reviews, short notes, literature reviews, and evaluations. Bibliometric analysis indicated a growing research field with significant author collaboration and a substantial research impact. Despite the decrease in the number of publications, research in this field remains relevant and continues to evolve, with great potential for enhancing education and understanding of microbiology through AR technology. Further analysis is needed to understand the specific reasons for the decline in publications, considering various contextual and influencing factors, such as citation count.

The United States emerged as the country with the most cited documents, holding significant influence and relevance in the global scientific community of AR microbiology. Several reasons contribute to this dominance: (1) substantial investments in research and development, including in technology and life sciences, enabling advanced research and high-quality publications; (2) the quality of educational and research institutions attracting top

researchers worldwide, contributing to high-quality research output.

This study offers several notable contributions to the field. First, it represents a pioneering effort to systematically map the intersection between augmented reality and microbiology through bibliometric methods. While previous research has explored AR in various educational contexts, few have focused specifically on microbiology, making this analysis both timely and novel. Second, the use of rigorous bibliometric techniques-including performance analysis, co-occurrence network visualisation, and thematic mapping, provides a comprehensive and data-driven overview of the research landscape. Third, the identification of core themes, such as microbiology education and learning enhancement, offers valuable insights for future educational innovation and technological integration. These features collectively enhance the value of the study as a foundation for further exploration and development in this emerging interdisciplinary field.

Implications for Practice and Future Research

The findings of this study have several implications for both educational practice and future scholarly inquiry. The identification of central themes such as "microbiology", "augmented reality", and "learning" emphasises the growing recognition of AR as a transformative tool in science education. Practitioners in microbiology education can leverage AR to create immersive learning experiences that may enhance conceptual understanding, engagement, and student motivation. However, the limited number of studies identified also highlights a need for greater empirical investigation into the pedagogical effectiveness and scalability of AR tools in diverse learning environments.

For future research, there is a substantial opportunity to explore the design, implementation, and long-term impact of AR-based interventions in microbiology curricula. Comparative studies assessing AR versus traditional methods, as well as mixed-methods research exploring learner experiences, would further enrich the field. Additionally, cross-disciplinary collaborations involving educators, technologists, and microbiologists could foster more robust development of AR applications tailored to subject-specific needs. Longitudinal and cross-cultural studies would also be valuable in examining the sustainability and generalisability of AR's educational benefits.

Conclusion

There has been a notable increase in interest and activity in augmented reality within the field of microbiology, particularly in 2022. This surge in interest is evident across various medical disciplines, including medicine, dentistry, and education. The primary focus of AR applications in microbiology has centred on human health, particularly within the medical field. Research has been concentrated on developing AR applications for various areas, such as antimicrobial and anti-infective agents, biofilm studies, ophthalmology, and dentistry.

The United States has emerged as the leading nation in terms of the number of publications and citations in this field. The University of California stands out as the most prolific institution in AR research related to microbiology. It is important to note that this analysis is limited to data available within the Scopus database and may not encompass all relevant publications from other databases. Additionally, the quality of the research has not been explicitly assessed in this analysis. Nevertheless, AR research in microbiology remains a dynamic and rapidly evolving field. There is substantial potential for further exploration and development, making it a valuable area of future research.

Acknowledgements

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