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RESEARCH TRENDS OF AUGMENTED REALITY IN BIOLOGY LEARNING: CONTENT AND BIBLIOMETRIC MAPPING ANALYSIS

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ABSTRACT

Purpose - Through the use of content analysis, this study was aimed at identifying the patterns in research conducted during the past decade and investigating the bibliometric outcomes of articles focused on augmented reality (AR) utilization in biology learning.

Methodology - This study conducted a bibliometric analysis. To perform the bibliometric mapping analysis, 116 articles were reviewed. A total of 111 articles published between 2014 and 2023 in the Scopus database were selected for the content analysis. The bibliometric analysis centered on 69 selected articles.

Findings - The most frequently used keywords in these articles were “AR,” “development,” and “application.” Furthermore, among the articles reviewed, it was observed that there was a recent focus on marker-based material on paper. This finding indicates that the focus of the latest articles is AR media modeling, use, comparison with conventional media, and AR development in a biology learning context. Saidin, Iftene, and Bonete were the most frequently cited authors in this field. The content analysis shows that development and practical guidance have been the most extensively examined variables in the articles. Development and experimental studies were the most frequently used research designs in the last ten years.

Significance - Future research in this field will be improved by using mixed-methods examining variables that enhance students’ interpersonal skills, and not just by developing and knowing the extent to which users can operate AR applications.

Keywords: Augmented reality, biology, education, learning tools, media.

INTRODUCTION

Augmented Reality (AR) brings together tangible and digital elements within a common setting, facilitating interactive real-time functionality between physical and virtual objects (Azuma, 1997; Moro et al., 2021). AR has the potential to enhance user perception, enabling a clearer understanding of the surrounding environment and facilitating interaction with the real world (Iftene & Trandabăt, 2018). As a transformative technology, it also has the potential to revolutionize traditional learning methods by allowing the shift toward technology-based learning approaches (Wulandari et al., 2020). AR has been widely applied in the form of mobile applications, using cameras to visualize objects and facilitating learning everywhere. AR enables students to swiftly access site-specific information sourced from various channels, granting them immediate access to relevant information (Muhayat et al., 2019; Yuen et al., 2011).

The rapid growth of technology has led to its widespread utilization in the development of learning materials, including interactive multimedia (Syawaludin et al., 2019; Wilujeng et al., 2018). Recent releases of the *Horizon Reports*, which assess technologies that have a significant impact on education, have emphasized the considerable potential of immersive technologies, particularly AR and Virtual Reality (VR), in the educational domain (Alexander et al., 2019; Becker et al., 2018; Brown et al., 2020; Johnson, 2016). The integration of technology into education promises to inaugurate a new era in the field of learning. Technologies such as AR and VR can greatly facilitate the support provided to learners engaged in complex learning situations. They also enable the implementation of VR training, leading to enhanced efficiency and effectiveness in educational settings (Hanafi et al., 2019; Mustami et al., 2019).

The adoption of technology for educational purposes has been a beneficial advancement. Designing a learning environment that integrates the latest technology can influence how students learn (Dehghani et al., 2023). The use of this technology is very important, including in biology learning. Biology is a scientific discipline dedicated to studying and elucidating the organization, operation, growth, and categorization of living organisms and life (Celik et al., 2020). Educational resources in the field of biology are often abstract and challenging to comprehend (Chang & Yu, 2018; Nurhasanah et al., 2019; Wang et al., 2019). Understanding the structures of complex macromolecules, such as proteins or nucleic acids, can be challenging for many students (Peterson et al., 2020). Other biological teaching materials emphasize such important topics as the cardiovascular mechanism, which is considered a particularly difficult topic of study, in terms of its structure and function, and because of its complex and dynamic nature.

Recent years have seen a surge in review studies centered on AR. However, reviews that specifically address the realm of biology learning are comparatively rare (physics and chemistry are more common). The present study has carried out a review of AR using bibliometric analysis. Bibliometrics involves analyzing publication titles, abstracts, and keywords to identify trends and patterns in scholarly literature over time. It provides insights into the quantitative aspects of academic publications, such as citation counts, publication trends, and author productivity. A bibliometric analysis also identifies keywords that are often used by authors in published articles. That is because keywords are words or expressions that represent ideas or concepts presented by writers or researchers in publications according to their respective scientific field. With these keywords, readers can search for content easily, merely by using a few important words on which they seek information. These keywords also make an important contribution in the field of biology learning because keywords are an important resource for categorizing ideas, notions, or concepts for researchers and readers, making it easier for them to get the appropriate information. Another analysis examined the number of most cited authors in the field. Such an analysis will assist other researchers in the same field, especially in biology education, in determining the impact of the research that has been conducted on other people in the same field of interest. Although the most cited author or researcher is not necessarily an expert in the field, the number of citations obtained by the author or researcher demonstrates that the results of the published research have benefited other researchers or general readers. By examining bibliometric data, researchers can gain a deeper understanding of the evolution of research topics, the influence of particular fields or authors, and emerging trends in scientific disciplines (Boonroungrut et al., 2022). In addition, other indicators used in content analysis, such as the material used, the author's country of origin, research variables, research methods, type of data analysis, and so on, are very important components for obtaining comprehensive data, results, interpretations, and conclusions that can be used as references or illustrations for future AR research in biology learning.

The present study was aimed at filling the gap in the bibliometric analysis of AR research in biology learning, by conducting a literature review on the incorporation of AR in biology learning, encompassing the findings of several studies. Saidin et al. (2015) examined research studies on the use of AR in education. Irschick et al. (2022) reviewed studies on the utilization of 3D visualization techniques to recreate and study the physical structure of organisms. Sharma et al. (2022) reviewed studies on AR in educational environments. Munyemana et al. (2023) reviewed studies on the changing patterns in the application of computer-assisted instruction in biological sciences education. Sural (2018) uncovered the perspectives of future educators regarding the implementation of AR in classroom environments. According to Syawaludin et al. (2019), creation of interactive multimedia using AR was intended to boost the critical thinking capabilities of students. Mustami et al. (2019) also stated that a biology textbook integrated with AR had proved a valuable resource for biology learning activities due to its demonstrated validity, practicality, and high degree of effectiveness. Table 1 presents a summary of these studies.

Table 1

Results of Reviewed AR Articles in Biology Learning

Author & Year	Research Findings
Iftene & Trandabăt (2018)	Using AR to enhance the communication and collaboration abilities of children.
Wilujeng et al. (2018)	The application proves to be highly beneficial for students studying plant physiology within the field of biology.
Mustami et al. (2019)	The creation of a biology textbook integrated with AR has resulted in a valuable resource for biology learning activities due to its demonstrated validity, practicality, and high degree of effectiveness.
Hanafi et al. (2019)	The suggested application will be custom-tailored for students in a higher-education setting, specifically targeting newcomers who are about to embark on their first laboratory experiments.
Dehghani et al. (2023)	AR-based infographics were more effective in promoting deep learning and conceptual understanding of the heart and cardiac cycle than traditional instructional methods.
Celik et al. (2020)	The integration of MAR applications can be an effective tool for teaching the anatomical structure of the heart.
Peterson et al. (2020)	Allows learners to visualize and manipulate biomolecular structures in three-dimensional space.
Saidin et al. (2015)	AR technologies possess inherent positive potential and advantages that can be effectively incorporated into educational settings.
Irschick et al. (2022)	Provide opportunities for CFD and machine learning approaches to demonstrate their efficacy in solving fluid dynamics problems and image classification tasks, respectively.
Sharma et al. (2022)	Assist other researchers in pinpointing potential avenues for future studies.
Munyemana et al. (2023)	Despite the positive impact on learning outcomes, there is still a need for further advancements in using modern technologies such as VR and AR specifically in the context of biology teaching and learning.

Author & Year	Research Findings
Bonete et al. (2019)	The integration of VR and AR visualization expands the range of tools available to students for engaging with content in structural biology. It takes the level of interaction to a heightened state of immersion.
Weng et al. (2020)	The utilization of AR technology promises to enhance students' learning outcomes at the analytical level and to positively influence their attitudes toward biology education.
Petrov & Atanasova (2020)	The application of AR technology, particularly in STEM education, provides students with the opportunity to explore, practice, and interact with STEM content without concerns about financial constraints or ethical considerations, such as the cost of consumables or potential harm to animals.
Fuchsova & Korenova (2019)	Using AR technology can prove to be a highly effective tool for teaching human biology. AR can be used to create interactive and immersive visualizations of biological processes and structures, allowing learners to explore and manipulate them in three-dimensional space.
Garzón et al. (2017)	AR can be an effective tool for teaching and learning biochemistry.
Nuanmeesri (2018)	The AR tool for teaching about the heart received widespread acceptance from users at the highest level.
Layona et al. (2018)	An AR application for learning human anatomy, featuring 3D objects and descriptions of organs and their positions, is accessible through the web.
Arslan et al. (2020)	The utilization of AR/VR in education shows promise and is beneficial in the teaching and learning process.
Rodríguez et al. (2021)	The Molecule AR web can enhance students' learning experience and understanding of complex STEM concepts.
Abriata (2020)	Developers who used the building blocks were able to create web-based AR applications for molecular visualization and modeling more efficiently and effectively compared to traditional methods.
Verdes et al. (2021)	Students who used the mobile learning applications demonstrated higher levels of engagement, motivation, and achievement in invertebrate zoology than those who did not use the applications.
Chang & Yu (2018)	AR technologies were more effective in promoting conceptual understanding and problem-solving skills than traditional laboratory methods.
Reeves et al. (2021)	AR holds the potential to enhance bioscience education by serving as a valuable teaching aid, particularly when the visualization of 3D models plays a central role in achieving learning outcomes.
Williams et al. (2020)	The Genetic Code Kit provides flexibility in addressing various learning objectives beyond transcription and translation. It supports hypothesis-driven scientific inquiry and experimentation.
Sharmin & Chow (2020)	The AR flashcard application demonstrated compatibility with both iOS and Android systems, successfully identifying the target image and smoothly substituting it with the corresponding output image on the device screen.
Wang et al. (2022)	Introducing AR instruction led to a significant increase in students' flow experiences and motivation to learn, simultaneously decreasing their cognitive load.
Aivelo & Uitto (2016)	Engaging in the programming of and participation in an AR location-based mobile game has the potential to enhance students' comprehension of scientific models.

Author & Year	Research Findings
Stepanyuk et al. (2020)	Modern information and communication technology enables the development of a unified information environment, which is built upon integrated computer networks and communication systems.
Abriata (2022)	Technology-enhanced science education at home had several benefits, including increased flexibility, personalized learning, and opportunities for self-directed learning.
Jiang et al. (2022)	The need to offer access to diverse representations and various forms of interactions with these representations is crucial to facilitate effective science learning.
Hoog et al. (2020)	The deployment of these tools was relatively rapid and cost-effective, making them accessible to a wider range of students and educators.
Cortés et al. (2021)	Throughout the process, the participants' creations progress from initial representations that encompass a visual depiction of the process to representations exhibiting greater semantic and semiotic complexity.
Deslis et al. (2019)	Efficient incorporation of mobile technologies can improve both learning outcomes and students' attitudes.
Wang et al. (2019)	In general, students found the game to be beneficial and user-friendly for learning.
Loucif et al. (2019)	Students have enjoyed learning and interacting with human anatomy.
Adnan (2018)	Mobile AR can transform a passive biology lecture into an active learning experience.
Moedjiono et al. (2018)	Using AR technology for learning media and biology subjects through the natural feature tracking reading technique.
Erwinsah et al. (2019)	The utilization of AR technology in the education sector is anticipated to enhance learning methods, making them more interactive and engaging.
Ba et al. (2019)	The AR app called "APP Learn (Heart)" is specifically designed as an interactive and educational tool that enables every student to learn about the structure and function of the heart through an engaging and interactive gameplay experience.
Rodríguez et al. (2022)	Advancements are required to create the "ideal tool" for the future of chemistry education and professional work.
Nur Hidayat et al. (2020)	The mobile-based learning medium known as the "Virtual Jungle application" can assist in the educational process, particularly in the identification of plants and plant anatomy, so as to captivate the interest and enthusiasm of junior high school students.
Qamari & Ridwan (2017)	AR media presents an intriguing opportunity to use it as a learning tool for studying dicotyledonous plants within the field of biology.
Susilo et al. (2021)	Using AR for mobile-based learning media to visualize topics related to biology.
Ramos & Comendador (2019)	The tool can be applied to junior high school students, potentially enhancing both motivation and performance.
Somakeerthi et al. (2020)	Amazon biology is an effective and efficient learning tool, using visual materials to teach, and is practical.
Gregorcic & Torkar (2022)	Implementing AR can assist lower secondary school students in comprehending the intricacies of the circulatory system.
Sakulphon et al. (2015)	Neither students' attitudes toward biology nor gender differences affected their perception of AR technology.
Ihsan et al. (2023)	The marker-less augmented reality (AR)–based learning tool focusing on the concept of cell organelles is deemed valid and viable as an instructional medium.

Author & Year	Research Findings
Fadhli et al. (2022)	The intervention can generate entertaining and cost-effective activities that foster student engagement, serving as a potential solution to Zoom fatigue concerns.
Kumar et al. (2023)	To enhance the comprehension of human anatomy and its functions, one can incorporate VR simulation–based training for a more immersive and effective learning experience. Biology teachers or medical institutions may opt for high-definition 3D VR models instead of conventional organ specimens in jars. This approach enables students to engage with and grasp the subject matter more experientially.
Ciloglu & Ustun (2023)	Mobile AR applications were considered innovative, non-disruptive, and effective for acquiring knowledge, engaging, captivating, and enjoyable. They enhanced information retention, provided a concrete understanding of the subject, and facilitated the learning process.
Stojšić et al. (2022)	A significant portion of students viewed mobile AR applications as valuable and user-friendly tools. They exhibited positive attitudes toward these educational technologies and expressed a willingness to use them if given the opportunity.
Lam et al. (2023)	The game was pragmatic and well-constructed, based on various usability factors.
Annisa & Subiantoro (2022)	The integration of MARRS into socio-scientific issue-based biology learning has a positive impact.
Rodríguez et al. (2023)	Bears significant implications for the education sector, showcasing the potential of AR technology to enhance learning results and underscoring the need for teacher training in its implementation.
Chuang et al. (2023)	The AR-based chatbot system developed in this study had a significant impact on the indicators within the ARCS motivation model.
Nurhayati et al. (2022)	The development of AR learning media for environmental pollution made a positive contribution to the biology learning process, fostering student interest in the subject.
Wommer et al. (2023)	The implementation of the Insect Go game has improved the learning of entomology among middle school students.
Firdaus et al. (2022)	The AR app can assist teachers and students in the teaching and learning process while also serving as a source of inspiration for students to delve into the study of biology, particularly the material related to the *Escherichia coli* bacteria.
Pasha et al. (2021)	Interactive AR technology can help students in learning biology, especially regarding human movement systems.
Rahmadani & Sunarmi (2023)	The AR-assisted e-module is considered valid and viable for incorporation into the biology learning curriculum, specifically for teaching about viruses. Its implementation is expected to enhance student learning outcomes, retention, and science literacy.
Li et al. (2021)	AR learning environments prioritize the development of both teamwork and independent thinking abilities. Additionally, AR learning environments are particularly advantageous for visual learners compared to verbal-based approaches.
Jiang et al. (2020)	The system proves to be beneficial for learners, particularly K-12 students, as it allows them to use spare time outside the classroom to enhance their understanding of DNA cognition.
Hong et al. (2020)	Integrating AR into game-based learning environments not only attracts the attention of learners, but also promotes meaningful acquisition of domain knowledge.

Author & Year	Research Findings
Yusof et al. (2020)	Users have embraced the application, finding it intriguing to learn about the process of water transport in plants through hands-on experience.
Hassan & Abdelbaki (2018)	An accurate and resilient hand gesture recognition system, known as "ABL-HGR."
Arifin et al. (2019)	The Taxondroid application, employing AR technology, engages teenagers in the learning of biology, specifically the subject of animal taxonomy.
Rodríguez et al. (2022)	The use of virtual and augmented reality in science education had several benefits, including increased student motivation, improved understanding of complex concepts, and the ability to perform virtual experiments in a safe and controlled environment.

The present study was also aimed at finding trends and novelties related to AR research over the last 10 years (2014–2023) in biology learning as opportunities for future research based on bibliometric analysis. The 10-year time frame is chosen because of the increased development and use of technology that has occurred during that time frame in the education field. This study is expected to serve as a valuable reference for researchers in the future. The research questions delineated in this study, all associated with entries in the Scopus online literature repository, are as listed below:

1. How are the prevalent keywords distributed in articles discussing AR utilization in the field of biology learning?
2. Which authors receive the greatest number of citations in articles related to AR utilization in biology learning?
3. Which articles, categorized by author and country, have garnered the greatest number of citations in the field of AR utilization for biology learning?
4. What kind of connection exists in the application of AR for learning in the field of biology?
5. Which fluctuating patterns were observed in articles regarding the application of AR in biology learning?
6. What types of materials were used for AR applications in the context of learning biology?
7. Which methodological trends were identified in articles that concentrated on the application of AR in the field of biology learning?
8. What were the primary methodologies for data analysis used in articles discussing the implementation of AR in the context of biology learning?

METHODOLOGY

Research Design

This study uses bibliometric analysis methodology. Bibliometrics is a statistical technique employed to examine scientific data, uncover research themes, monitor scientific advancement, and evaluate the impact of research (Suwandi et al., 2023). Derived from publication titles, abstracts, and keywords, bibliometrics is intended to identify trends from past-to-present studies (Boonroungrut et al., 2022).

Article Samples

The study used a sample of 69 publications retrieved from the Scopus database, all the publications were aligned with the specified keywords, with a primary focus on "AR, Biology, and Learning." These publications comprise both journal articles and conference proceedings.

Indicator

Publications chosen for this study are from the past decade (2014–2023) and were identified through the Scopus database using Publish or Perish software, Microsoft Excel, and Vos Viewer. The metrics employed in this investigation included the following: assessing the volume of publications, citation counts, and the overall interconnectedness depicted in the visual representation of the data.

Research Procedure

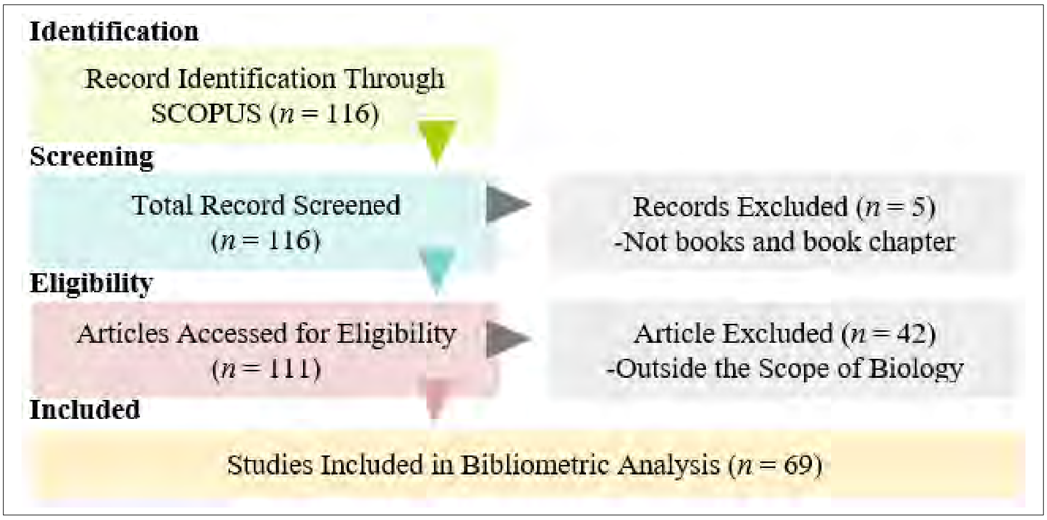
The academic articles selected for this study were sourced from the Scopus database, chosen due to its extensive size, high quality, and credibility. Scopus is one of the largest curated databases for abstracts and citations, offering extensive global and regional coverage of scientific journals, conference proceedings, and books (Singh et al., 2021). It ensures that only top-quality data are indexed through a strict content selection process and ongoing re-evaluation by an independent Content Selection and Advisory Board (CSAB) (Cortegiani et al., 2020). This guarantees that the database indexes only carefully curated, high-quality content, reinforcing the credibility of Scopus (Baas et al., 2020).

Another reason why this study only used one database (Scopus) was that the Scopus database was one of the most targeted databases and was required for graduates of college programs (especially doctoral programs) and for international recognition of various types of research with strict selection criteria. Moreover, the Scopus database selects and evaluates the journals it indexes strictly and periodically to maintain the quality of publications indexed by the Scopus database.

The present study's Scopus database searches revealed 116 records consisting of the words "augmented reality," "Biology," and "Learning." The selected samples were 69 articles, which excluded five articles based on books and book chapter resources and 42 article journals falling outside the scope of biology. Moreover, the samples analyzed in this study consisted of articles authored or coauthored by 255 individuals and referenced by 617 other documents. The PRISMA guideline was employed to identify the specific articles included in this research, as illustrated in Figure 1 (Moher et al., 2009).

Figure 1

PRISMA Flow for Sample Identification



Some of the journals most popular with researchers in the field based on identified samples were *Biochemistry and Molecular Biology Education* (5.80% of the total sample), *IJIET* (2.90% of the total sample), and *JECR* (2.90% of the total sample).

Language, Data Inclusion, and Exclusion Criteria

Language of Articles

All articles identified were English-language articles.

Data Inclusion Criteria

This study included research articles, review articles, and proceedings articles that had focused on AR research in biology learning.

Data Exclusion Criteria

Several articles with a focus irrelevant to the research were excluded from the analysis. Although some articles found through keyword searches may mention augmented reality or biology learning, many of them did not directly discuss the interaction between these two topics. For example, some articles might discuss AR in the context of other disciplines, such as chemistry or physics, or address general educational aspects without specifically linking them to biology learning. Additionally, there were articles that had focused on AR technology from a technical standpoint without exploring its application in the context of biology learning. Therefore, these articles with irrelevant focuses were excluded to ensure that the present analysis remained consistent and directed toward mapping research trends related directly to AR in biology learning.

Data Analysis

The research data were analyzed using bibliometric analysis techniques that employed VosViewer software and manually using Microsoft Excel software. This investigation was intended to scrutinize the key topics at distinct stages of their evolution and anticipate current trends along with their future trajectory. Vos Viewer was employed for these analyses to identify potential primary categories (Cano et al., 2022).

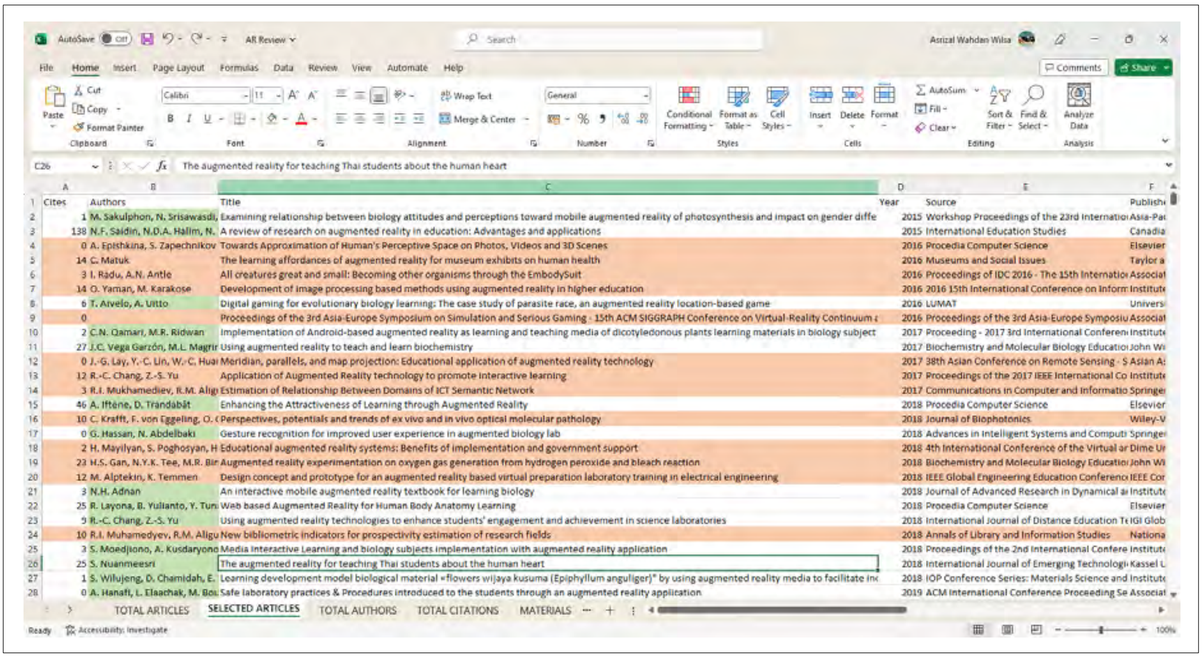
Content analysis was conducted manually by reading the identified articles one by one, categorizing and calculating them manually with the help of Microsoft Excel software. Specifically, the stages of content analysis were as follows:

1. Article search results from the Publish or Perish software were first converted into CSV format as in the data collection section above so that they could be opened in Microsoft Excel software.
2. The CSV file was opened using Microsoft Excel software.
3. A tab was created in Microsoft Excel to make it easier to analyze such sections as total articles, selected articles, total authors, total citations, popular journals, materials, and so on.
4. Next, the articles are read and analyzed one by one, while researchers take notes, count, and classify them according to the following categories: total articles, publication year, selected articles, total authors, total citations, popular journals, materials, and so on. To make it easier, color highlights would be used to mark selected articles.
5. Every stage of this analysis had to be carried out carefully. Researchers had to record, mark, categorize, and count to obtain conclusions from the analysis that had been conducted.

Content analysis of data using Microsoft Excel is as presented in Figure 2 below.

Figure 2

Content Analysis with Microsoft Excel Software



FINDINGS

The findings of this study will be discussed under the following headings:

The Keywords Most Frequently Used in Articles on AR Utilization in Biology Learning

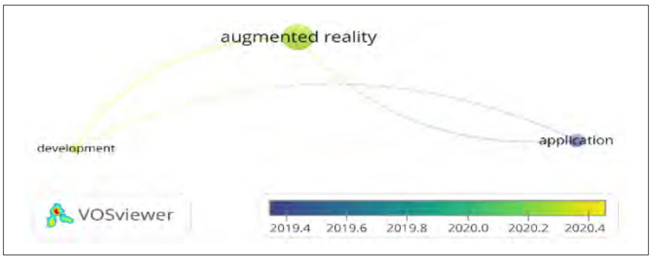
To generate visual representations from textual data containing commonly used keywords, the study used co-occurrence analysis and selected author keywords. The minimum threshold for the occurrence of a keyword was set at nine, and the automatic selection process would choose a minimum of three keywords. The visual representation is as presented in Figure 3. This map reveals the existence of three clusters, with the predominant keyword being "augmented reality" *(f = 36).* Following closely were the keywords "development" *(f = 10)* and "application" *(f = 18),* signifying their high usage. These findings suggest that most articles had focused on the advancement and implementation of AR. From this visualization, it is evident that research on AR in biology learning started to surge in 2019, initially emphasizing applications and then evolving to focus on AR development. The distribution of the article count by year is as depicted in Figure 4.

Figure 3

The Most Frequently Employed Terms in Articles Discussing AR Utilization in Biology Learning

Figure 4

The Dispersion of Articles Using the Specified Keywords Across Different Years



The Most Commonly Employed Terms in Abstracts of Articles Regarding the Utilization of AR in Biology Learning Research

To generate a map using textual information derived from frequently used words in article abstracts, the bibliography from the Scopus database has been imported into the Vos Viewer Software. Meanwhile, the abstract calculation method used binary counting. The minimum threshold for term occurrences was established at 10, and the automatic selection of terms was configured to be 34. The map is as presented in Figure 5. This visual representation indicates the presence of two clusters, with the term “reality” occurring the most frequently in the abstracts *(f = 91)*. The top keywords included “education” *(f = 50)*, “model” *(f = 35)*, “tool” *(f = 34)*, “paper” *(f = 28)*, and “development” *(f = 26)*. These findings suggest that most of the articles had concentrated on the realm of education within the AR media domain, encompassing topics such as modeling, utilization, comparisons with traditional media, and the development of augmented reality. When the distribution of these keywords was shown for each year, it was also revealed that the latest articles contained content about how AR was used as a medium and was applied in the learning process. The presentation of the distribution of the frequently used words in abstracts for each year can be observed in Figure 6.

Figure 5

Predominantly Employed Terms Identified in Abstracts of AR Research on Biology Learning

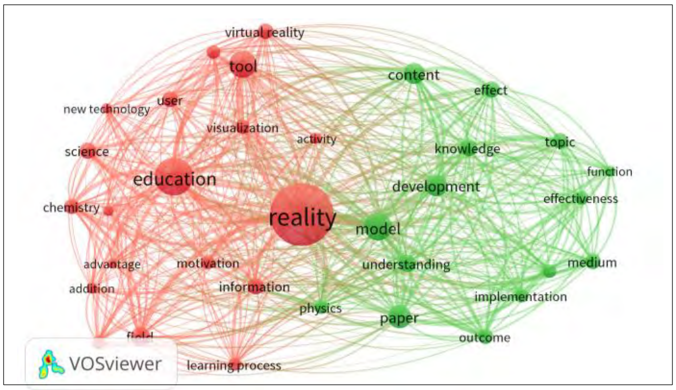
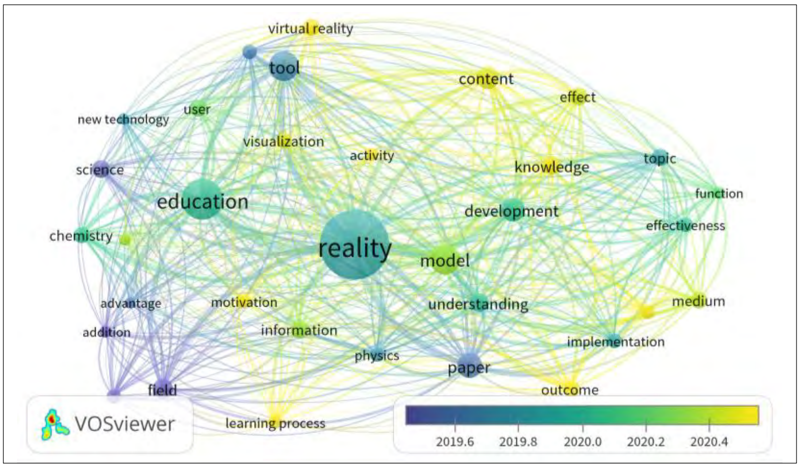


Figure 6

The Distribution of Frequently Used Terms in Article Abstracts Across Years in AR Research on Biology Learning



Authors with the Most Citations in Studies Related to the Application of AR in the Research on Biology Learning

To create a visualization depicting the main contributors with high citations, citation analysis was used, and particular authors were selected. The minimum threshold for documents originating from a specific country was established at 1, and the minimum citation count by country was set at 20. The software automatically determined and selected 12 authors based on the predefined criteria. The map is as shown in Figure 7. This map shows that *Saidin (138 citations)* and *Iftene (46 citations)*, were the authors with the highest citation counts in the field, and were frequently referenced. Also cited were *Bonete (39 citations), Weng (36 citations),* and *Petrov (35 citations)*.

Figure 7

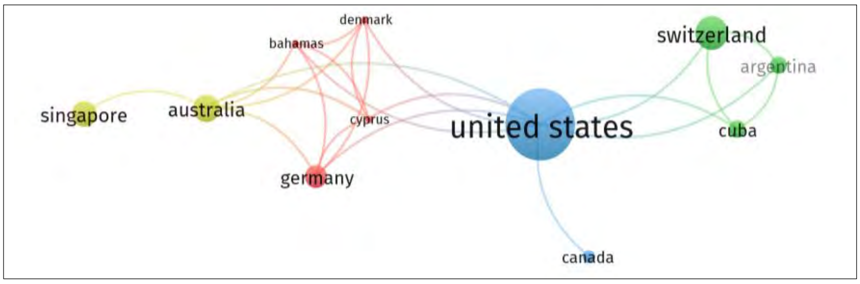
Distribution of Most Cited Authors in Articles About AR in Biology Learning

Most Cited Articles by the Author's Country of Origin on AR Utilization in Biology Learning

To generate a map indicating the country of origin of the most cited authors, citation analysis and the selection of specific countries were employed. The minimum threshold for the number of documents from a specific country was established at 1, and the minimum threshold for the number of citations by country was set at 20. The software automatically chose 12 authors based on the predefined criteria. The map in Figure 8 shows the following number of citations for each country: the United States had 112 citations, Switzerland had 39 citations, and Germany had 26 citations.

Figure 8

Distribution of the Most Cited Articles by the Author's Country of Origin

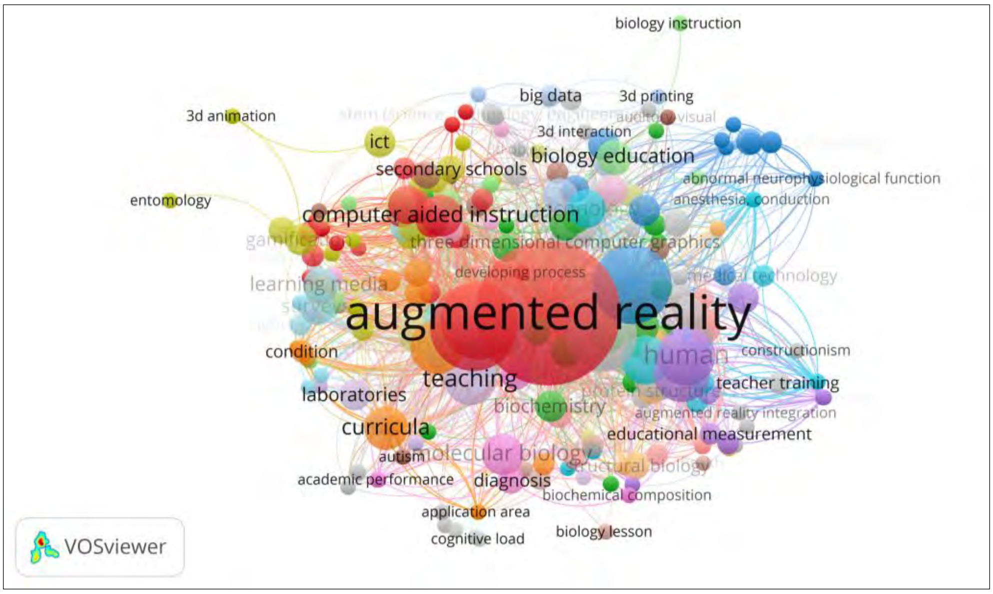


AR Relationship Network in Biology Learning Research

To create a relationship network, a map based on bibliographic data was created using the Scopus database in the Vos Viewer Software. In this visualization, type analysis was employed through co-occurrence with unit analysis keywords and through using the full counting method. The minimum threshold for keyword occurrence was set at 1, and the automatic selection included 885 keywords. The map shows 32 clusters with 11,693 links and a total link strength of 12,811. The visualization is as presented in Figure 9 below.

Figure 9

Network of Relationships Through AR in Biology Learning



Findings of the Content Analysis

Analyzed Variables in Articles on the Application of AR in Biology Learning

Research variables in research on AR in the context of biology learning were also explored. The most used research variables were "development" (f = 26), "practical guide" (f = 26), and "application" (learning supplement and tools) (f = 22). Several other variables were also identified, including "learning outcomes," "validity," "practicality," and "effectiveness." Table 2 displays the comprehensive findings.

Table 2

Occurrences of Variables Investigated in the Articles

Examined Materials	Frequency	Percentage (%)
Development and Practical Guide	26	37.68
Application (Learning Supplement and Tools)	22	31.88
Validity, Practicality, and Effectiveness	5	7.25
Learning Outcomes	4	5.80
Students' Experience	3	4.35
Motivation	2	2.90
User Evaluation, Learning Performance, Student Engagement and Achievement, Student Acceptance, Student Attractiveness, Student Attitude, and Learning Style	1	1.45

Material Types Were Used for AR Utilization in Biology Learning Research

The review of the articles also investigated the materials employed for AR in biology education. Among the preferred options, marker-based materials on paper (f = 37) and mobile applications (f = 15) stood out. Additionally, various articles had discussed the utilization of *markerless-based materials*, *interactive simulations*, and *AR game systems*. The corresponding outcomes are as detailed in Table 3.

Table 3

Frequency of Materials Examined in Reviewed Articles

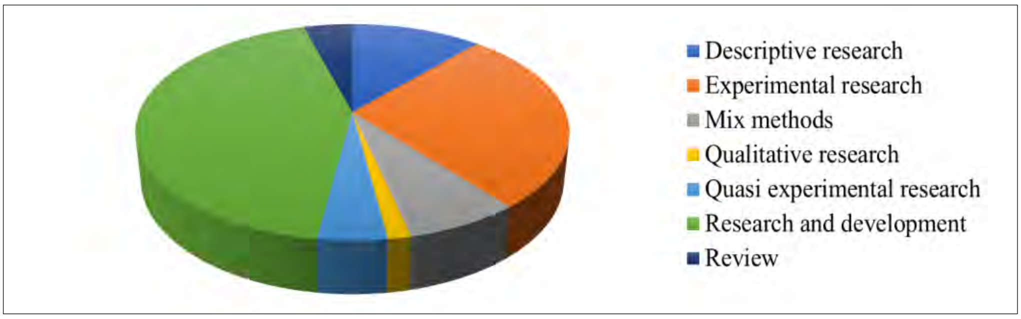
Materials Examined	Frequency	Percentage (%)
Marker-Based Material on Paper	37	53.62
Mobile Application	15	21.74
AR Game System	7	10.14
Interactive Simulation, Markerless-Based Material	4	5.80
Digital Marker-Based Material	2	2.90

Methodological Trends Found in Articles on AR Utilization in Biology Learning Research

The methodological trends for AR in biology learning were examined in the reviewed articles. Research and development (f = 30) and experimental research (f = 19) were the most methodological approaches for examining AR utilization in biology learning. Additionally, several articles referred to the use of review, qualitative research, and quasi-experimental research. Full findings are as displayed in Figure 10 below.

Figure 10

Methodological Patterns in Articles Exploring the Application of AR in Biology Learning



Data Collection Tools in Articles on AR Utilization in Biology Learning Research

The review of the articles scrutinized the tools employed for data collection in research on the utilization of AR in biology learning. *Questionnaires (f = 23)* and *tests (f = 15)* emerged as the most frequently used data collection tools. Moreover, various articles mentioned the utilization of alternative data collection methods such as surveys and observations. The relevant findings are as presented in Table 4.

Table 4

Occurrence of the Types of Data Collection Instruments in the Articles Scrutinized

Types of Data Collection Tools	Frequency	Percentage (%)
Questionnaire	23	33.33
Test	15	21.74
Other	12	17.39
Survey	9	13.04
Observation	4	5.80
Systematic Review	3	4.35
Interview	2	2.90
Alternative Assessment Tools	1	1.45

Predominant Data Analysis Approaches in Articles Investigating the Implementation of AR in Biology Learning Research

The present study also analyzed the data analysis methods employed in research on the utilization of AR in biology learning. *Descriptive analysis (f = 38)* stood out as the most frequently used method. Additionally, various articles mentioned the application of alternative data analysis approaches, including *t-tests* and *content analysis*. The relevant findings are as detailed in Table 5.

Table 5

Frequency of the Data Analysis Methods in the Articles Reviewed

Data Analysis Methods	Frequency	Percentage (%)
Descriptive Analysis	38	55.07
Other	12	17.39
T-test	9	13.04
Content Analysis	3	4.35
Anova, Mann–Whitney U Test	2	2.90
Chi-Square, Correlation, Pearson Correlation	1	1.45

DISCUSSION

In this study, research trends regarding AR in biology learning were identified through bibliometric analysis using the Scopus database. This study has used both bibliometric mapping analysis and content analysis. According to the bibliometric analysis carried out, the most frequently used research keywords were "augmented reality," "application," and "development." These findings suggest that the primary focus of research concerning AR in biology education was the application and advancement of AR technologies. When viewed based on the top keyword visualization overlay for each year, the findings showed that the focus of the latest research led to the development of AR as shown by the number of keywords "development" and "AR" in AR research in biology learning for the period from 2019 to 2023. This visualization overlay can be seen in Figure 4 above. These results were also based on the bibliometric analysis by Garzon et al. (2021), which had found that the development of more mobile AR applications was the most frequently conducted type of research. One of the most researched AR developments was the development of AR in the form of mobile applications (Arici et al., 2019; Cheng & Tsai, 2013; Hincapie et al., 2021). It shows that research interest in AR increases annually (Garzón et al., 2021).

The content analysis carried out in the present study found that the "development and practical guide" was the most frequent variable used by researchers. The analysis was based on the keyword "development," which is among the most frequently used terms in educational research. For instance, the studies by Arslan et al. (2020), Hong et al. (2020), Susilo et al. (2021), and Rodríguez et al. (2023) highlight a strong focus on the development of AR technology for education. These studies encompass various applications, ranging from the development of AR applications for biology education, the design and development of educational AR-based games, to mobile learning utilizing AR as a learning medium. Due to advancements in technology, the implementation of AR in the field of education has become increasingly viable. The availability of affordable computers and mobile devices has facilitated the development of new AR applications, eliminating the need for expensive equipment such as head-mounted displays, which had been previously necessary (Akçayır & Akçayır, 2017). Meanwhile, the types of material used for AR applications in biology learning showed that most of the AR applications used were AR marker-based materials on paper, as in the case of this study (Fadhli et al., 2022; Nuanmeesri, 2018; Nurhayati, 2020; Reeves et al., 2021). Incorporating AR into biology lessons offers the potential for students to engage in independent learning and self-assessment at their own convenience. This implies that students will have the opportunity to enhance their understanding of the subject matter through interactive AR experiences, evaluate their knowledge (Sharmin & Chow, 2020), and improve their performance (Ramos & Comendador, 2019). Students expressed high levels of motivation and interest in using this application as a means of learning biology concepts (Herrera et al., 2019).

The research and development approach stands out as the most commonly employed research method. It is a systematic process used for the creation and validation of educational products. This process follows a series of steps often referred to as the "R&D cycle." These steps involve examining relevant research findings related to the product under development, creating the product based on these findings, conducting field tests in the intended setting, and revising the product to address any deficiencies identified during the field-testing stage. This suggests that the product fulfills its objectives as defined by its behavioral criteria (Borg, 1983). Experimental research is another widely used research method. This method is used to objectively test the effect of AR technology on student learning (Hrastinski & Keller, 2007). Annisa and Subiantoro (2022) concluded that learning with a Mobile AR Respiratory System positively affected integration into socio-scientific issue-based biology learning. Sakulphon et al. (2015) also determined that utilization of AR technology enabled individuals of any gender to learn about the biological process of photosynthesis. Moreover, irrespective of their prior attitudes toward biology, both genders could actively participate and engage in the learning process through mobile AR. Meanwhile, Weng et al. (2020) concluded that AR had a positive impact on enhancing students' learning experience in biology. Their findings indicated that questionnaires and tests were the most widely used data collection tools in research. As the primary and predominant method of collecting quantitative data, the questionnaire ensured a standardized and comparable process of data collection (Taherdoost, 2022). In AR-related research, the questionnaire has been deployed to obtain data from respondents regarding the quality of AR used in terms of validity, practicality, and effectiveness (Arslan et al., 2020; Mustami et al., 2019; Garzón et al., 2017; Hidayat et al., 2020). Descriptive analysis has been the most widely used type of data analysis. The findings described reflect the stages commonly applied in R&D research, which involve the use of instruments such as questionnaires and tests to collect quantitative data, followed by descriptive analysis methods. The use of questionnaires as a data collection tool ensures a standardized process and allows for valid comparisons across respondents. Meanwhile, descriptive analysis is used to provide a detailed and clear depiction of the data, offering comprehensive insights into the effectiveness or quality of the product being tested, which is an essential part of every stage of research and development. Several novelties based on bibliometric analysis are presented below:

- Typically, research centers on the advancement and utilization of AR in the context of biology learning.
- The research variables used in research generally only cover the implementation of AR in biology learning.
- Motivation, attitude, learning style, literacy, and critical thinking are among the more interesting variables to study in the future, compared to merely knowing user feedback in learning to use AR.
- The research and development methodology has been widely employed and is increasingly emphasized. This indicates that the development research trend can continue in the future.
- The mixed-methods research method can provide a future opportunity to obtain more complete and accurate information in the field of AR-related biology learning.
- Questionnaires and tests can be alternative research data collection tools related to AR in biology learning.

The results of the bibliometric analysis serve as crucial elements in guiding researchers for future investigations involving AR media in biology education. In future, AR should serve not merely as a tool for assessing its capabilities as a supporting medium for biology learning; rather, it must evolve into a pivotal medium that enhances a broad range of competencies that are essential for students. This extends beyond a mere grasp of learning materials and encompasses diverse skill sets. To achieve more meaningful outcomes in future research, adopting a mixed-methods approach becomes imperative. Using mixed-methods research will introduce a higher level of complexity by considering various types of measured variables, resulting in more comprehensive data that can offer nuanced insights into the field. The exploration of this subject is becoming more compelling because numerous abstract biological concepts remain unexplored through the visualization capabilities of AR. Additionally, empirical evidence indicates that students exhibit interest and motivation when engaging with biology through AR media across different educational levels. Research in this field remains limited in scale compared to other scientific disciplines such as physics and chemistry. This potential presents an opportunity for both researchers and educators to enhance the overall quality of student learning, particularly within the realm of biology. Although the data for this study were sourced exclusively from the Scopus database, it is hoped that the findings will prove valuable, serving as a reference and laying the groundwork for future research opportunities.

LIMITATIONS AND CONCLUSIONS

Studies concerning AR in the context of biology learning have been carried out and published in the Scopus database. The examined sample articles in this study are expected to assist researchers in the field of biology education in their future research endeavors, as indicated by the bibliometric analysis. Review articles in this study only use the Scopus database. However, a review on the same topic that will be carried out using a different database may provide a broader picture.

In summary, research concerning AR in biology learning focuses on the creation and implementation of AR technologies. In this study, the predominant methodology employed is the research and development method, incorporating data collection through questionnaires and data analysis conducted in the form of a descriptive analysis. In general, research variables previously studied just touched on application and development, or on practical instructions in making AR, even though other variables such as motivation, attitude, and student learning styles using AR are more interesting variables. However, these have not been extensively studied in the field. Therefore, future research in this are of concern will be improved by using a mixed-methods approach accompanied by a focus on variables that foster students' interpersonal skills, not just by developing and knowing the extent to which AR applications can be operated by users. Furthermore, the results of the development of AR applications that are used for biology learning, as well as research articles by researchers are also not widely published. In fact, if the studies on AR applications are published, they will provide an opportunity for deeper exploration by other researchers, and the focus of research related to AR will be further developed.

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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