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Integration of Augmented Reality (AR) in Biology Education: A Systematic Literature Review

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Abstract: 21st-century learning encourages the integration of Augmented Reality (AR) technology as a support for learning media to improve learning effectiveness. This systematic literature review explores research trends and the integration of Augmented Reality (AR) in biology learning, especially at the formal education level. This study analyzed 23 articles from Scopus, Sage, and ERIC databases published between 2015 and 2023 to answer the six research questions posed. The analysis showed several key findings: 1) Most of the research related to AR implementation in biology materials was conducted in Indonesia and the United States; 2) College students are the dominant research subjects in AR; 3) AR-related research has increased significantly since 2015, reaching a peak in 2020, but experiencing fluctuations until 2023; 4) The majority of research focuses on using RnD research methods, with efforts to develop AR technology in various biological topics; 5) The most applied biological material topic using AR technology is the anatomical structure of human organs; 6) The challenges of AR implementation in biology learning include accessibility, hardware availability, cost, training, and adaptation to pandemic conditions. Based on these findings, future research recommendations include diversification of research subjects, development of innovative AR learning models, and more in-depth research on factors that influence the effectiveness of AR implementation, particularly in developing countries. It is also important to consider developing strategies to overcome the barriers identified to increase the success of AR implementation in the context of biology learning. Evaluation of the impact of AR use on student learning outcomes needs to be the focus of future research to complement the current findings.

Keywords: Augmented reality, Biology education, Systematic literature review, Research trends, Implementation challenges

Introduction

Changes in the needs and demands of the modern world encourage education to adapt to technology to prepare students to face future challenges. The use of technology in 21st-century learning is not just about introducing new tools, but also about creating learning experiences that are relevant to the demands and dynamics of the modern world. This century's learning encourages the integration of technology as a support for learning media to increase learning effectiveness. Augmented Reality (AR) is a modern technology that is developing rapidly

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and has proven its potential in the teaching and learning process (Sirakaya & Si Rakaya, 2018; Kalana et al., 2020). Learning using AR supports interactive, interesting experiences and creates opportunities for active participation for students (Kiryakova et al., 2018). The rising adoption of AR in education is probably because it aids in actively retaining information by bridging the divide between the physical and digital realms within the educational setting, incorporating virtual elements onto the real-world surroundings (Squire & Klopfer, 2007; Cheng & Tsai, 2013).

The use of AR in educational contexts continues to grow with awareness of its potential to improve the quality of learning. AR not only provides a more interactive learning experience but also opens up new opportunities in presenting information and complex concepts (Arslan et al., 2020). This technology can be integrated into various disciplines, from science and mathematics to the humanities, creating a more dynamic and relevant learning environment (Saidin et al., 2015). In the world of education, AR has been used to create realistic simulations, facilitate exploration in learning, and improve students' understanding of teaching material. Teachers can use AR to explain abstract concepts more visually and interestingly, triggering student curiosity and involvement (Susilo et al., 2020). In addition, using AR in learning can help students build 21st-century skills such as critical thinking, collaboration, and digital literacy (Schmidthaler et al., 2023). With technology continuing to develop, implementing AR in learning can be the key to creating a more immersive and relevant learning experience for today's generation of students.

The use of AR in science can positively impact learning, research, and the understanding of scientific concepts. AR technology is suitable for studying science (Annisa & Subianto, 2022; Wu et al., 2013) and is primarily utilized to explore concepts that are not directly visible to the eye (Kalana et al., 2020). Biology, as a part of science, encompasses a wealth of abstract material that can be challenging to comprehend due to the complexity of life concepts, particularly when the learning content is microscopic or not readily observable (Nurhasanah et al., 2019; Wang et al., 2022). Consequently, digital visualization technology holds significant importance in biology education, especially since specialized equipment like high-quality microscopes is often financially out of reach for educational institutions (Erbas & Demirer, 2019; Jenkinson, 2018). Thus, the integration of AR into biology learning becomes relevant and facilitates more effective learning.

Augmented Reality (AR) is often recognized as a promising educational tool that can be incorporated into biology lessons to overcome the limitations of conventional teaching approaches (such as the difficulty in visualizing abstract concepts, students' limited engagement and interest in class, and their struggles with comprehending intricate subjects). Mobile apps featuring AR functionalities offer opportunities for use in online, blended, or traditional teaching environments, which proves especially valuable in emergency situations (Stojšić et al., 2022). This technology was also utilized during the Covid-19 pandemic, where AR aided in enhancing the effectiveness of student learning at home (Chuang et al., 2023; Crompton et al., 2021). The COVID-19 pandemic necessitated a shift to distance education, requiring additional methods for presenting classroom and laboratory materials that students could access via devices (Cook et al., 2021). Research by Hoog et al. (2020) demonstrates that smartphones can be utilized in the field to access AR content swiftly created by teachers. In supporting learning during the pandemic, Abriata's (2022) study emphasizes the importance of adapting education to address complexity, change, uncertainty, vulnerability, and resilience.

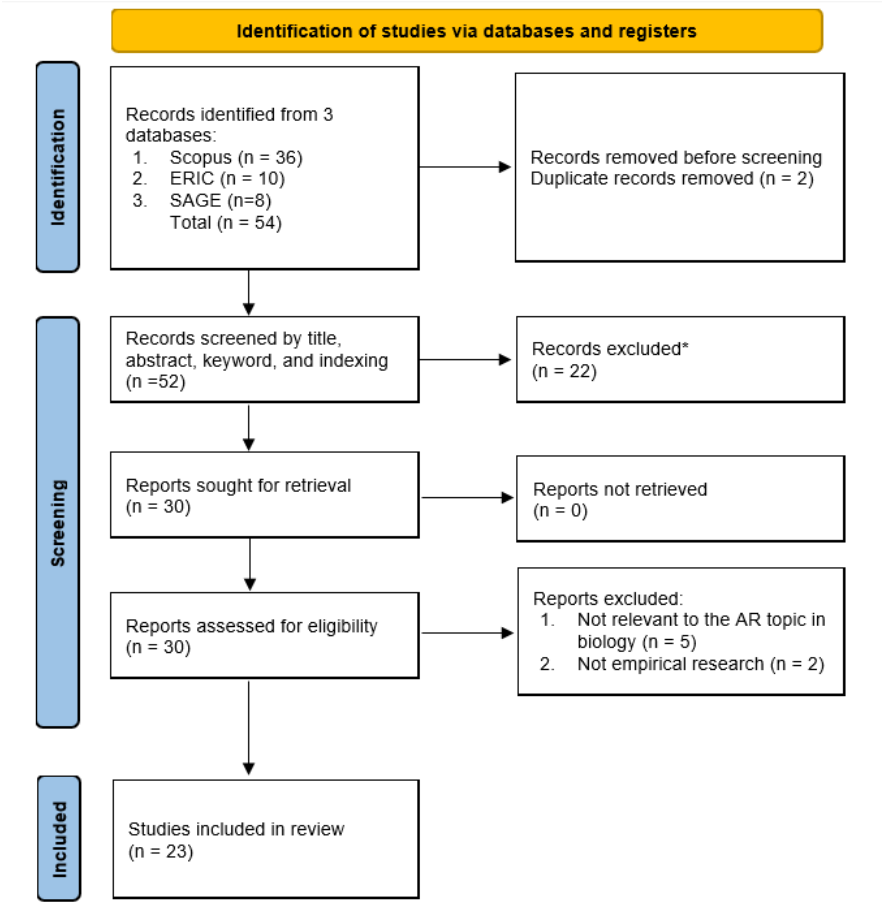
Furthermore, educational resources crafted with AR technology have a beneficial impact on students' motivation and cognitive development (Sotiriou & Bogner, 2008). Research suggests that AR applications can enhance students' learning experiences and support their cognitive functions, showcasing considerable promise for educational settings (Leighton & Crompton, 2017). In general, students display a favorable disposition toward learning when they perceive innovative technologies like AR as accessible and beneficial (Chang et al., 2013). AR implementation can make a substantial contribution to improving 21st-century learning by offering a more interactive, immersive, and engaged learning experience (Nesterov et al., 2017; Arslan et al., 2020). Learning using AR provides a customizable learning approach tailored to the needs and characteristics of individual students, thus holding great potential to transform the dynamics of education.

Given the significant benefits of Augmented Reality (AR) in supporting the learning process, efforts to develop and expand the implementation of AR in learning need to be intensified. This study aims to explore research trends and the integration of AR in biology learning at the formal education level. This research endeavors to provide answers to the following research questions: 1) How are AR-related studies distributed across various countries? 2) What educational level is intervened with AR learning in biology education? 3) How has AR-related research developed in the last decade (2013-2023)? 4) What research methods are most widely used in exploring the use of AR in biological materials? 5) What biological topics are most widely applied using AR technology? and 6) What challenges are faced in implementing AR in biology learning? Through this study, it is

hoped to make a significant contribution to our understanding of the application of AR in the context of biology learning.

Method

This section outlines the methodology utilized to review recent research (from January 2013 to December 2023) on Augmented Reality (AR) in biology education. A systematic literature review approach was employed to locate, choose, and critically evaluate pertinent studies, as well as to gather and analyze data from research presented in a structured scientific format (Juandi, 2021). The process of article search and selection in this review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and utilized the Scopus, ERIC, and SAGE databases to conduct a systematic review based on keywords such as "Augmented Reality" or "AR" and "biology education" or "biology learning". From this method, a total of 54 articles were identified and subsequently screened according to predefined criteria.



*Note:
1. Publicaion year as ineligible by automation tools (n=1)
2. Publications do not include Article and Conference Paper (n=7)
3. Not open access (n=14)

Figure 1. Source searching and selection process using PRISMA

Figure 1 above, involved several stages, including identification, screening, and inclusion. Initially, 54 articles were retrieved from the three databases (n=36 - Scopus; n=10 – ERIC; n=8 - SAGE) using predetermined keywords. Two duplicate articles were excluded, resulting in 52 articles for further screening. After applying inclusion and exclusion criteria, 22 articles were eliminated, leaving 30 articles for detailed examination. Finally, 23 articles meeting the criteria were chosen for systematic review and subsequent analysis. Each selected article's abstract was meticulously reviewed to identify relevant themes or sub-themes, followed by a thorough examination of the full text to gather additional information aligned with the research objectives.

Results and Discussion

Distribution of Studies related to AR in Various Countries

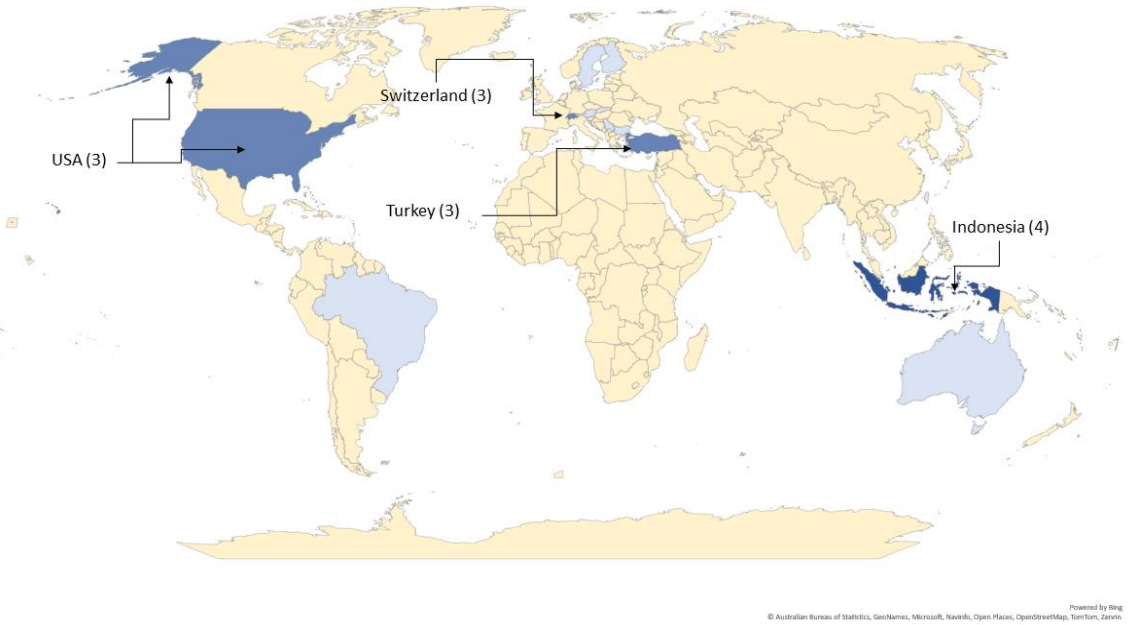


Figure 2**.** Distribution of studies related to AR in various countries

Figure 2 visually shows the distribution of Augmented Reality (AR) research in various countries using blue gradients. The results of the analysis of 23 articles show that Indonesia is a leader in AR research on biological materials with 4 articles recorded. Furthermore, Turkey, Switzerland, and the United States each contributed 3 studies. The results of this study identified that other countries participating in the AR study were Austria, Taiwan, Serbia, Singapore, Bulgaria, Slovakia, Finland, Sweden, Brazil, and Australia, each with one study.

Understanding the spread of AR research in various countries plays an important role because it provides deep insight into each country's contribution to global technological progress. Even though Indonesia is still classified as a developing country, its response to technology, especially AR, has proven to be very proactive and has had a positive impact (Annisa & Subiantoro, 2022; Erwinsah et al., 2019; Susilo et al., 2021; Wilujeng et al., 2018). However, overall, developed countries such as Switzerland, the United States, Austria, Taiwan, Singapore, Finland, and Sweden are also proven to be exploring AR studies. Through these findings, it is hoped that there will be international collaboration in AR research as a joint effort to achieve innovative and effective solutions, as well as build a strong working network between researchers and industry. A deep understanding of AR approaches and applications in different countries provides additional insight into the innovation and its potential use in specific sectors. Furthermore, knowledge about the dissemination of AR research can provide significant support in the design of relevant educational programs, advancing human resource development in the field of AR.

The Level of Education that Intervenes in the Implementation of AR

This study not only examines the distribution of AR research across countries but also identifies the primary subjects of AR research over the past decade. The findings reveal that the majority of studies have focused on university students, as illustrated in Figure 3.

This visualization highlights that AR implementation is predominantly observed in universities, with 13 articles supporting this observation. This preference for university-level implementation is attributed to the higher technological readiness of university students compared to those at lower levels of education. Moreover, educators are also targeted to enhance learning outcomes using AR. While AR applications in biology education have been extended to secondary schools, as evidenced by 3 articles, only one article discusses AR studies at the elementary school level. This demonstrates the adaptability of AR to different educational levels, thereby enhancing learning experiences to be more effective and relevant. Additionally, one study examines laboratory

instrument developers, showcasing innovative approaches and tools developed to facilitate distance learning and laboratory work, particularly in response to the challenges posed by the COVID-19 pandemic (Abriata, 2022).

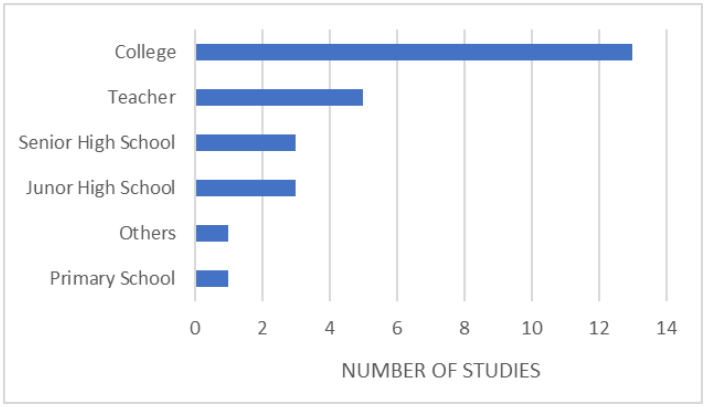


Figure 3. The educational level intervened with AR learning in biology education

Understanding the educational levels involved in AR implementation in biology education holds significant importance for several reasons. Firstly, identifying the educational level for AR implementation allows for personalized learning experiences, enabling developers and educators to allocate resources and efforts more effectively. This targeted approach is expected to enhance the efficiency and effectiveness of AR implementation in achieving biology learning objectives at specific educational levels. Additionally, information about the educational focus of AR aids in curriculum development tailored to meet the needs of students at that level, thereby optimizing learning outcomes and strengthening the integration between biology content and AR experiences.

Furthermore, implementing AR at various educational levels enables institutions to plan for the sustainability and further development of AR implementation. This supports long-term planning initiatives aimed at enhancing the quality of biology education through the integration of AR technology. Additionally, evaluating the impact of AR usage at different levels facilitates the identification of areas for improvement and adjustment. This understanding informs the development of appropriate training programs and technology support strategies, ultimately enhancing the effectiveness of AR implementation in biology education. By targeting the population that is the primary focus of AR implementation in biology education, the utilization of this technology can be more precise, efficient, and have a greater positive impact on student learning.

Research Development Trends related to AR in the Last Decade

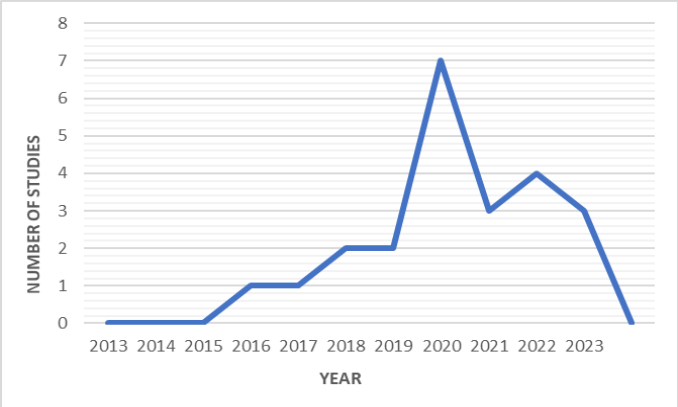


Figure 4. The level of education that intervenes in the implementation of AR

This research offers a comprehensive understanding of research trends in the integration of AR in biology learning by systematically analyzing articles published from 2015 to 2023. As AR technology advances rapidly, tracking its development provides valuable insights into its progress, aiding educators and researchers in staying updated with the latest developments. This information about AR advancements assists teachers and educational policymakers in adapting curricula and teaching methods to better align with biology learning needs.

Identifying research trends over the years sheds light on how the use of AR in biology learning evolves, including newer studies, changes in methodologies, or new discoveries that enhance the learning experience. With ongoing research development, scientific publications on AR integration are expected to furnish practitioners and researchers with both theoretical and empirical foundations to design and implement innovations in biology learning.

Research Methods in Exploring the Use of AR

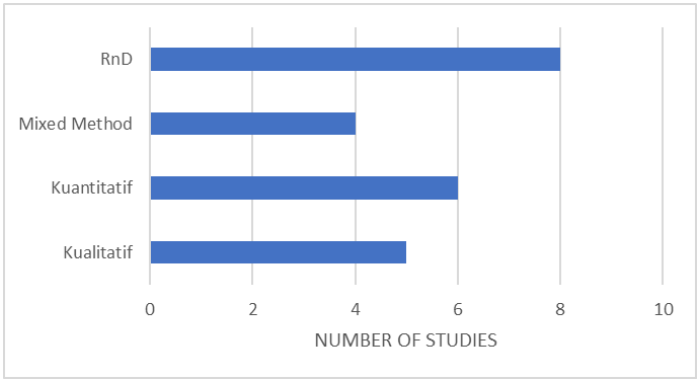


Figure 5. The research method is used to explore the use of AR on biological material

The results of reviewing the 23 articles indicate that the Research and Development (R&D) method has been widely used in the past decade. Additionally, quantitative research methods were employed in 6 studies, qualitative methods in 5 studies, and mixed methods were found in 4 studies. Most research utilizing the R&D method to develop AR technology across various biological topics lays the groundwork for future studies. The integration of augmented reality in education is viewed as a means to offer accessible and engaging content for students. AR is implemented through the creation of various applications/websites, such as integrated AR applications on smartphones (Arslan et al., 2020; Hoog et al., 2020; Vega Garzón et al., 2017), AR websites (Abriata, 2022; Rodríguez et al., 2021), and various mobile open sources enabling the visualization of abstract biological content using AR (Celik et al., 2020). Moreover, AR development involves collaborative systems that utilize online platforms as the main interface and incorporate AR technology to construct chatbots allowing social media interaction (Chuang et al., 2023). These R&D studies provide a foundation for further research to enhance and develop effective methodologies for integrating AR in biology learning settings.

Other research focuses on the implementation of AR developed through quantitative and mixed-method research. Several studies demonstrate that learning biology using AR positively impacts motivation, self-efficacy, and collaboration (Ciloglu & Ustun, 2023; Fuchsova & Korenova, 2019; Vega Garzón et al., 2017). AR-enhanced learning activities have also been shown to enhance students' understanding of biological concepts (Peterson et al., 2020) and improve learning outcomes, especially during the Covid-19 pandemic when students were learning at home (Abriata, 2022; Cook et al., 2021). Additionally, other studies indicate that AR-based learning enhances students' analytical, perspective-taking, and investigative reasoning skills (Annisa & Subiantoro, 2022). AR implementations are further enhanced through gamification to create authentic, experimental, and collaborative learning experiences (Cook et al., 2021; Vega Garzón et al., 2017). Moreover, AR implementation can be tailored to meet individual student needs, allowing for more personalized instruction that accommodates each student's unique learning style.

Qualitative research has also proven valuable in uncovering educators' experiences and reflections on using or creating AR games (Aivelo & Uitto, 2016). Another focus of qualitative research is eliciting student responses and qualitatively evaluating the use of AR headsets in biology learning contexts (Peterson et al., 2020). Involving users (teachers and students) in qualitative research helps understand their experiences with AR in biology learning, identifying positive aspects, challenges, and user needs essential for improving technology design and implementation. Furthermore, qualitative research assesses how AR contributes to students' understanding of biological concepts and engagement, providing a deep understanding of AR's impact on students' learning achievement, motivation, and perceptions. Importantly, qualitative research sheds light on specific contexts and obstacles encountered in integrating AR into biology learning, helping identify inhibiting factors and offering insights into overcoming these challenges.

Emphasis on Relevant Biology Topics

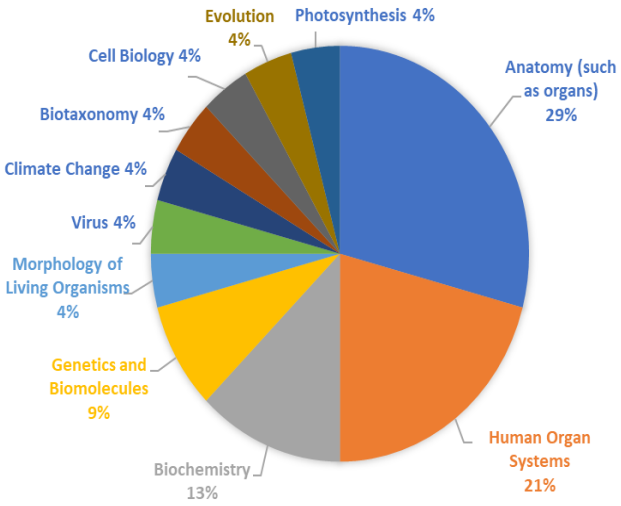


Figure 6. The biological material topics discussed in AR implementation

The integration of AR in education is increasingly vital to enhance the learning process and adapt to the demands of the 21st century. In the context of biology, which often involves abstract concepts, visualizing material can significantly aid student comprehension. This study aims to assess the extent to which AR is utilized in biological topics. Results from the analysis of various studies reveal that the focus on the anatomical structure of human organs is the most common application of AR technology, accounting for 29% of the articles reviewed. Additionally, applications related to organ systems in humans represent 21% of the articles. This prevalence is attributed to the complexity of organ systems and structures, where AR enables students to visualize biological organs and systems realistically in 3D, facilitating better understanding of intricate structures and relationships.

Another prominent topic explored in the reviewed articles is biochemistry, accounting for 13%. Many biological processes at the molecular or microscopic level are challenging to grasp through traditional teaching methods. AR enables students to observe chemical processes within the body at a closer scale, enhancing comprehension of cell and molecule interactions in a more realistic context. Various other biology topics also benefit from AR usage, allowing students to visualize living organisms, cell structures, and biological processes in a more immersive 3D format, thereby improving comprehension of complex biological concepts. Students can engage with virtual objects, delve deeper into biology topics, and test their knowledge through interactive activities. AR facilitates the creation of realistic simulations, such as ecosystem simulations or biological experiments, which are often impractical in traditional classroom settings.

Furthermore, implementing AR requires consideration of the Technological Pedagogical Content Knowledge (TPACK) framework approach. This framework assists teachers in developing specific learning strategies, particularly in biology, and selecting the most suitable technological tools to support these strategies. Overall, previous research offers valuable insights directly relevant to the biology curriculum, guiding the development of more comprehensive and pertinent AR content for biology learning.

Challenges of Implementing AR in Biology Learning

The main challenges to implementing Augmented Reality (AR) in biology education include issues of accessibility, hardware availability, cost, training, and adaptation to pandemic conditions. From the articles analyzed, it's clear that technology accessibility poses a significant hurdle, particularly in developing countries. Not all students have equal access to mobile devices, the internet, or other necessary tools, which hampers their participation in AR learning. Additionally, limited ownership of hardware like tablets or smartphones among students further diminishes the effectiveness of this technology. Other research points out barriers related to the substantial technical and financial costs of obtaining and preparing AR tools. This underscores the importance of adequate infrastructure and resource support, especially for implementing AR in STEM education.

Another obstacle stems from the lack of knowledge and skills in using AR technology among prospective science teachers. Educators require a thorough understanding to effectively integrate AR into their teaching practices. Without adequate training, they may feel uncertain or lack confidence in incorporating AR into learning activities. Therefore, comprehensive education and training in using AR in educational settings are essential to equip prospective science teachers with the necessary skills and knowledge. Additionally, support from schools, educational institutions, and governments in providing resources and training can help overcome these barriers.

During the COVID-19 pandemic, implementing AR in biology education faces additional challenges, such as adapting to changes in teaching approaches and transitioning to distance learning. Biology teachers must creatively integrate AR through online platforms, offer virtual demonstrations, and ensure curriculum relevance. Adapting devices and maximizing technology use are crucial in overcoming these barriers, making AR a valuable tool for enhancing students' understanding of biological concepts, even in remote learning settings. The identified barriers present significant challenges in implementing AR technology in biology education. It's hoped that by recognizing these challenges, stakeholders like curriculum developers and teachers can design more effective strategies to overcome them.

Conclusion

In conclusion, this systematic literature review highlights the increasing importance of integrating Augmented Reality (AR) technology into biology learning to enhance learning effectiveness in the 21st century. The analysis of 23 articles from various databases between 2015 and 2023 revealed several key findings. Firstly, AR implementation in biology education is predominantly studied in Indonesia and the United States, with college students being the primary research subjects. Secondly, there has been a significant increase in AR-related research since 2015, peaking in 2020, although experiencing fluctuations until 2023. Thirdly, the majority of research focuses on using Research and Development (R&D) methods to develop AR technology across various biological topics, with the anatomical structure of human organs being the most applied biological material topic using AR technology. Lastly, the challenges of AR implementation in biology learning include accessibility, hardware availability, cost, training, and adaptation to pandemic conditions.

Recommendations

Based on these findings, future research recommendations include diversifying research subjects, developing innovative AR learning models, and conducting more in-depth research on factors influencing the effectiveness of AR implementation, particularly in developing countries. It is also crucial to devise strategies to overcome the identified barriers to increase the success of AR implementation in biology learning contexts. Additionally, evaluating the impact of AR use on student learning outcomes should be a priority for future research to complement the current findings and guide further advancements in AR integration in biology education.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

Acknowledgements or Notes

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