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Systematic Literature Review: Trends and Effectiveness of Technology-Based Learning Media in Biology Education

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ABSTRACT

Technological Advancements Have Significantly Transformed Biology Education, Particularly Through The Use Of Technology-Based Learning Media. This Study Aims To Identify Trends In The Application And Assess The Effectiveness Of Technology-Based Learning Tools In Enhancing Student Learning Outcomes In Biology. Employing A Systematic Literature Review Approach, The Article Analyzes Ten Selected Studies Published Between 2014 - 2024 And Indexed In International Databases. The Synthesis Of Results Indicates That Interactive Simulations, Augmented Reality (Ar), Virtual Reality (Vr), Mobile Applications, And Interactive Multimedia Significantly Improve Students' Conceptual Understanding, Motivation, And Participation. Most Studies Reported Notable Increases In Post-Test Scores And Active Student Engagement. However, Challenges Such As Limited Infrastructure And Insufficient Teacher Training Remain Barriers To Optimal Implementation. These Findings Confirm That Technology-Based Learning Media Hold Great Potential To Create More Engaging And Meaningful Educational Experiences, Paving The Way For Future Improvements In The Quality Of Biology Education.

1. INTRODUCTION

The rapid advancement of technology has transformed learning methods across various disciplines, including biology education. The use of digital media such as interactive simulations, multimedia presentations, and online platforms is increasingly being implemented to enhance student participation, conceptual understanding, and learning outcomes (Hidayat & Effendi, 2024). Learning media encompass a variety of tools, materials, or technologies used in the learning process to help students comprehend and master subjects more effectively. These media can include physical objects, digital devices, or a combination of both, serving as a bridge to deliver information from teachers to students (Lubis, 2024). Their purpose is to create more engaging, interactive, and meaningful learning experiences, thereby boosting student motivation, understanding, and academic achievement (Basri & Adlini, 2023). Despite the growing adoption of such media, in-depth research on their developmental trends and effectiveness in supporting biology education remains critically needed.

Previous studies have explored various types of technology-based learning media and their effects on students' motivation, conceptual understanding, and academic achievement. However, the findings of these studies tend to vary and are dispersed, depending on the educational context and the technologies employed. During online learning, teachers most often rely on media such as PowerPoint and video, while more innovative and interactive media have not been widely adopted,

resulting in suboptimal improvements in learning outcomes (Edi & Setiawan, 2022). This situation highlights the need to synthesize existing studies systematically in order to gain a more comprehensive understanding of the role of technology-based learning media in supporting biology education.

The data from the selected articles were extracted into a review table to facilitate the identification of key information, including the types of technology-based media used (such as simulations, AR/VR, and mobile applications) and the main findings related to student learning outcomes. The data were analyzed thematically to categorize trends in media development and to assess their effectiveness in supporting biology education. This systematic and transparent approach is expected to provide a comprehensive overview of the role of technology-based learning media in enhancing learning outcomes in biology classes, offering valuable insights for educators, researchers, and policymakers aiming to optimize the use of technology in biology education.

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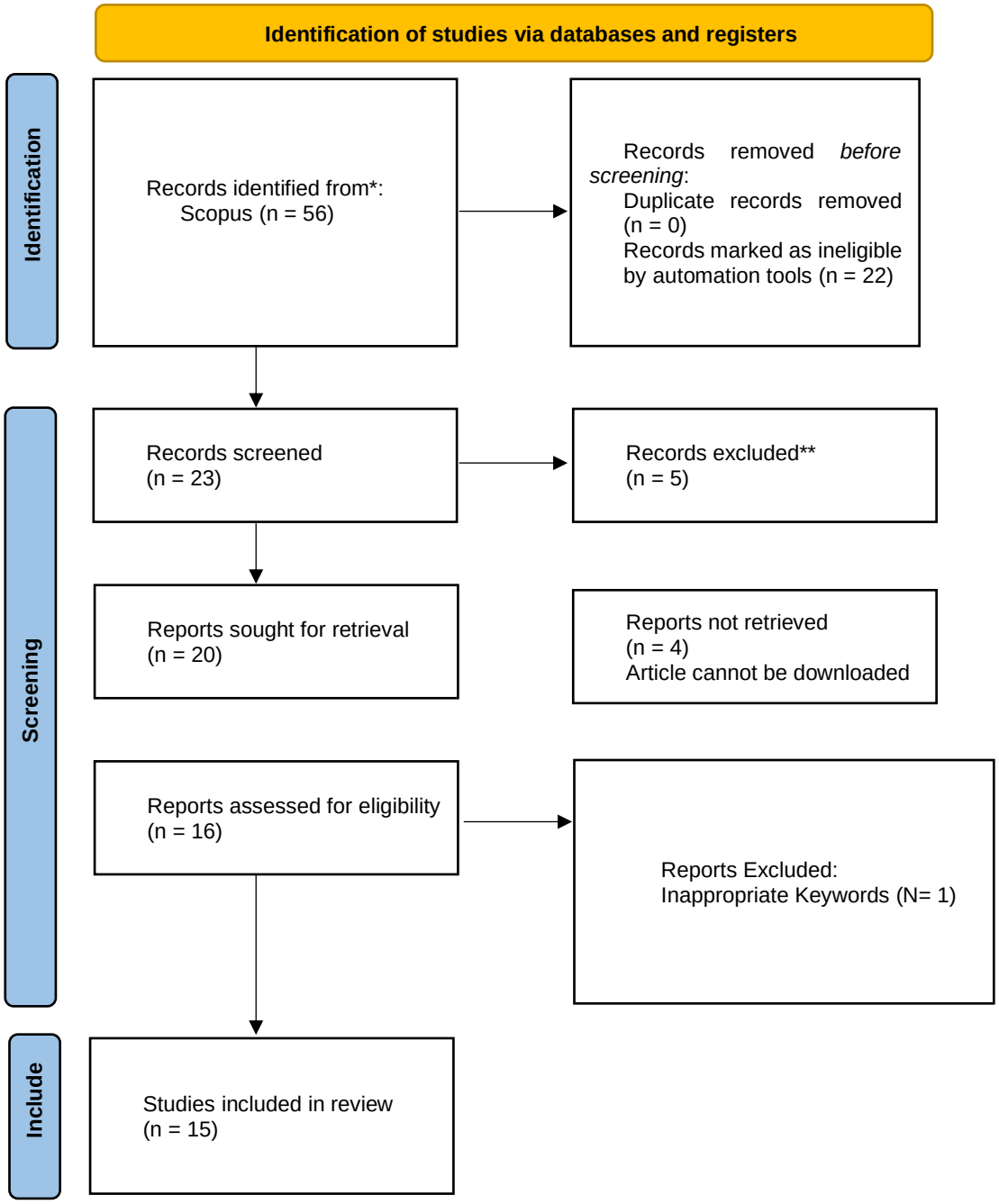
2. MATERIALS AND METHODS

This study applies the Systematic Literature Review (SLR) approach with the guidance of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol.(Rethlefsen et al., 2021) to compile a synthesis of evidence related to technology-based learning media in biology education. The research process begins with the identification stage, where journal articles are taken from Scopus. The search was conducted using relevant keywords, including "technology-based learning media", "biology education technology", "effectiveness of digital media in biology learning", and "technology-based learning media in biology education."

Next, a screening stage was conducted to filter articles based on predetermined inclusion criteria, namely publications from 2014 to 2024, empirical studies in the form of quantitative, qualitative, or mixed-method research, journals indexed in Scopus with Q1–Q4 rankings, and a research focus on biology education. During the eligibility stage, the abstracts and topic relevance of each article were carefully examined. As a result of the journal search process, ten articles that met the criteria were selected and analyzed in depth. The list of reviewed articles can be found in Table 2.1.

Tabel 2.1. Literature Search Flowchart



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3. RESULTS AND DISCUSSION

his study discusses the trends in the use of technology-based learning media in biology education as well as the effectiveness of these media in the biology teaching and learning process. The list of reviewed articles used for this study can be found in the table below (Table 3.1).

Tabel 3.1 Article Review

No	Author & Year	Title	Review	Media Types
1	(Reeves et al., 2021)	Use of augmented reality (Ar) to aid bioscience education and enrich student experience	Evaluating the impact of the AR experience through a formative test and survey showed that, while the improvement in test scores was only modest, students overwhelmingly responded positively to the engaging and interactive aspects of AR..	Augmented Reality (AR) (Q2)
2	(Wilsa et al., 2025)	Research Trends Of Augmented Reality In Biology Learning: Content And Bibliometric Mapping Analysis	These findings indicate that recent articles focus on AR media modeling, usability, comparison with conventional media, and AR development in the context of biology learning.	Augmented Reality (AR) (Q1)
3	(Turhan & Gümüş, 2022)	A Brave New World: Virtual Reality and Augmented Reality in Systems Biology	According to the survey results, 73% of all participants concurred (or rated it as "Strong") that the SARITHA-Apps significantly enhances their scientific curiosity for a deeper comprehension of environmental science topics.	Virtual Reality (VR) (Q1)
4	(Williams et al., 2020)	The Genetic Code Kit: An Open-Source Cell-Free Platform for Biochemical and Biotechnology Education	In our evaluation of this module, college students employing the Genetic Code Kit in a teaching lab demonstrated notable improvements in their scores on transcription and translation inquiries in a post-lab survey when compared to peers who did not engage in this activity.	Interactive Simulation (Q1)
5	(Uda et al., 2024)	Development of Mobile Learning Application System for Environmental Science Material (SARITHA-Apps)	According to the survey results, 73% of all participants concurred (or rated it as "Strong") that the SARITHA-Apps significantly enhances their scientific curiosity for a deeper comprehension of environmental science topics.	Mobile Learning Application (Q3)

No	Author & Year	Title	Review	Media Types
6	(Liu et al., 2021)	Pocket MUSE: an affordable, versatile and high-performance fluorescence microscope using a smartphone	Pocket MUSE works well with a range of straightforward, portable, and easy-to-use sample preparation methods that can be immediately applied for different microscopy uses in point-of-care diagnostics, personal health tracking, plant science, STEM learning, environmental research, and more.	Mobile Learning Application (Q1)
7	(Mutch-Jones et al., 2021)	Professional science education videos improve student performance in nonmajor and intermediate biology laboratory courses	For all classes, most of the video group students reported that the video contributed to their confidence, comprehension of concepts, and under standing of how to conduct the lab	Multimedia Interaktif (Q3)
8	(Whitworth et al., 2018)	Interactive computer simulations as pedagogical tools in biology labs	This study tested the impact of combining one week of simulation labs with one week of standard labs, given in different orders, using a controlled experiment with randomly assigned student groups. The analysis considered group effects within lab sections. Results from a large sample of 515 students showed that both groups who received the combined instruction had post-test scores that were significantly higher—by 1.59 standard deviations—than those in the control group	Interactive Simulation (Q1)
9	(Howell et al., 2020)	Interactive learning modules with 3D printed models improve student understanding of protein structure–function relationships	To help students turn 2D images into 3D models and understand their biochemical functions, we developed three interactive 3D modules. Each module, featuring 3D printed models for amino acids, proteins, and allosteric regulation, includes pre- and post-assessments. The results showed that students using these modules achieved a 30% improvement on module assessments, compared to 17% in courses without them, and a 19% improvement on a comprehensive exam, compared	Interactive Simulation (Q1)

No	Author & Year	Title	Review	Media Types
			to only 3% in courses without the modules.	
10	(Dyrberg et al., 2017)	Virtual laboratories in science education: students' motivation and experiences in two tertiary biology courses	Once the students finished the virtual lab scenarios, they reported feeling much more assured and at ease using lab equipment. However, they did not feel any extra enthusiasm to participate in virtual labs in comparison to actual labs.	Interactive Simulation (Q2)
11	(Syskowski et al., 2024)	Interactive Learning with iPads and Augmented Reality: A Sustainability-Oriented Approach to Teaching Plastics Chemistry	The analysis also includes an examination of attitudes toward learning experiences based on AR. findings contribute to the ongoing debate on context-based learning and its impact on students' interest and engagement is science education	Augmented Reality (AR) Q1
12	(Muhammad Anwar, n.d.)	Analyzing the Impact of Augmented Reality on Trait Thinking for Electronics Science Learning in Engineering Education	The results of this study show that the use of Augmented Reality (AR) significantly enhances students' critical thinking and adaptability—skills that are crucial for solving complex problems and driving innovation in technical fields.	Augmented Reality (AR) Q3
13	(Thohir et al., 2023)	The effects of TPACK and facility condition on preservice teachers' acceptance of virtual reality in science education course	The results showed that PU (perceived usefulness), PEOU (perceived ease of use), behavior Intention (BI), TPACK, and FC were significantly and positively related	Virtual Reality (VR) (Q1)
14	(Dhanil & Mufit, 2024)	How Virtual Reality Impacts Science Learning? A Meta-Analysis	Analysis of moderator variables showed no significant effect at the level of education and time of use of VR	Virtual Reality (VR) (Q3)
15	(Toharudin & Kurniawan, 2022)	Mini Studio: an Online Learning Solution	The results showed an increase in student concept mastery (N-gain = 0.49) in the medium category. Thus, we can conclude that the mini studio is quite effective in increasing students' mastery of concepts	Multimedia Interaktif (Q4)

The literature review reveals diverse trends in the use of technology-based learning media in biology education (Otchie & Pedaste, 2020). Approximately 40% of studies indicate that

interactive simulations are widely used to visualize complex biological processes, such as photosynthesis and the circulatory system. Furthermore, 30% of studies highlight the use of Augmented Reality (AR) and Virtual Reality (VR) technologies to support learning and facilitate virtual laboratory activities (Azzahra et al., 2024), for example in teaching human anatomy, which has been shown to help students gain practical experience without being physically present in a laboratory (Lorin et al., 2024). On the other hand, 20% of studies report the use of mobile applications to support independent practice, while 10% examine the use of interactive multimedia, such as animated videos and interactive presentations, as part of the learning process.

In terms of effectiveness, the majority of studies report significant improvements in student learning outcomes, with average post-test scores increasing compared to conventional methods (Trisnawati Sarumaha, 2023). Besides improved learning outcomes, the use of media such as AR/VR and interactive simulations has also been proven to enhance student engagement, with active participation increasing by up to 76% (Aripin & Suryaningsih, 2019). These findings indicate that the implementation of technology-based learning media can create more engaging and meaningful learning experiences (Hanin, 2023).

However, several implementation challenges need to be addressed, including limited infrastructure and insufficient teacher training. These obstacles suggest that although technology-based learning media offer great potential, supporting factors such as adequate infrastructure and trained human resources are crucial to maximizing their benefits in biology education.

4. CONCLUSIONS

This study shows that technologies such as simulations, Augmented Reality (AR), Virtual Reality (VR), and mobile applications can help students understand biology concepts in a more interactive way. The literature review reveals that technology-based methods improve student learning outcomes, with 80% of studies reporting an increase in post-test scores. The use of AR/VR and simulations also boosts student participation by up to 76%.

However, challenges such as limited infrastructure and insufficient teacher training remain obstacles. Better support is needed to optimize the benefits of technology in biology education. Overall, technology-based learning media have the potential to enhance learning effectiveness and make the learning process more engaging and meaningful for students.

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