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Mapping the landscape of biology learning media publications in Indonesia: A bibliometric analysis

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Abstract: Media integration in biology education is increasingly emphasized to support active, meaningful, and student-centered learning. This bibliometric analysis aims to explore trends, patterns, and research focus areas on media use in biology learning over the past ten years. This study employed a Scopus search using the keywords "Learning media" and "Biology," which then yielded 114 initial records. A PRISMA-based screening process was applied, limiting inclusion to original research articles published between 2016 and 2025, written in English, classified under the social sciences, and available as open access publications. After applying all criteria, 17 articles were included for in-depth analysis. The results show a fluctuating but generally increasing trend in publication frequency, especially in recent years. Most studies employed a research and development (RnD) method approach to evaluate the effectiveness of media in improving student learning outcomes and engagement. Indonesian authors contributed the most publications, with a high collaboration pattern of at least four authors on each published article. The biology topics studied include food biology, environmental biology, general biology, modern biology, genetics, biodiversity, botany, taxonomy, and immunology, all of which are topics with high conceptual complexity and therefore require the support of visual and interactive media in their learning. This review successfully maps the research landscape on the use of media in biology education and serves as a valuable reference for future studies in selecting relevant biological content, methodological frameworks, and collaborative approaches.

Keywords: Biology education, conceptual complexity, engagement, learning media

Abstrak: Integrasi media dalam pendidikan biologi semakin ditekankan untuk mendukung pembelajaran yang aktif, bermakna, dan berpusat pada siswa. Analisis bibliometrik ini bertujuan untuk mengeksplorasi pola, dan area fokus penelitian tentang penggunaan media dalam pembelajaran biologi selama sepuluh tahun terakhir. Studi ini menggunakan pencarian Scopus dengan kata kunci "Media pembelajaran" dan "Biologi," yang kemudian menghasilkan 114 catatan awal. Penerapan proses penyaringan berbasis PRISMA, membatasi inklusi pada artikel penelitian asli yang diterbitkan antara 2016 dan 2025, ditulis dalam bahasa Inggris, diklasifikasikan di bawah ilmu sosial, dan tersedia sebagai publikasi akses terbuka. Setelah menerapkan semua kriteria, 17 artikel dimasukkan untuk analisis mendalam. Hasilnya menunjukkan tren frekuensi publikasi yang berfluktuasi tetapi umumnya meningkat, terutama dalam beberapa tahun terakhir. Sebagian besar penelitian menerapkan pendekatan metode penelitian pengembangan (RnD) untuk mengevaluasi efektivitas media dalam meningkatkan hasil belajar dan keterlibatan siswa. Penulis Indonesia sebagai penyumbang publikasi terbanyak dengan pola kolaborasi tinggi dengan minimum 3 orang penulis pada setiap artikel yang diterbitkan. Topik biologi yang dikaji meliputi biologi pangan, biologi lingkungan, biologi umum, biologi modern, genetika, biodiversitas, botani, taksonomi, dan Imunologi yang merupakan topik kajian dengan kompleksitas konseptual tinggi sehingga memerlukan dukungan media visual maupun interaktif dalam pembelajarannya. Tinjauan ini berhasil memetakan lanskap penelitian tentang penggunaan media dalam pendidikan biologi dan berfungsi sebagai referensi berharga untuk studi masa depan dalam memilih konten biologis yang relevan, kerangka metodologis, dan pendekatan kolaboratif.

Kata kunci: Pendidikan biologi, kompleksitas konseptual, keterlibatan, media pembelajaran

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INTRODUCTION

The integration of instructional media into science education, particularly biology has gained increasing attention as educators seek to enhance conceptual understanding, student engagement, and meaningful learning outcomes. This pedagogical shift has not only transformed how knowledge is accessed but has also opened new learning spaces in which instruction becomes more flexible, personalized, and learner-centered (Hardianto et al., 2024). As a core discipline characterized by abstract and conceptually complex content, biology requires the support of appropriate media to facilitate visualization, conceptual linkage, and internalization of biological processes and phenomena (Husamah et al., 2022). Within this context, instructional media in biology refers to any instructional tool whether digital, visual, auditory, or tactile designed to mediate the delivery of biological content and strengthen learning outcomes (Akamu et al., 2024; Setyantoko et al., 2023).

Research on instructional media in biology education has been widely documented. The incorporation of diverse forms of educational media such as interactive simulations, animations, mobile-learning applications, augmented reality (AR), virtual laboratories, visualized infographics, and digitally mediated platforms contextualized within local cultures has shifted from being merely optional to becoming a pedagogical necessity in twenty-first century biology classrooms (Kassa et al., 2024; Ouhaichi et al., 2023). The use of instructional media is now recognized as a crucial component for fostering more interactive and effective biology learning environments (Koca & Kizilay, 2024; mustofa et al., 2024; Yomaki et al., 2023). Complex scientific content in genetics, biotechnology, and physiology demands concrete and interactive media to bridge the gap between abstract biological concepts and real-world phenomena (Permana et al., 2024).

Instructional media used in biology education serves multiple pedagogical purposes, including enhancing conceptual mastery, stimulating curiosity, promoting scientific reasoning, and fostering collaborative learning. Recent studies have demonstrated that the use of media reduces misconceptions in core biological topics such as cell division, biotechnology, and genetics (Navarro et al., 2024; Rosamsi et al., 2023). Moreover, empirical evidence indicates that media integration not only influences cognitive outcomes, but also contributes to positive shifts in students' attitudes toward biology, supports self-directed learning, and strengthens digital literacy (Chuang et al., 2023; Syahfitri & Safitri, 2024). These findings align with constructivist learning principles, wherein instructional media functions as a mediating tool that enables learners to actively construct knowledge through experiential engagement and interaction (Ntaila & Mbaraka, 2023).

Although numerous studies have examined the integration of instructional media in biology education, the existing body of research remains fragmented and primarily focused on product development or classroom implementation. Prior reviews have mainly addressed broader areas such as STEM media (Faria & Miranda, 2024), mobile learning in science education (Kumalasari et al., 2023), augmented reality in natural sciences (Permana et al., 2024), or technology-enhanced laboratories (Miller et al., 2025). To date, no comprehensive review has specifically synthesized empirical publications on the use of instructional media within the biology domain, nor mapped the evolution, methodological landscape, and thematic orientation of this field. This gap highlights the lack of consolidated knowledge regarding how media have been conceptualized, developed, and applied in biology learning over time.

Therefore, this review is warranted to systematically map research trends, identify dominant methodological patterns, and reveal topical distribution within biology-based instructional media studies. The novelty of this paper lies in its explicit focus on biology education, its integration of bibliometric mapping with systematic literature screening, and its emphasis on the Indonesian context as one of the emerging contributors in this field. Such insights are essential for clarifying the current research structure and informing future directions in media-based biology education research.

Research question (RQ)

The formulation of research questions was used to determine the scope of the review and to establish a clear analytical focus. The research questions were developed in response to the needs of the selected topic and are expressed as follows:

RQ1: What are the publication trends and research characteristics of Indonesian studies on instructional media in biology?

RQ2: How is instructional media in biology currently characterized and implemented in Indonesia?

The limitations of this review focus on article distribution by publication year, trending keywords, collaboration patterns, research methods, biological sub-disciplines, and educational levels at which the instructional media were implemented.

METHOD

Study type

This study employs a bibliometric analysis, a research method recognized for its validity, reliability, and replicability (Ouhaichi et al., 2023). Through this method, researchers are able to critically identify, assess, and synthesize existing literature to address specific research questions (Xiao & Watson, 2019; (Snyder, 2019).

Search article and inclusion criteria

The authors used the keyword “learning media” in the SCOPUS database search menu. The retrieved data were exported in *.CSV and *.RIS formats and subsequently integrated into a reference manager (Mendeley). VOSviewer software was employed to visualize the data for clearer, more informative, and communicative representation. The SCOPUS search query applied in this study was: TITLE (“learning media”) AND (“learning media” + “biology learning”) AND (LIMIT-TO (PUBYEAR, 2025) OR LIMIT-TO (PUBYEAR, 2016)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (PUBSTAGE, “final”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SUBJAREA, “SOCI”)) AND (LIMIT-TO (OPEN ACCESS, “Open Access”). Using this search strategy, we identified 17 articles. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol was used to guide the inclusion and exclusion process, following Gallagher et al. (2016), and as also adopted by Husamah et al. (2022) and Hardianto et al. (2024).

The inclusion criteria comprised four points. First, only articles published within the last ten years, from January 2016 to July 2025, were considered. Second, the selected articles were required to fall under the Social Sciences subject area, have a final publication

status, and be written in English. Third, the articles had to be openly accessible. Fourth, both the abstract and full text were required to demonstrate relevance to the topic of this study.

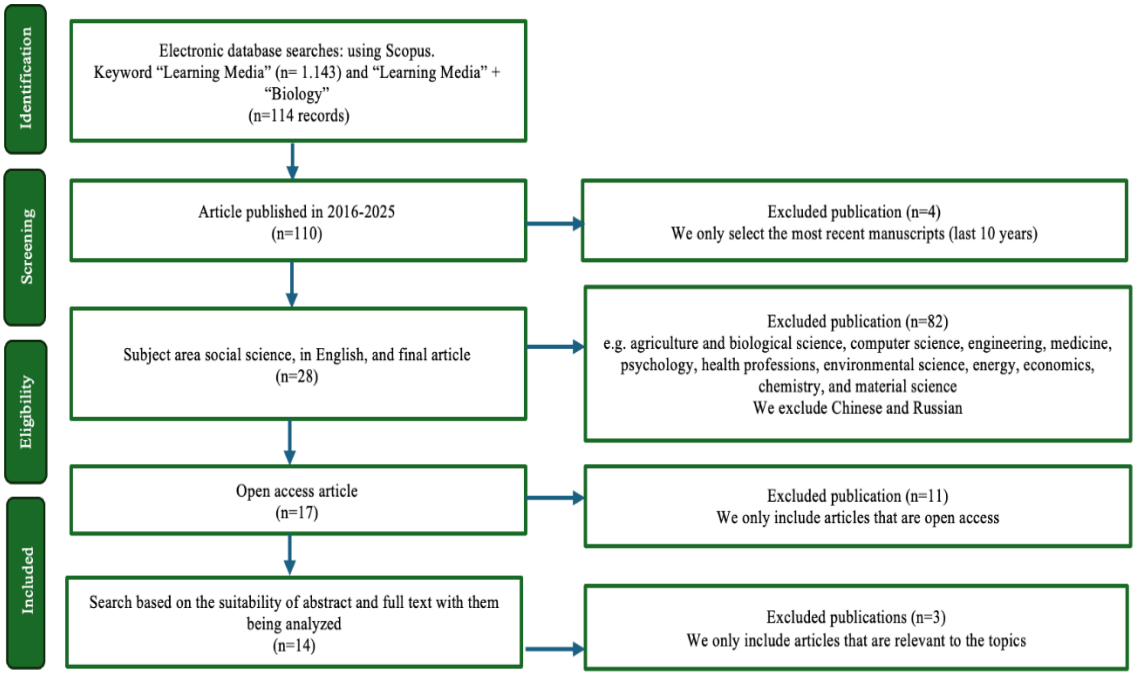

Fig. 1. The PRISMA model

Based on the screening process illustrated in Figure 1, the initial search using the keyword "media pembelajaran" yielded a total of 1,143 articles. However, because the present bibliometric analysis specifically focuses on the use of instructional media within the context of biology education, the search was refined by adding more specific keywords. This refinement reduced the results to 114 articles, indicating that 1,029 records were excluded due to irrelevance to the focus of the study. The authors restricted the selection to articles published between 2016 and 2025 to ensure that only recent and relevant publications were included, as this ten-year span represents contemporary developments in the field. The temporal filtering resulted in 110 eligible articles, while 4 records were excluded. Subsequent filtering limited the data set to English-language, Social Sciences–indexed, and final-stage publications to maintain consistency and avoid misinterpretation, given that English serves as the lingua franca of academic communication. This stage yielded 28 articles. Conversely, 82 non-English publications and articles outside the relevant disciplinary scopesuch as agriculture, computer science, engineering, medicine, psychology, health professions, environmental science, energy, economics, chemistry, and materials science were removed from the review.

In the next stage, the screening was limited to studies available in open-access format, particularly those related to educational research. This process yielded 17 records, while 11 articles were excluded due to restricted access. At the final eligibility stage, the authors carefully examined the abstracts and full texts to ensure relevance to the focus of the review. Following this refinement, a final set of 14 articles met all predetermined criteria, whereas 3 records were excluded for failing to satisfy the core thematic requirements of the study.

RESULTS AND DISCUSSION

Year distribution of learning media publication in biology subject

The temporal distribution of publications is a key indicator for examining the evolution of research on instructional media in biology education. Chronological mapping enables the identification of emerging research trends, shifts in thematic interests, and changes in scholarly priorities over time. Figure 2 depicts the publication trends for studies on instructional media in biology between 2016 and 2025.

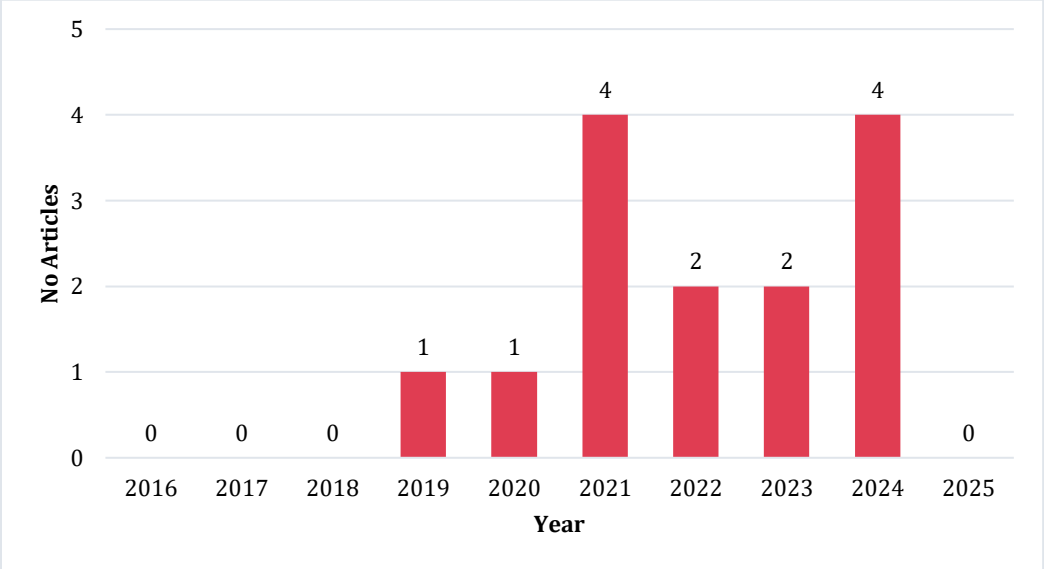

Fig. 2. Distribution of publication years

Figure 2 provides an overview of the temporal distribution of publications, offering a preliminary indication of how research on instructional media in biology education has developed between 2016 and 2025. This trend requires further examination to understand how scholarly interest in the use of media in biology education has evolved, and how external factors such as global pandemic disruptions and curriculum reforms may have influenced its trajectory. Notably, no publications on this specific topic were observed between 2016 and 2018. This absence likely indicates that the integration of instructional media into biology education was still in its formative stage and had not yet attracted substantial attention within the academic community. The first publications appeared in 2019, marking the initial emergence of a research body that would subsequently continue to expand.

A notable shift occurred in 2021, during which the number of publications increased to four. From our perspective, this surge was not coincidental. The COVID-19 pandemic brought about a rapid and significant transformation of the educational landscape. Teachers, students, and institutions worldwide were compelled to adapt swiftly, and instructional media became essential tools for making remote biology learning more interactive and accessible. As highlighted by Chuang et al. (2023), the pandemic accelerated the adoption of immersive tools such as virtual reality in science classrooms, not only for content delivery but also for sustaining student engagement during fully online learning (Irianti et al., 2023).

In 2022–2023, a slight decline was observed, with only two articles recorded during this period. However, we consider this decrease to be temporary. The year has not yet concluded, and publication processes often require several months to complete. According to Elsevier (2023), education journals typically take between four and nine months to release accepted manuscripts, suggesting that many submissions from 2024 may still be under review or pending publication.

It is also noteworthy that prior to 2019, no articles met the inclusion criteria of this review. This indicates that research focusing specifically on systematic reviews and media use in biology education is relatively recent. Triyanto et al. (2022) support this observation, demonstrating that interest in media-based science education has grown substantially in recent years, driven by advances in educational technology and the increasing need to design more adaptive and engaging learning environments.

Publication output related to instructional media continued to rise in 2024, reaching its highest point and mirroring the peak observed in 2021, when education systems had already become accustomed to online learning. In that year alone, five articles were published. This momentum coincided with the full implementation of Indonesia's Kurikulum Merdeka, which emphasizes flexible, student-centered, and context-responsive learning approaches (Kemendikbudristek, 2024). At the same time, government-funded programs such as PKM, MBKM, and Hibah Riset Dosen Pemula offered incentives and resources for educators and researchers to explore innovative media-based instructional strategies (Ditlitabmas, 2025). As highlighted by Annisa and Subiantoro (2023), curriculum reform has stimulated the development of instructional media that is both innovative and grounded in local contexts, and this impact is clearly reflected in recent publication trends.

Type of research of learning media publication in biology subject

Categorizing research types constitutes an important component of this systematic review, as it helps clarify the methodological landscape of studies on instructional media in biology education. This process allows for the identification of dominant approaches as well as their respective strengths and limitations. A summary of the research types is presented in Table 1.

Table 1. Classification of research designs on instructional media in biology education

No	Type of Research	N	References
1	Quantitative	2	(Elme et al., 2022a; Uda et al., 2024)
2	Mixed-Method	1	(Safitri et al., 2024)
3	RnD	10	(Azrai et al., 2024; Khastini et al., 2021; Leksono et al., 2021, 2023a; Nurhayati et al., 2022; Ristanto et al., 2020; Sukenda et al., 2019; Susantini et al., 2021; Susanto et al., 2024; Suwandi et al., 2023)
4	Qualitative	1	(Isnaeni et al., 2021)

Table 1 shows that the Research and Development (R&D) method dominates the field, accounting for 10 studies. This suggests that biology instructional media research is heavily driven by efforts to design, refine, and validate new instructional tools. Such

dominance reflects educational demands for innovative media that can mediate complex biological concepts and translate them into more tangible and comprehensible learning experiences(Azrai et al., 2024; Khastini et al., 2021).

The R&D method is deemed relevant not only because it produces theoretical findings, but also because it yields tangible products that can be directly implemented in instructional practice, such as e-modules, interactive applications, or technology-based digital media (Elme et al., 2022). Moreover, this approach is flexible, as it integrates descriptive, evaluative, and experimental phases that enable researchers to systematically assess the validity, practicality, and effectiveness of instructional media (Mardiyah et al., 2020; Rahmawati & Cintamulya, 2025). In the context of educational digitalization, the adoption of R&D reflects a strong push toward technological innovation aligned with the demands of twenty-first century learning. Accordingly, the predominance of R&D highlights a research orientation in biology that prioritizes practical and applicative contributions to improving instructional quality (Paxinou et al., 2020).

Despite the clear dominance of R&D, several studies employed quantitative approaches to empirically verify the effectiveness of instructional media. Two quantitative studies, for example, focused on measuring improvements in learning outcomes and conceptual understanding through statistically tested numerical analysis. This indicates that beyond the development of new products, research on biology instructional media also requires objective evidence regarding the impact of media use on students' academic performance (Ntaila & Mbaraka, 2023; Vekli & Çalik, 2023; Zulkifli et al., 2022).

In addition to the dominance of R&D studies and the presence of quantitative research, one study employed a mixed-method approach and another adopted a qualitative design. The mixed-method approach was selected for its capacity to provide more comprehensive analyses by integrating quantitative data such as learning outcomes with qualitative information regarding students' experiences and perceptions (Syahfitri & Safitri, 2024). However, its use remains limited due to the relative complexity of the design and the methodological skills required to integrate both forms of data.

Meanwhile, qualitative research emphasized in-depth exploration of instructional contexts, such as teacher–student interactions and factors influencing the implementation of instructional media (Isnaeni et al., 2021). Yet, in the context of digital media research, qualitative designs are often perceived as less efficient, as prevailing research interests prioritize product evaluation and practical applicability; furthermore, qualitative inquiry presents technical and ethical challenges in digital data collection and analysis (Silverman, 2020; Mathews, 2023; Vasileiou et al., 2018). Despite their limited number, mixed-method and qualitative studies nonetheless provide important contributions by offering interpretive and contextual dimensions that cannot be captured solely through R&D or quantitative approaches.

Keywords of learning media publication in biology subject

Figure 3 displays the co-occurrence map of keywords related to the theme "learning media in biology" as visualized through VOSviewer. The visualization reveals a strong interconnectedness among several key terms, with the main nodes being learning media, biology, students, and education computing. These keywords form the most prominent and densely linked network clusters, indicating that research in this domain

predominantly focuses on the use of technology-based instructional media to support biology learning processes.

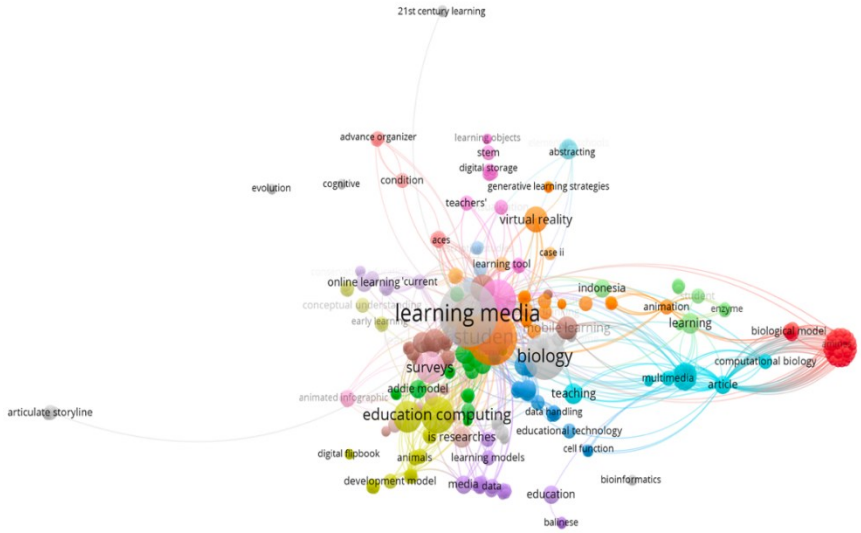

Fig. 3. VOSviewer visualization of the co-occurrence analysis of keywords

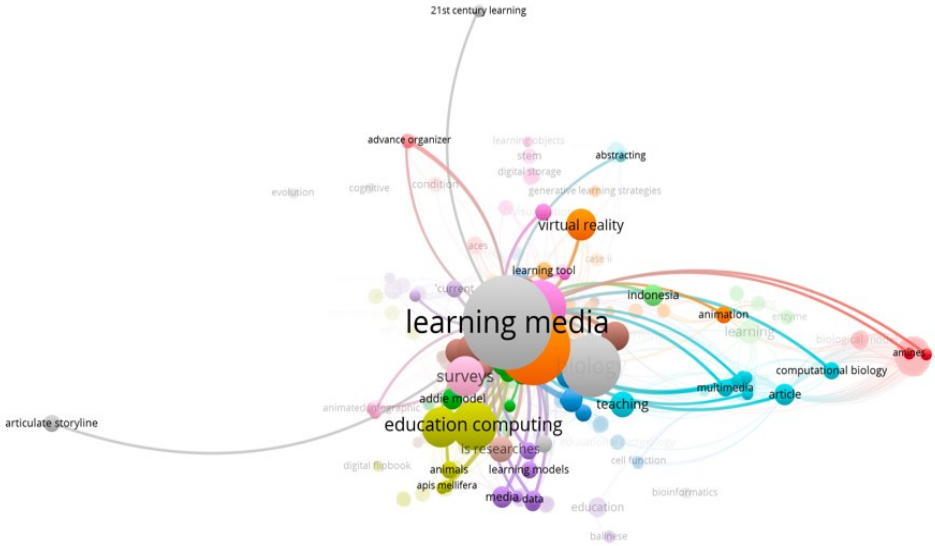

Fig. 4. VOSviewer visualization of the keyword co-occurrence analysis

Figure 4 presents the keyword co-occurrence network related to biology education, visualized using VOSviewer software. The keyword learning media appears as the central node with the highest degree of dominance and connectivity, functioning as a linking bridge across several thematic clusters. This node demonstrates strong associations with other keywords such as students, biology, education computing, virtual reality, and multimedia, collectively emphasizing the integration of digital media and technological tools in biology learning. These findings indicate a shift in biology education research toward more

innovative and interdisciplinary approaches, highlighting the contribution of instructional media in enhancing learning effectiveness (Sharif et al., 2025).

The interconnectedness of these nodes also highlights a research orientation that focuses on transforming biology learning through virtual experiences and the use of digital media. Such approaches not only broaden access to learning resources, but also demonstrate research interest in developing learning environments that are more interactive, flexible, and visually oriented (Kassa et al., 2024; Schmidthaler et al., 2023). This pattern reflects a pedagogical shift from traditional instruction toward models that enable students to explore biological concepts through technology-mediated experiential learning. Accordingly, the integration of technology in biology education represents a pedagogical strategy that emphasizes contextualization, efficiency, and instructional innovation (Whitworth et al., 2018).

The keyword students functions as a subject node that underscores the central role of learners in biology education. Digital media are employed to enhance student engagement, motivation, and learning outcomes (Bogiannidis et al., 2023; Schindler et al., 2017). The keyword biology represents the main disciplinary object, emphasizing complex conceptual domains such as ecology, genetics, and anatomy, for which innovative media are utilized to facilitate conceptual understanding (Tarng & Hsu, 2024; Weng et al., 2019). Furthermore, the keyword education computing denotes the integration of computational and information technologies into biology education, supporting data analysis, simulation, and the application of digital learning models (Park & Weng, 2020). The keyword virtual reality indicates the adoption of immersive simulations as instructional tools. Such technologies enable interactive learning experiences that approximate real-world practices, allowing students to explore biological phenomena that are difficult to replicate in conventional laboratory settings (Miller et al., 2025; Garza-Martínez, 2020).Finally, the keyword multimedia highlights the use of text, imagery, animation, and interactive video to enrich the presentation of biological content and strengthen student understanding of abstract concepts through dynamic visual representations (Fan et al., 2018; Koca & Kizilay, 2024). Collectively, these keywords reflect essential dimensions within the field from the centrality of the learner to the integration of computing, virtual reality, and multimedia technologies for facilitating comprehension of complex biological concepts. This complexity underscores the need for interdisciplinary collaboration, as illustrated in Figure 5.

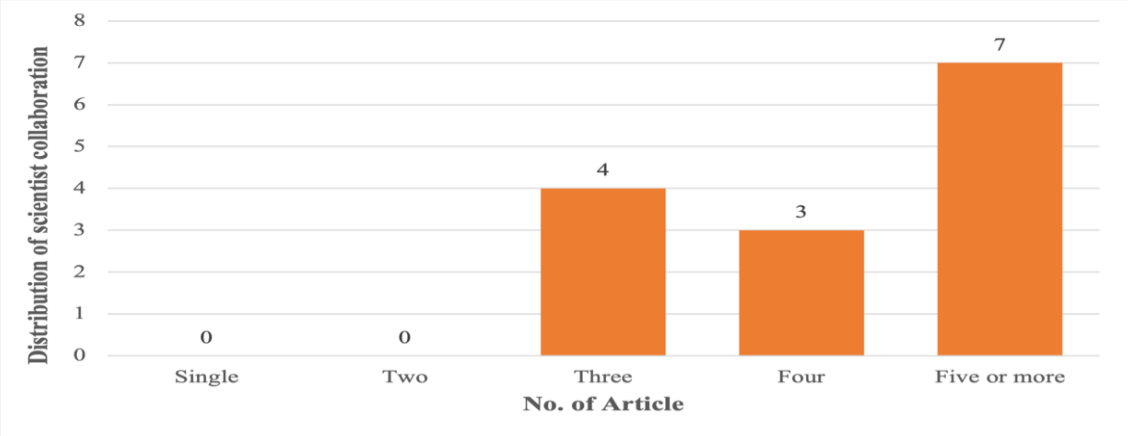

Fig. 5. Collaboration networks among authors

Based on the data presented in Figure 5, research publications on instructional media in biology appear to be entirely collaborative in nature. No single-author or two-author manuscripts were identified. The highest number of publications (seven articles) was authored by groups consisting of five or more researchers, followed by four articles authored by three researchers, and three articles authored by four researchers. This pattern indicates that research on this topic is predominantly conducted through large team-based collaboration, suggesting a need for multidisciplinary contributions. Such collaboration often integrates expertise in biological content, pedagogy, digital technology, and instructional media development, resulting in publications that are more comprehensive and aligned with advances in technology-enhanced biology education (Uysal & Bicen, 2025).

The dominance of collaborative publications corresponds with recent findings in biology education research, which indicate that instructional media particularly digital and interactive tools require input from multiple areas of expertise. As noted by Safitri et al. (2024), the development of instructional media in biology frequently involves science educators, instructional designers, programmers, and education researchers working collectively to ensure that learning tools are both scientifically accurate and pedagogically effective. Such multidisciplinary collaboration enables instructional media to address complex biological concepts through engaging formats such as virtual simulations, augmented reality (AR), gamification, and video-based instruction (Majewska & Vereen, 2023). The increasing number of publications involving five or more authors also suggests that large-scale projects and institutional collaborations are becoming more common in biology education research. This trend may be driven by national initiatives to strengthen STEM learning outcomes, particularly through technology integration (Kurniati et al., 2022; Uysal & Bicen, 2025).

In addition, collaborative publications reflect a broader shift in research culture in which media development is no longer considered an individual task, but rather a collective endeavor involving content validation, usability testing, and classroom implementation (Myburgh, 2022). The absence of single-author publications may also indicate the increasing methodological complexity of media-based research in biology. As argued by Laubscher et al. (2024), collaboration enhances both the quality and credibility of research findings, particularly when investigating the impact of instructional media on students' understanding of abstract biological processes commonly found in modern biology curricula. In sum, the publication patterns suggest that research on instructional media in biology is inherently collaborative, often conducted in teams of five or more researchers, reflecting its interdisciplinary nature, methodological demands, and institutional support for STEM-related educational innovation.

Biology topic distribution

Figure 6 displays the distribution of recent research in digital media–based biology education across nine major subtopics. Genetics, Food Biology, Environmental Biology, General Biology, and Biodiversity each appeared in two publications, whereas Taxonomy, Botany, Immunology, and Modern Biology were represented by only one publication. These findings indicate that research remains relatively evenly distributed across subtopics, with no single topic demonstrating clear dominance.

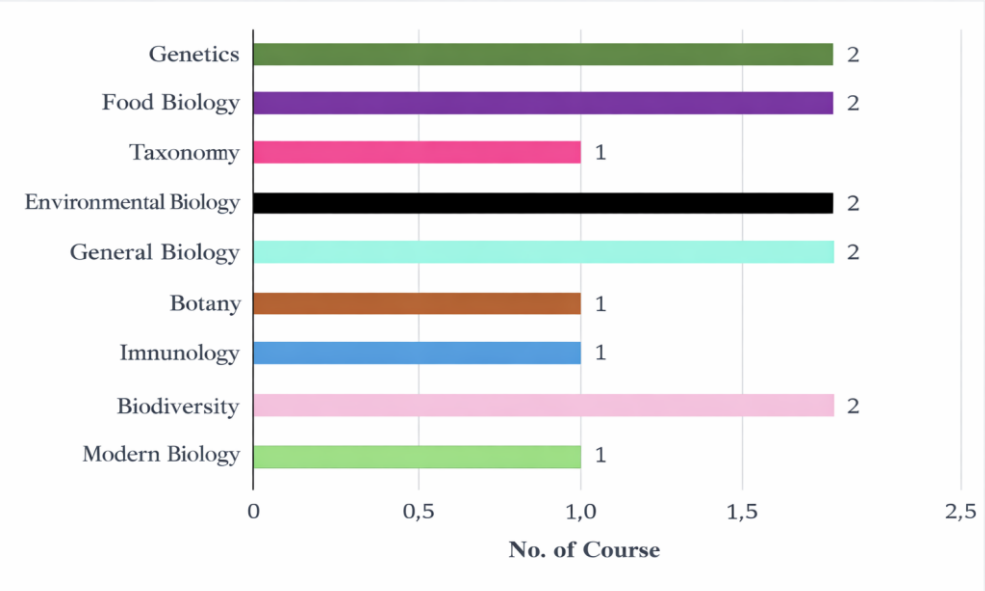

Fig. 6. Distribution of biology subject topics addressed through instructional media

Within the topic of Genetics, two publications emphasized the importance of digital media for explaining mechanisms of inheritance and gene expression. Ristanto et al. (2020) demonstrated that digital media can support students' understanding of DNA–protein interactions. This aligns with Azrai (2020), who developed digital media to facilitate the comprehension of complex biological concepts such as genetics. Similarly, the topic of Food Biology also accounted for two publications. This area has gained attention due to its relevance to food security issues. Morimoto and Ponton (2021) noted that interactive animation enhances learning interest while providing practical insights into the processing of biological resources. In a similar vein, Leksono (2021) asserted that interactive digital content in food-related topics can bridge conceptual knowledge with modern agricultural practices.

The topics of Environmental Biology and General Biology each contributed two publications. Satriya et al. (2020) reported that ecosystem simulations supported students' understanding of organismal interactions. These results were reinforced by Vekli and Çalik (2023), who showed that digital media applications assisted students in interpreting environmental interactions. Likewise, Susantini (2019) indicated that biology e-books enabled university students to connect foundational theoretical concepts with real-world phenomena.

The topic of Biodiversity also accounted for two publications, generally focusing on the development of media featuring species visualization and biodiversity documentation. Bogiannidis et al. (2023) reported that multimedia integration enriched students' understanding of conservation concepts, while Ristanto (2020) developed a digital flipbook that effectively visualized biological diversity in an engaging format. In contrast, the topics of Taxonomy, Botany, Immunology, and Modern Biology were each represented by only one publication. This limited output suggests that these topics are still considered more suitable for hands-on and field-based instructional approaches. Susanto et al. (2024) emphasized that taxonomy and botany are more effectively taught through direct field observation.

Moreover, Suwandi's (2020) study on virtual gardens remains in a trial phase, and thus its contribution has not yet expanded substantially. The relatively sparse distribution where each subtopic yields only one or two publications indicates that the use of digital media in biology education remains in an early exploratory phase. The absence of a dominant topic further suggests that research has yet to converge on a specific thematic focus, instead dispersing according to the practical demands of individual subdisciplines. This pattern supports the notion that biology education continues to search for optimal modes of integration among scientific content, pedagogy, and technology.

The existance of learning media in biology subject

The authors examined 14 articles to explore the current landscape and positive impact of instructional media in biology education. Table 3 summarizes key information derived from these studies. From the analysis, four key aspects regarding the use of instructional media in biology learning were identified.

Table 2. Key information from each article

No.	Information	The Relationship of Important Information to the Media
1	The use of AR-based mobile learning was shown to significantly enhance students' understanding and learning engagement in genetics (Safitri et al., 2024).	Digital media in biology education have the potential to strengthen students' cognitive competencies by enhancing conceptual understanding, abstract visualization, and immersive learning experiences
2	Virtual reality in modern biology instruction effectively visualized complex concepts, thereby enhancing students' conceptual understanding and engagement (Susanto et al., 2024).	
3	The Virtual Garden digital media positively enhanced students' conceptual understanding, motivation, and interactivity in learning biological classification (Suwandi et al., 2023).	
4	Virtual reality in STEM instruction effectively enhanced conceptual understanding and learning experiences in genetics (Elme et al., 2022).	
5	The Imunopedia digital flipbook was shown to effectively improve students' understanding of immune system concepts and learning motivation through interactive and accessible content delivery (Ristanto et al., 2020).	
6	Multimedia-based biology instructional media demonstrated high effectiveness in improving students' understanding, increasing learning motivation, and supporting teachers in delivering content in a more interactive and engaging manner (Sukenda et al., 2019).	
7	The Virtual Food (VIFO) media demonstrated effectiveness in improving students' critical thinking skills,	Innovative media in biology education

	learning autonomy, and learning outcomes in alignment with 21st-century learning demands (Azrai et al., 2024).	have the potential to empower higher-order thinking skills, self-regulation, and learner autonomy through the development of critical thinking, metacognitive strategies, and structured interactive materials
8	The SARITHA-Apps mobile learning media improved students' understanding, motivation, and learning autonomy (Uda et al., 2024)	
9	Android-based instructional media played a strategic role in enhancing students' critical thinking skills, strengthening scientific attitudes, and optimizing learning effectiveness (Isnaeni et al., 2021).	
10	The development of a metacognitive digital e-book was shown to contribute to strengthened self-regulation and increased learner autonomy (Susantini et al., 2021).	
11	E-learning media on post-harvest mushroom topics positively contributed to improving students' knowledge and developing critical thinking skills through structured and interactive content (Khastini et al., 2021)	
12	Biology instructional digital media based on local tuber biodiversity played a strategic role in enhancing conceptual understanding and fostering appreciation of local natural resources (Leksono et al., 2023).	Contextual and local wisdom–based media in biology education have the potential to foster students' affective and social competencies by increasing motivation, interactivity, environmental literacy, and appreciation of local biodiversity
13	Augmented Reality–based instructional applications contributed significantly to improving students' learning outcomes, motivation, and interactive engagement in biology learning (Nurhayati et al., 2022).	
14	An online instructional website on the biodiversity of Rawa Danau contributed to enhancing students' conservation literacy, environmental awareness, and ecological participation (Leksono et al., 2021).	

The analysis (as presented in Table 2) highlights three key points regarding the role and application of media in biology education. First, the findings demonstrate the role of digital media in strengthening cognitive competencies, particularly conceptual understanding and biological visualization. Augmented Reality (AR) and Virtual Reality (VR) media were shown to be effective in visualizing abstract concepts such as genetics and modern biology, thereby enabling students to grasp conceptual relationships that are difficult to achieve through lecture-based instruction alone (Elme et al., 2022; Sharif et al., 2025). Media such as Virtual Garden and the Imunopedia flipbook also contributed to interactive representational processes that support optimal cognitive outcomes (Ristanto et al., 2020; Sukenda et al., 2019). These findings align with Schindler et al. (2017), who argue that digital technologies can enhance learner engagement while strengthening students' conceptual understanding.

Second, the analysis confirms the contribution of innovative media to the development of critical thinking skills, self-regulation, and learner autonomy. For example, Virtual Food (VIFO) and SARITHA-Apps enhanced motivation and supported students' ability to manage their own learning processes (Leksono et al., 2023; Uda et al., 2024). Likewise, metacognitive e-books activated students' self-regulatory skills, while e-learning on post-harvest mushroom topics fostered critical thinking through structured content delivery (Isnaeni et al., 2021; Susantini et al., 2021). In line with Talan et al. (2022), digital media can encourage students to take ownership of their learning and facilitate greater learner autonomy.

Third, the analysis reveals the role of contextual media in fostering motivation, environmental literacy, and local appreciation. Digital media grounded in local tuber biodiversity enhanced conceptual understanding while cultivating appreciation for local natural resources (Morimoto & Ponton, 2021). Similarly, the Rawa Danau online biodiversity media contributed to improvements in conservation literacy and environmental awareness (Khastini et al., 2021). Meanwhile, AR and other interactive media demonstrated effectiveness in increasing motivation and classroom interactivity in biology instruction (Nurhayati et al., 2022). Consistent with Garza-Martínez (2020), contextually grounded media not only reinforce cognitive domains but also foster deeper affective awareness among students. Despite these benefits, the implementation of media in biology education faces accessibility challenges. Device requirements, software availability, and stable internet connectivity pose barriers for students from lower socioeconomic backgrounds (Sobach et al., 2023).

CONCLUSION

This review reveals an increasing trend in the publication of articles on biology instructional media in Scopus-indexed journals, particularly in the post-pandemic period. The analysis confirms that digital media such as virtual reality (VR), augmented reality (AR), mobile applications, and web-based platforms are being increasingly adopted in biology education contexts. Most of the analyzed publications employed experimental or development-based methodologies, with consistently positive findings showing contributions to cognitive learning outcomes, learning motivation, and higher-order thinking skills. Furthermore, collaboration patterns indicate a dominance of national research teams, with substantial contributions from Asian regions, particularly Indonesia.

The findings show that the development of instructional media in biology is progressing rapidly, as evidenced by the growing number of publications and diversification of media types. The distribution of biology topics, however, remains unbalanced: Genetics, Food Biology, Environmental Biology, General Biology, and Biodiversity were most frequently investigated, while studies on Taxonomy, Botany, Immunology, and Modern Biology were relatively underrepresented. This imbalance suggests that the current use of instructional media contributes unevenly to the overall development of biological understanding. Despite demonstrating consistent benefits for cognitive outcomes, motivation, and higher-order thinking skills, challenges related to access limitations and the digital divide remain barriers to equitable learning opportunities. Future research should focus on developing instructional media that are innovative,

inclusive, and contextually adaptive in order to bridge access disparities and optimize their role in biology education.

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