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The utilization of Augmented Reality in visualizing ecosystem concepts to create contextual and meaningful biology learning: A literature review

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Abstract. The twenty-first century education requires innovation in the development of learning media that can communicate complex material more effectively than conventional media, such as blackboards, textbooks, or student worksheets (LKS). This innovation is necessary to bridge the gap between the complexity of the material and the limitations of traditional teaching methods. Complex topics like ecosystems are hard to observe directly, so they need to be visualized using interactive media. This study examines the use of Augmented Reality (AR) to visualize ecosystem concepts and enhance contextual biology learning. A Systematic Literature Review (SLR) of 923 articles obtained from Google Scholar (publication range 2020–2024) was selected based on specific inclusion–exclusion criteria, resulting in 10 relevant articles. Content analysis identified patterns in AR implementation. Results showed that AR enhances students' understanding, motivation, and engagement, with most studies using the Research and Development (R&D) model to develop effective learning media. Integrating local values and contextual approaches through AR strengthens education rooted in local wisdom while supporting scientific literacy, ecological empathy, and digital competencies.

Abstrak. Pendidikan abad ke-21 menuntut adanya inovasi dalam pengembangan media pembelajaran yang mampu mengkomunikasikan materi kompleks secara efektif dibandingkan media konvensional, seperti papan tulis, buku teks, atau lembar kerja siswa (LKS). Inovasi ini diperlukan untuk menjembatani kesenjangan antara kompleksitas materi dengan keterbatasan metode pengajaran tradisional. Materi yang kompleks seperti topik ekosistem sulit diamati secara langsung, sehingga perlu divisualisasi dengan media interaktif. Studi ini mengkaji penggunaan Augmented Reality (AR) untuk memvisualisasikan konsep ekosistem dan meningkatkan pembelajaran biologi yang kontekstual. Systematic Literature Review (SLR) terhadap 923 artikel diperoleh dari Google Scholar (rentang publikasi 2020–2024) diseleksi berdasarkan kriteria inklusi–eksklusi tertentu hingga diperoleh 10 artikel yang relevan. Analisis isi mengidentifikasi pola implementasi AR. Hasil menunjukkan bahwa AR meningkatkan pemahaman, motivasi, dan keterlibatan siswa, dengan sebagian besar studi menggunakan model Research and Development (R&D) untuk mengembangkan media pembelajaran yang efektif. Integrasi nilai lokal dan pendekatan kontekstual melalui AR memperkuat pendidikan berbasis kearifan lokal sekaligus mendukung literasi sains, empati ekologis, dan kompetensi digital.

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Introduction

The twenty-first century education requires major changes in how learning is conducted, including in biology education. Learning is no longer sufficient as merely the transmission of material from teacher to student but must also foster critical thinking, creativity, collaboration, and communication skills (Akmal, 2019). In the context of Biology, this requirement can be achieved through a contextual learning approach, which connects theoretical concepts with real-life phenomena in everyday life. This approach is believed to make the knowledge gained more meaningful, relevant, and deeply ingrained in students' long-term understanding (Pratiwi et al., 2024).

However, the actual conditions in the field show that there is a gap between these expectations and classroom learning practices. Biology learning is still dominated by conventional teacher-centered methods (Maghfiroh et al., 2022). High dependence on static print media such as textbooks or student worksheets (LKS) that are visually unattractive and lack interactivity is a common problem in many schools (Febrianto et al., 2021). However, modern learning requires interactive and digital media to engage students' interest and enhance their understanding (Priyadewi et al., 2024).

The weaknesses of conventional methods become increasingly apparent when dealing with complex and abstract material such as ecosystems. Concepts such as energy flow and biogeochemical cycles occur on scales of time and space that are not visible to the naked eye, requiring a high level of abstract thinking and systemic reasoning (Haya et al., 2025; Nurfadilah & Rochintaniawati, 2021). The breadth of the material and the complexity of these concepts present a unique challenge in the learning process (Rachmaningsih & Purnomo, 2024). Without adequate visual media support, delivering material through lectures tends to make students passive, unmotivated, and unable to fully understand the concepts (Nurfadilah & Rochintaniawati, 2021; Kuroru & Rahma, 2023).

Limitations in the classroom encourage students to seek alternative learning resources. Data shows that 80% of students prefer the internet as their main source of learning (Nurfadilah & Rochintaniawati, 2021). However, without proper guidance and sufficient digital literacy skills, students are at risk of accessing inaccurate, overly simplistic, or unscientific information. Misconceptions are often reinforced by readings from unreliable sources (Alonemarera, 2020). As a result, self-directed learning, which should be helpful, can instead reinforce incorrect understanding and hinder the achievement of learning objectives.

To break the chain of misconceptions and bridge the media gap, interactive and visual learning is needed. Augmented Reality (AR) technology emerges as a potential solution by integrating 2D/3D virtual objects into the real environment in real-time (Alfitriani et al., 2021; Sharif et al., 2025). This technology enables the visualization of abstract concepts such as energy flows or food webs into tangible and interactive 3D models, making them easier to understand concretely (Alfitriani et al., 2021). The advantage of AR lies in its interactivity and spatial exploration capabilities, which provide a participatory and contextual experience (Kuswinardi et al., 2023; Priyadewi et al., 2024).

Empirical studies show that AR can increase student motivation, engagement, and learning outcomes in Biology (Subran & Mahmud, 2024). However, its application is still largely focused on general topics such as anatomy or cell structure (Marston et al., 2024; Meslilesi et al., 2017; Aripin & Suryaningsih, 2019). The use of AR in the context of environmental education for formal learning in schools, especially on ecosystem material related to the local context, is still very limited and more promotional in nature (Wahyuni et al., 2021). This indicates a significant research gap that needs to be bridged.

Based on the above interpretation, supporting biology learning in the 21st century requires the integration of contextual approaches and interactive media. Conventional practices have proven to be suboptimal in facilitating the understanding of abstract concepts such as ecosystems, and even indirectly encourage students to use invalid learning resources that exacerbate misconceptions. Augmented Reality (AR) technology emerges as a promising solution for interactive visualization. However, its potential has not been thoroughly explored for ecosystem-related content within the context of formal education.

Therefore, this study aims to systematically examine the potential of AR in visualizing ecosystem material to create contextual, meaningful, and relevant biology learning for students. Specifically, this study answers the following questions:

1) What are the trends in research related to the use of Augmented Reality (AR) in biology learning, particularly on the topic of ecosystems, in the last five years?
2) What are the main findings from the literature review on the effectiveness of using Augmented Reality (AR) in enhancing understanding of complex and abstract ecosystem concepts?
3) What are the scientific implications of utilizing Augmented Reality (AR) in developing more contextual and meaningful biology learning strategies, and its implications for improving students' science literacy in the digital age?

Research Methods

1) Type

This research method uses a Systematic Literature Review (SLR) to identify, evaluate, and synthesize secondary data relevant to the research topic. The SLR approach was chosen to provide a comprehensive overview of recent studies on the use of Augmented Reality (AR) in biology education, particularly in ecosystem material.

The article selection process was carried out systematically through several stages based on specific inclusion and exclusion criteria (presented in Table 1). These criteria were adapted from the framework developed by Fajeriadi et al. (2024) to ensure that the articles analyzed were of high quality, relevance, and validity. Out of a total of 923 articles identified in the initial search, a screening of titles and abstracts was conducted, followed by a full-text analysis, ultimately resulting in the selection of 10 most relevant articles for in-depth analysis.

Table 1 Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Studies relevant to the topic	Non-empirical studies
Published within the last 5 years	Publications in languages other than English/Indonesian
Studies using empirical methods	Conference papers, dissertations, or research reports
Full access to articles	Studies with small samples
Publication in national journals	Articles that do not include the necessary data

2) Data source and time

The data source for this literature review is scientific articles obtained from the Google Scholar digital database. Google Scholar was chosen because of its wide coverage of scientific literature, both national and international. However, strict screening was applied to ensure that the selected articles were from accredited and peer-reviewed journals. The data search process was conducted on July 29, 2025, using the keyword "Augmented Reality in ecosystem biology learning." The search results focused on articles relevant to the visualization of ecosystem material to create contextual and meaningful learning.

3) Data collection techniques

Data collection in this study was conducted through a literature search on Google Scholar, focusing on scientific articles published between 2020 and 2024. The publication range was limited to 2024 because, in a systematic review based on the PRISMA model within the Systematic Literature Review (SLR) framework, articles published less than one year prior to the search date are generally not recommended for analysis. This is due to potential limitations in citations, the lack of widespread validation of research quality, and the possibility of changes in publication status, such as revisions or retractions of articles. The article selection process was conducted sequentially according to the procedure outlined in Figure 1.

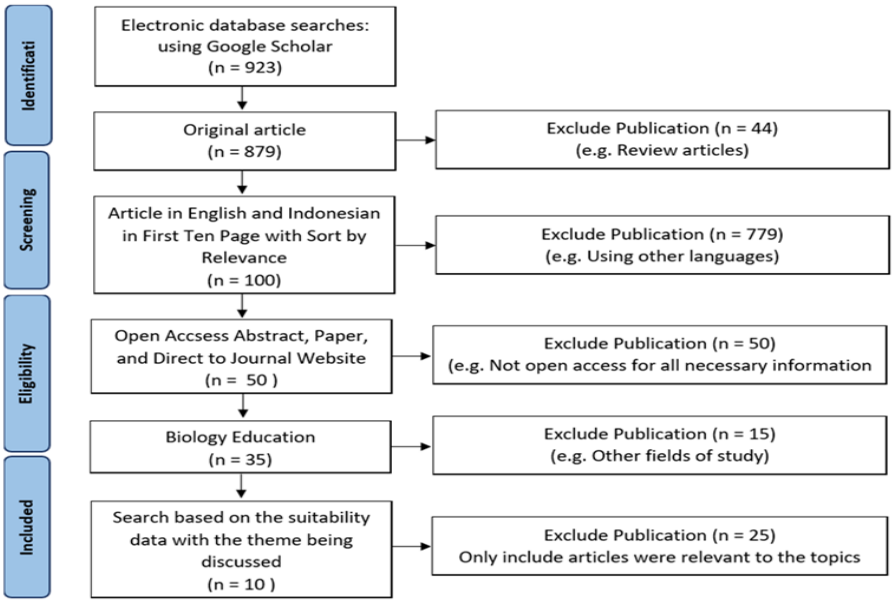

Figure 1 Article selection process in SLR studies using the PRISMA model

4) Data analysis techniques

The data in this study were analyzed using content analysis techniques to systematically identify, organize, and interpret the content of the articles based on specific themes, categories, or meanings related to the focus of the study. According to Krippendorff (2019), content analysis is a research technique that produces replicable and valid inferences from textual data into the context of its use. The analysis was conducted through several steps, namely: (1) identifying the content of each selected article; (2) identifying the main themes that emerged in the articles; (3) grouping the findings into several categories, such as media development methods, the use of AR in learning, its impact on student understanding, and its relevance to local values; and (4) compiling a summary based on these themes to answer the research objectives.

Results and Discussion

Based on the number of relevant documents, there has been a significant increase from year to year, as shown in the following graph, which records the total number of documents from 2020 to 2024.

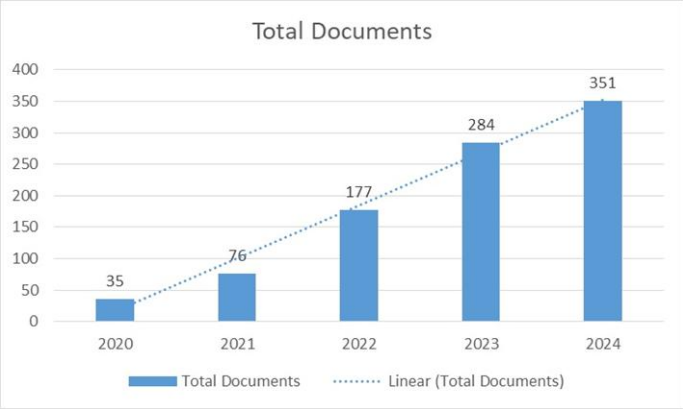

Figure 2 Graph showing the distribution of the number of documents from 2020 to 2024.

Based on Figure 2, the research trend on the use of Augmented Reality (AR) in Biology education shows a significant increase over the past five years (2020–2024), in line with the demand for digital transformation in education. AR technology has begun to be widely explored as an innovative learning medium, particularly due to its ability to visualize abstract and complex concepts that are difficult to explain using conventional methods. Various international studies indicate positive and consistent growth in the number of publications on the use of AR in education, with a significant surge particularly in 2023 (Situmorang & Tarigan, 2025). This suggests that the application of AR in Biology education, including on the topic of ecosystems, aligns with the emerging global trend of educational technology innovation.

The selection of articles from the results of a systematic review using the PRISMA model within the framework of a Systematic Literature Review (SLR) of 923 articles collected through the Google Scholar digital database resulted in 10 articles published in national journals. The findings from these 10 articles indicate that the application of Augmented Reality (AR) in the field of ecosystems remains relatively limited compared to other topics such as organ systems or anatomy, and is further detailed in Table 2.

Table 2 Findings from the Ten Most Relevant Articles

Code	Researcher (Year)	Problem	Method	Findings
A1	Wahyuni et al. (2021)	Damage to mangrove ecosystems due to human activities; the need for conservation education.	Research and Development (R&D) with the ADDIE model	Augmented Reality effectively raises public awareness of mangrove conservation in a more interactive and contextual way.
A2	Oktaviana et al. (2022)	Limited field activities during the pandemic; low student engagement in biodiversity learning.	One group pretest-posttest design	AR-based virtual field trips improve the quality of education, encourage motivation, understanding of conservation, and students' biodiversity literacy skills.

Code	Researcher (Year)	Problem	Method	Findings
A3	Qorimah et al. (2022)	The images are not very appealing and do not help in understanding the abstract concepts in the food chain material.	Research and Development (R&D) with the ADDIE model	AR is very much needed because the majority of food chain material is abstract, and the development of AR media is recommended for application in classroom learning activities.
A4	Pusparani et al. (2021)	The lack of contextual science media based on local culture.	Research and Development (R&D) with the ADDIE model	Ethno-augmented reality media has been proven to be valid and helpful in understanding abstract scientific concepts.
A5	Pranahadi et al. (2024)	Low student motivation in biology learning, especially in the subject of tissue structure and function.	Collaborative Classroom Action Research (PTK-K)	Augmented Reality increases students' motivation to learn and their self-confidence, although the integration of broader scientific concepts is still limited.
A6	Nirwanto et al. (2021)	Lack of media variety and limited resources make it difficult for students to understand ecosystem material.	Research and Development (R&D) with the Borg & Gall model	Augmented Reality puzzles effectively improve students' understanding and engagement in learning about ecosystems.
A7	Ahmad et al. (2022)	Learning media in 3T areas is still simple and ineffective.	One group pretest-posttest design	Augmented Reality media improves learning outcomes with high levels of engagement and satisfaction, and is suitable for use in various educational backgrounds and age groups.
A8	Nengsih et al. (2023)	Students find it difficult to fully understand ecosystem material using traditional teaching methods that lack interactivity.	Research and Development (R&D) with the 4D model	Augmented Reality media was developed with high validity and positive student responses; it is recommended for use with adequate technological support.
A9	Priyanti et al. (2023)	Limited access to technology and resources, as well as a lack of teacher readiness, pose challenges to the implementation of innovative biology teaching methods.	Qualitative approach with case study design	The integration of technology and innovative pedagogy enhances students' critical thinking and collaboration skills.
A10	Pradita et al. (2024)	Limited resources and a lack of scientific knowledge and skills among young people.	Research and Development (R&D) with the Borg & Gall model	Augmented Reality enhances student engagement and motivation through interactive, cross-disciplinary learning experiences.

Based on the data in Table 2, most research is still in the stage of developing AR-based media, with a primary focus on product validation and small-scale trials. This reflects that the use of AR in the ecosystem context is still in the early stages of exploration, despite its significant pedagogical potential. These studies generally use a Research and Development (R&D) approach, with some adopting development models such as ADDIE or other models, indicating a strong orientation toward creating technology solutions that are applicable in the classroom.

One of the most notable findings is the dominant use of Research and Development (R&D) methodology. Six out of ten studies analyzed (A1, A3, A4, A6, A8, A10) clearly used the R&D approach, with many of them adopting development models such as ADDIE, 4D, or Borg and Gall. The trend toward using R&D methods indicates that AR research in Biology education in Indonesia is driven by efforts to address practical problems. Researchers are not only focused on understanding the use of AR but are also actively creating technological solutions to address real-world needs in the classroom. Some studies even produced concrete products, such as AR media for mangrove ecosystem conservation (A1), Ethno-Augmented Reality media integrating local wisdom (A4), and AR-based puzzle media for ecosystem content (A6).

Meanwhile, the Collaborative Classroom Action Research (PTK-K) approach shows that AR media is effective in increasing student motivation and confidence, even though the integration of scientific concepts is still limited (A6). This further enriches the diversity of methodological approaches in the development of AR-based learning media in the field of Biology. Overall, these findings reflect a research culture that emphasizes practical impact, contextuality, and direct relevance to learning needs in the biology classroom, particularly in understanding complex and abstract ecosystem material.

The main challenge in learning about ecosystems is the complexity and abstract nature of the material. Concepts such as energy flow, biogeochemical cycles, and interactions in food webs occur on spatial and temporal scales that are difficult to observe directly, requiring a high level of abstract thinking. Findings from the analyzed articles consistently show that AR technology is able to respond to these challenges effectively. A study by Qorimah et al. (2022) found that 87.5% of concepts in food chain material are abstract, making the use of AR essential for visualizing them (A3). Other

studies also confirm the effectiveness of AR in overcoming students' learning difficulties (A4) and in improving their understanding of ecosystem material in general (A6). With its ability to visualize invisible processes such as cellular interactions or energy flows in ecosystems, AR serves as a bridge connecting abstract concepts with the real world (Permana et al., 2024).

The study also highlights the positive influence of AR on students' affective domain. Studies indicate that the use of AR significantly enhances students' motivation and engagement in the learning process (A2, A7, A10) and offers a far more engaging alternative compared to static media such as textbooks (A3, A4). These findings are consistent with international literature, as Zufahmi et al. (2025) state that AR makes learning more enjoyable and motivating. Furthermore, a large-scale systematic review reported that the greatest benefit of using AR in Biology learning is reflected in the affective domain (56.3%), surpassing cognitive and psychomotor aspects (Subran & Mahmud, 2023). This increase in motivation is important, as it is a prerequisite for deeper and more sustained cognitive engagement.

An overview of the impact and patterns of AR utilization in biology education is summarized in Figure 3, which illustrates the interrelationships between various aspects of the findings.

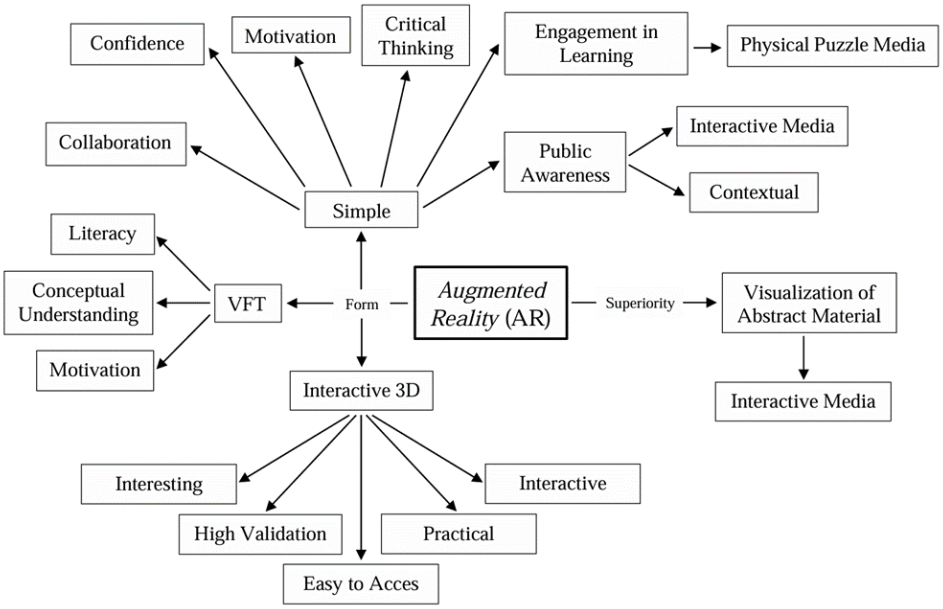

Figure 3 Scheme of AR Utilization Patterns in Biology Learning

This study also highlights the potential of AR in realizing contextual, meaningful, and real-life experience-based learning for students. Figure 3 illustrates the interrelationship between various positive aspects of AR utilization, including the integration of local and ecological values relevant to the learning context. Several studies in Table 2 show a strong orientation toward the development of AR media that promote local and ecologically relevant values, such as mangrove ecosystem conservation (A1), the integration of ethnoscience in Ethno-Augmented Reality media (A4), and increased learning motivation through a locality-based approach (A5). This approach aligns with the principles of Contextual Teaching and Learning (CTL), which connects learning content to the real world and students' cultural backgrounds. Thus, the primary scientific contribution of this study lies not only in the shift of focus from general topics like anatomy to ecosystem-related content but also in the localization of content that strengthens the roots of place-based education. Research like A4 serves as tangible evidence that ecosystem concepts can be contextualized through local cultural practices, positioning AR as a bridge between global science and authentic local realities.

Several studies have also pointed to the application of AR in the context of environmental education and conservation. Study A1 (Wahyuni et al., 2021) shows that AR can increase public awareness of mangrove conservation in an interactive way, while A2 (Oktaviana et al., 2022) confirms that AR media that adopts virtual field trips can improve students' understanding of biodiversity and environmental conservation. This opens up vast opportunities to integrate AR into current ecological issues in broader ecosystem learning.

Overall, the use of Augmented Reality (AR) in Biology education demonstrates consistent positive impacts on cognitive, affective, and scientific skill aspects. AR acts as a catalyst for active learning, not merely a visual tool. In culture-based learning, AR creates interactive experiences that encourage students to build knowledge independently and foster a sense of ownership (Ababil, 2025). These findings align with Fauziyah et al. (2024), who demonstrated increased student engagement and positive attitudes when technology integrates culturally relevant cognitive and

affective aspects. Research such as A4 and A5 also reinforces that AR can enhance understanding of abstract concepts, motivation, and self-confidence, as well as encourage locally-based learning designs that make Biology meaningful academically, culturally, and ecologically.

The integration of AR with local wisdom in PBL-based biology (biodiversity) learning modules was found to be highly effective in improving critical thinking, ecological understanding, and the meaning of learning for students (Aripin & Suryaningsih, 2019). This aligns with findings indicating a strong need for contextual teaching materials that integrate local wisdom + AR, to strengthen students' cultural identity while making Biology/IPAS more meaningful and digitally interactive (Sari et al. 2025).

The implications of this approach are far-reaching, namely in improving students' scientific literacy, enabling them to relate scientific concepts to global challenges such as climate change, biodiversity conservation, and environmental sustainability. Thus, this study comprehensively addresses three key points: first, that the trend of utilizing AR in Biology education has shown a significant increase over the past five years; second, that AR has proven effective in visualizing complex and abstract ecosystem concepts; and third, that AR has a scientific impact in promoting more contextual, meaningful learning, and directly contributes to enhancing students' scientific literacy in the digital age. In this context, AR is not only a tool for knowledge transfer but also an instrument for fostering scientific character, ecological empathy, and digital literacy, all of which are crucial in the era of the Fourth Industrial Revolution and Society 5.0.

Conclusion

This study concludes that the use of Augmented Reality (AR) in biology education, particularly in ecosystem-related material, significantly helps simplify abstract concepts and enhance student motivation and engagement, while also strengthening contextual and locally-based learning. Over the past five years, research trends have shown an increase in the number of studies developing AR media using a Research and Development approach, reflecting a strong push to create innovative and practical learning solutions. The scientific impact of this study indicates that AR holds great potential in supporting future education, particularly in developing students' scientific literacy, ecological awareness, and digital competencies in line with 21st-century needs. Therefore, it is recommended that future research expand the scope of field trials, integrate interdisciplinary approaches, and develop more adaptive and accessible AR media to support transformative and sustainable Biology learning.

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