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Enhancing Ecosystem Understanding and Motivation through Augmented Reality Learning Media: A Mixed-Methods Study at SMP Negeri 4 Bajo

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Abstract: This study aims to implement Augmented Reality (AR)–based learning media for introducing ecosystem concepts at SMP Negeri 4 Bajo and to analyze its effect on students' conceptual understanding and learning motivation in science learning. This research employed a sequential mixed methods design, integrating qualitative and quantitative approaches in successive phases. The initial qualitative stage involved interviews and classroom observations to identify students' prior understanding of ecosystem concepts and the need for digital learning media. The findings informed the design and development of an AR application incorporating image marker and audio marker features. The quantitative phase evaluated the effectiveness of the AR media through classroom implementation and learning outcome analysis. The results indicate that the use of AR significantly improved students' understanding of ecosystem concepts, particularly food chains, food webs, and interactions among living organisms. Students showed increased enthusiasm, critical thinking, and active participation during learning activities. Teachers reported that AR media enhanced the interactivity and contextual relevance of science instruction. The findings provide empirical evidence that AR-based learning media can effectively support science instruction at the junior high school level. Teachers are encouraged to integrate AR into lesson planning to enhance student engagement and conceptual understanding, supported by appropriate training and technological infrastructure. This study contributes to educational technology research by demonstrating the effectiveness of a sequential mixed methods approach in developing and evaluating AR-based learning media for ecosystem learning.

Keywords: Augmented Reality, Conceptual Understanding, Ecosystem Concept, Educational Innovation, Science Learning

A. Introduction

SMP Negeri 4 Bajo is an educational institution committed to providing quality education services to the community in accordance with national education principles. This school not only focuses on academic achievement, but also plays a

vital role in developing the nation's character and culture amidst the challenges of educational globalization. Along with the rapid advancement of technology and science, this school continues to strive for innovation, both in terms of learning methods, improving teacher competencies, and utilizing digital media that is relevant to the needs of the times. These efforts are in line with the Sustainable Development Goals (SDGs), especially goal 4, which emphasizes the importance of quality, inclusive education and lifelong learning opportunities for all (Pramono & Martin, 2019). This emphasizes that improving the quality of education is an integral part of the global strategy in preparing the younger generation to face the era of digital transformation and the industrial revolution 4.0.

In the context of 21st-century learning, the integration of digital technology into the teaching and learning process is an important strategy for creating more interactive and contextual learning. One prominent innovation is the implementation of *Augmented Reality* (AR), a technology that combines three-dimensional virtual objects with real environments in real time. The application of AR in education has been shown to increase student motivation, engagement, and learning outcomes. Recent research by Prasetya et al. (2024) shows that AR-based learning has a significant impact on students' attention, material relevance, self-confidence, and learning satisfaction with an effect value ($d \approx 0.816$). These results confirm that AR-based learning designs are able to bridge abstract concepts into more concrete and easily understood by students, especially in science learning at the junior high school level. According to Safitri et al. (2022), the use of technology-based media such as AR can accommodate students' three primary learning styles auditory, visual, and kinesthetic thus making learning more adaptive to the differences in student characteristics. This aligns with research by Dewi (2021), which shows that 75% of humans acquire information through sight, 13% through hearing, and 6% through touch. These findings indicate that learning that combines visual and kinesthetic elements can improve students' conceptual understanding more effectively than conventional methods.

Several other studies have also confirmed the effectiveness of using AR in science learning. Chang et al. (2022) found that AR can enhance students' curiosity and intrinsic motivation through immersive and contextual learning experiences. Meanwhile, Fombona et al. (2022) added that the three-dimensional visualizations presented by AR can strengthen the memory of biological concepts through multisensory experiences. These research findings demonstrate that AR is not simply a visual aid, but a learning tool that can encourage active student engagement, enhance understanding of ecosystem concepts, and foster scientific thinking skills and digital literacy aligned with 21st-century demands (Silva, et al., 2023; Talan et. al, 2022).

Based on the description above, the researcher considers it necessary to conduct research into the development of learning media based on *Augmented Reality*. The application of AR to ecosystems at SMP Negeri 4 Bajo is an innovative step in supporting interactive, inclusive education that is oriented toward achieving 21st-century competencies. Furthermore, the implementation of AR is also expected to contribute to achieving the 2030 SDGs, particularly in improving the quality of education through innovative learning technologies. Therefore, this study aims to: (1) develop and implement an AR-based learning module for ecosystem topics; (2) assess its effectiveness in improving students' conceptual understanding; and (3) evaluate its impact on student learning motivation and engagement.

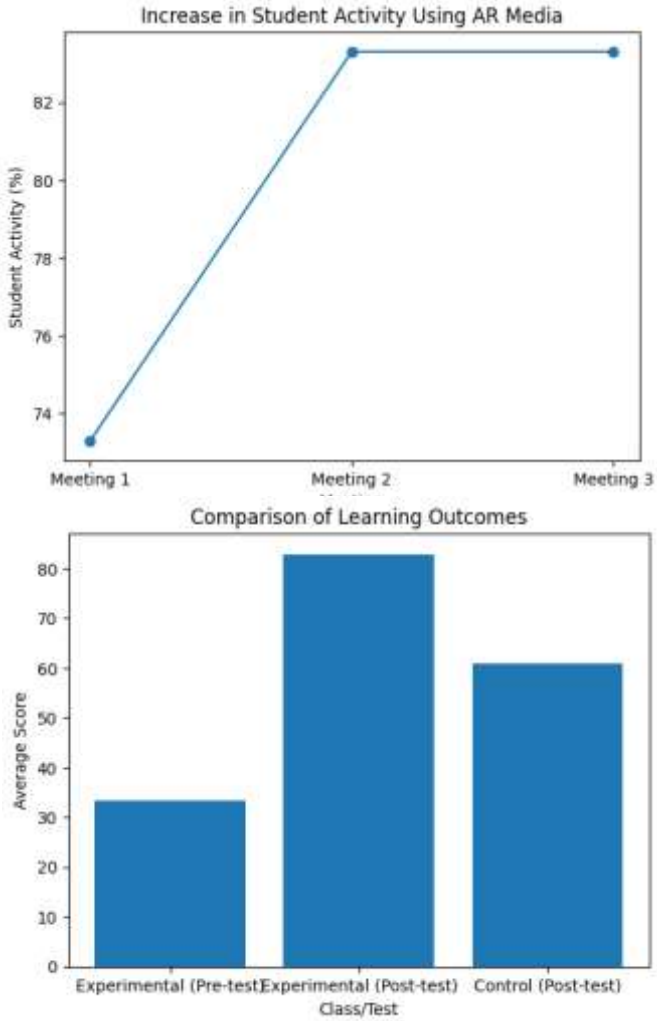
B. Methods

This research uses a mixed method (*mixed methods*) with a sequential mixed methods strategy, which combines qualitative and quantitative approaches in stages. In the initial stage, interviews and observations were conducted with several respondents to gain an understanding of the ecosystem concept and the need for learning media based on *Augmented Reality* (AR). These qualitative findings form the basis for the next stage, which focuses on system design, application development, and product trials through testing the image target marker, audio marker, and interactive AR button features. The research was conducted at SMP Negeri 4 Bajo with junior high school students as subjects. Data were obtained through interviews, observations, and supporting documentation. The research results were processed to assess the effectiveness of AR media in improving student's understanding of ecosystem concepts. Expected outputs include international scientific articles, Intellectual Property Rights (IPR), and AR application prototypes ready to be implemented by educators as innovative and interactive learning media.

C. Results and Discussion

The results of this study indicate that the use of Augmented Reality (AR) learning media significantly increased student activity and learning outcomes in ecosystem learning at SMP Negeri 4 Bajo. Student activity reached an average score of 79.6%, categorized as active, with a consistent increase from 73.3% in the first meeting to 83.3% in the second and third meetings. Students demonstrated high enthusiasm through questioning, discussion, and active exploration of three-dimensional ecosystem objects. In terms of cognitive outcomes, the experimental class showed a substantial improvement from a pre-test average of 33.27 to a post-test average of 82.87, with 83.4% of students achieving mastery learning. In contrast, the control class achieved a lower post-test average of 61.00, with only 13.4% of students meeting mastery criteria. Statistical testing confirmed that the data were normally distributed and homogeneous, and the independent sample t-test revealed a significant effect of AR media on student learning outcomes. The following is a graph of the increase in

student activity and a comparison of learning outcomes in the control and experimental classes.



These findings are consistent with previous studies that highlight the positive impact of AR on student engagement and academic performance in science learning. Chang et al. (2022) reported that AR enhances learning motivation and achievement by providing immersive and contextualized learning experiences. Similarly, Akçayı and Akçayır (2017) found that AR increases emotional engagement by allowing students to interact directly with realistic three-dimensional representations. The increased activity levels and improved learning outcomes observed at SMP Negeri 4 Bajo support these findings, suggesting that AR effectively transforms abstract ecosystem concepts into concrete and meaningful learning experiences.

In addition, the improvement in students' conceptual understanding aligns with studies emphasizing AR's role in contextual and experiential learning. Kamarainen et al. (2013), through the EcoMOBILE project, demonstrated that AR can bridge formal classroom learning with ecological phenomena by simulating real-world

environments. This aligns with the present study, where students were able to understand ecosystem dynamics realistically without direct field exploration. Likewise, Fombona et al. (2022) argued that AR strengthens memory and conceptual understanding through multisensory 3D visualization, which explains the higher proportion of students reaching the good and very good achievement categories in the experimental class (Koumpouros, 2024; Ladykova, et al., 2024).

Beyond cognitive outcomes, this study also found that AR facilitated collaboration, discussion, and scientific communication among students. This result is in line with Cheng and Tsai (2020), who reported that AR enhances collaborative learning and critical thinking skills, as well as Christopoulos et al. (2022), who emphasized AR's potential to support problem-based learning and the development of 21st-century skills. The active peer discussions observed during AR-based learning sessions at SMP Negeri 4 Bajo indicate that AR encourages students to engage not only with content but also with each other, fostering social interaction and shared meaning-making. From a broader perspective, these findings support the OECD's (2023) assertion that digital learning innovations such as AR are essential for building adaptive and future-oriented educational ecosystems. While the findings of this study largely align with positive evidence in the literature, several previous studies have reported mixed or less supportive results regarding AR implementation. For example, Huang et al. (2023) found that students with strong preferences for traditional learning approaches may struggle to adapt to AR-based instruction. Similarly, Law et al. (2025) and Baashar et al. (2022) highlighted that technical issues, limited infrastructure, and insufficient teacher digital literacy can reduce the effectiveness of AR integration. The discrepancy between these findings and the positive outcomes observed at SMP Negeri 4 Bajo can be explained by differences in implementation conditions and pedagogical strategies.

In this study, AR was implemented with strong teacher facilitation, prior technical preparation, and integration into a project-based learning framework. Teachers received adequate guidance on how to align AR activities with learning objectives rather than using AR as a stand-alone novelty tool. Moreover, the availability of functional devices and stable learning conditions minimized technical disruptions that are often reported as barriers in other studies. These factors contributed to students' smooth adaptation to AR-based learning and reduced the cognitive load associated with unfamiliar technology. As a result, AR functioned as a meaningful instructional medium rather than a source of distraction, explaining why the findings differ from studies that reported limited or negative impacts (Antonioli, et al, 2014; Mercier et al., 2025; Radu, 2022).

Overall, this study confirms that AR-based learning media not only improve students' understanding of ecosystem concepts but also support the development of scientific thinking, digital literacy, collaboration, and learning motivation. When supported by

adequate infrastructure, teacher readiness, and appropriate pedagogical design, AR has strong potential to enhance science learning at the junior high school level and to contribute to the achievement of Sustainable Development Goal (SDG) 4 on Quality Education through technology-driven educational innovation.

D. Conclusions

This study demonstrates that the integration of Augmented Reality (AR)–based learning media in teaching ecosystem concepts at SMP Negeri 4 Bajo significantly enhances students' conceptual understanding, learning motivation, and engagement in science learning. By transforming abstract ecological concepts such as food chains, energy flow, and biotic–abiotic interactions into immersive and interactive experiences, AR supports deeper scientific reasoning, fosters collaboration, and strengthens students' digital literacy. These findings confirm that AR-based instruction positively influences not only cognitive learning outcomes but also affective dimensions of learning, aligning with Sustainable Development Goal (SDG) 4 on Quality Education, which emphasizes innovative, inclusive, and technology-enhanced learning in the digital era. Despite these positive outcomes, this study has several limitations that should be acknowledged. The research was conducted with a relatively small sample drawn from a single junior high school, which may limit the generalizability of the findings. In addition, the intervention was implemented over a short period, making it difficult to assess long-term learning retention and sustained changes in students' scientific literacy or environmental awareness. There is also a potential novelty effect, as students' heightened motivation and engagement may partly stem from their initial exposure to AR technology rather than its sustained pedagogical value. Based on these limitations, future research should employ longitudinal designs to examine the long-term effects of AR-based learning on knowledge retention, scientific literacy, and problem-solving skills. Studies involving larger and more diverse samples across different regions and school contexts are needed to test the scalability and robustness of AR implementation. Further research should also investigate the cost-effectiveness and feasibility of AR integration, particularly in rural or under-resourced schools with limited technological infrastructure. Comparative studies between AR and other digital or inquiry-based learning models would provide deeper insights into the relative pedagogical strengths of AR. Such research will contribute to evidence-based decision-making for teachers, school leaders, and policymakers seeking to integrate emerging technologies into science education effectively and sustainably.

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