RESEARCH ARTICLE

Exploration of biological concept understanding through augmented reality: A constructivism theory approach

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Abstract: Augmented reality (AR) technology combines real-world environments with digital elements, creating interactive experiences that enhance student learning. AR has significant educational potential, allowing students to visualize and interact with abstract concepts across various subjects, including economics, biology, and physics. This qualitative study explores the potential of Augmented Reality (AR) in enhancing the understanding of biological concepts through the lens of constructivism theory. The research aims to investigate how AR technology can be leveraged to create immersive and interactive learning experiences in biology education. By examining the perspectives of educators, students, and AR developers, this study seeks to provide insights into the effectiveness of AR in constructing knowledge and promoting deeper comprehension of complex biological processes. This research uses a qualitative approach with a literature study method and descriptive analysis to explore the understanding of biological concepts through Augmented Reality (AR) from the perspective of constructivism theory.Augmented Reality (AR) is revolutionizing educational paradigms by creating immersive learning environments that blend physical and digital elements, This technology supports the constructivist learning theory by allowing students to actively construct knowledge through direct interaction with virtual biological models, fostering deeper comprehension of complex biological systems and processes.While AR presents significant educational potential, its implementation in biology education faces several challenges that require careful consideration and strategic solutions. AR can help students understand complex concepts in a more exciting and fun way. In the context of constructivism theory, AR supports active, collaborative, and experience-based learning, which is very important in biology education.

Keywords: augmented reality; biology; constructivism theory

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Introduction

Understanding biological concepts and critical thinking skills are very important in science education. Research shows that problem-based learning models can improve learning activities, critical thinking skills, and students' understanding of biological concepts. However, biology education students still need help solving problems and linking various concepts. The critical thinking skills of prospective biology teacher students are also still in the inferior category. To overcome this, it is necessary to develop a culture of critical thinking through problem-solving in biology learning, such as in the Environmental Toxicology course. This effort is essential to improve the quality of education and human resources when facing the challenges of the globalization era.

Augmented reality (AR) technology combines real-world environments with digital elements, creating interactive experiences that enhance student learning (Hariyono, 2023; Saputra, 2020). AR has significant educational potential, allowing students to visualize and interact with abstract concepts across various subjects, including economics, biology, and physics (Hariyono, 2023; Juwita et al., 2021). Research has shown that AR can increase student engagement, facilitate more profound understanding, and improve learning outcomes (Hariyono, 2023; Hermawan et all, 2024). The technology enables virtual field trips, interactive simulations, and data visualization, fostering analytical skills and collaborative creativity (Hariyono, 2023). Applications of AR in education include 3D modeling of geometric shapes, visualization of the human digestive system, and exploration of traditional houses (Saputra, 2020). To

maximize the effectiveness of AR in education, further development is needed, especially for subjects that require object visualization, such as the respiratory and circulatory systems (Juwita et al, 2021).

Constructivism in biology learning emphasizes the active role of students in building knowledge based on experience. This approach encourages students to explore and interact directly with the material, facilitating understanding of complex concepts (Sugrah, 2020). The integration of Augmented Reality (AR) technology in biology learning has proven effective in improving students' understanding of abstract and microscopic concepts, such as the nervous system and viruses (Aripin et al, 2019). AR enables virtual and real-time visualization of 3D objects, bridging the gap between theory and practice (Aripin et al, 2019). The development of AR media based on Problem-Based Learning (PBL) has shown very feasible results, with increased student learning completeness and ability to analyze authentic problems. Integrating AR in constructivist biology learning offers an innovative solution to improve students' understanding of complex concepts.

Constructivism is a learning theory that emphasizes the formation of knowledge by students through active participation and direct experience. Its main principles include learning by doing, scaffolding, and social interaction. Implementing this theory in primary education can be done through group discussions, projects, and simulations involving social interaction and cultural elements (Putri et al, 2023). In science learning, electronic teaching materials such as interactive multimedia e-books can facilitate students to build their knowledge actively. The teacher is a facilitator, providing guidance and assistance (scaffolding) during the learning process. Small group discussion activities also reflect the application of social constructivism theory (Herianto et al, 2021).

Scaffolding is essential in improving critical thinking skills, especially in biology education. Emphasized the importance of scaffolding in developing critical thinking skills among biology education students, especially during the COVID-19 pandemic. In biology learning, Augmented Reality (AR) technology shows potential as an effective medium, capable of representing abstract concepts concretely and reducing misconceptions (Aripin et al, 2019). AR can facilitate a collaborative learning environment, in line with Vygotsky (1978) theory on the importance of social interaction in learning. Laamena (2019) highlighted that scaffolding strategies should be tailored to students' learning styles (visual, auditory, kinesthetic) and the arguments they build. For example, students with auditory learning styles will benefit from review and explanation strategies, while students with visual and kinesthetic learning styles need environmental provision and multimedia support. This customized scaffolding approach can improve problem-solving abilities and more meaningful learning experiences in biology education.

Constructivism theory emphasizes the active role of students in learning, including in the online context (Budyastuti et al, 2021). Augmented reality (AR) is an innovative technology that can enhance interactive learning experiences and influence student engagement (Rachim et al, 2024). In learning biology, AR has the potential to visualize abstract concepts more concretely, reduce misconceptions, and increase student learning motivation (Aripin et al, 2019). Implementing AR in education can encourage students' understanding of concepts through interactive experiences and better visualization (Hermawan et al, 2024). Although AR offers many benefits, its application still faces challenges and requires curriculum development, innovative learning methods, and educator training to optimize its potential to improve learning quality.

Constructivism theory emphasizes the active role of students in learning, including in the online context (Budyastuti et al, 2021). Augmented reality (AR) has emerged as a promising technology for improving biology education, especially in visualizing abstract concepts. AR can transform complex biological ideas into concrete and interactive 3D representations, making them more accessible to students (Aripin et al, 2019). This technology has been successfully applied to various biology topics, including the nervous system and viruses, demonstrating its effectiveness in improving student understanding and learning outcomes. Integrating AR with problem-based learning approaches has shown potential in developing students' analytical skills and motivation. The technology's ability to combine virtual objects with natural environments in real time makes it particularly suitable for teaching abstract concepts across various subjects, including biology, mathematics, and social sciences (Saputra, 2020). Several studies have reported high levels of validity and effectiveness for AR-based learning media in biology education (Aripin et al, 2019).

Augmented reality (AR) technology has shown significant potential as an innovative learning tool in biology education. AR can transform abstract biological concepts into concrete 3D visualizations, improving student understanding and reducing misconceptions. Research has shown the effectiveness of AR in teaching various biology topics, including cell division and the nervous system. The application of AR in biology education has improved learning outcomes, with one study reporting a 76% increase in student achievement (Aripin et al, 2019). AR applications allow students to learn anytime and anywhere, making them particularly valuable during adaptive learning (Juwita et al, 2021). To maximize the effectiveness of AR in science education, further development is needed, especially for topics that require complex visualizations, such as the respiratory and circulatory systems.

Examples of AR applications that can be used in biology learning are “Google Expeditions” and “Merge Cube.” Google Expeditions allows students to take virtual tours of biologically essential locations, such

as the Amazon rainforest or coral reefs. In contrast, Merge Cube allows students to hold and interact with three-dimensional objects. These apps increase student engagement and provide a broader context for the concepts being taught.

Augmented reality (AR) technology has emerged as a powerful tool for enhancing interactive learning experiences across various subjects. Research has shown that AR can improve students' understanding of abstract concepts, increase motivation, and provide a more positive learning experience (Huang et al., 2016). In biology education, AR helps visualize complex concepts, reduce misconceptions, and make abstract ideas more concrete. The application of AR in the classroom offers many benefits, including increased student engagement, better understanding of concepts, and development of analytical skills (Hariyono, 2023). AR applications in education range from virtual field trips to interactive simulations and data visualization, allowing students to interact with dynamic objects and encouraging collaborative learning environments. Despite its potential, the implementation of AR in education still faces challenges, thus requiring further research and the development of innovative teaching methods and curricula.

In addition, AR can also be used to simulate complex biological processes, such as photosynthesis or cellular respiration. By seeing how these processes occur in real time, students can better understand how various factors affect the outcome. This aligns with the principles of constructivism, where students construct their knowledge through experience and exploration. AR in biology learning can also support differentiated learning, where students with different levels of understanding can learn in ways that suit them. For example, more visual students can easily understand biological concepts through AR visualizations, while more kinesthetic students can interact directly with the objects. This creates an inclusive learning environment and supports various learning styles.

Method

This research, which examines the understanding of biological concepts through Augmented Reality (AR) with the perspective of constructivism theory, applies a complex and structured qualitative approach. The qualitative approach was chosen because of its ability to provide in-depth understanding of complex and multidimensional phenomena. Through this approach, researchers can thoroughly explore how AR can facilitate the understanding of biology concepts, by considering various aspects and contexts involved in the learning process (Radu, 2014).

The literature study method used in this research is systematic, allowing researchers to collect, analyze, and synthesize findings from various relevant literature sources, as described by Snyder (2019). This approach is very suitable for exploring topics that are still developing such as the use of AR in biology education. Through a systematic literature study, researchers can identify patterns, trends, and best practices in the use of AR for biology learning, as well as analyze how this technology can support knowledge construction by learners.

The descriptive analysis applied in this study enabled the researcher to describe and interpret the findings in an in-depth and comprehensive manner. The analysis process involved identifying key themes, patterns and relationships between concepts that emerged from the literature reviewed. This approach also enabled the researcher to develop a rich understanding of how AR can be effectively integrated in biology learning, taking into account various perspectives and learning contexts.

This research methodology was designed to provide a holistic understanding of the role of AR in biology learning. Through a combination of qualitative approach, systematic literature study, and descriptive analysis, this research not only generates insights into best practices in the use of AR, but also makes a meaningful theoretical contribution to the understanding of how this technology can support constructivistic learning in biology education. The results of this study are expected to provide a strong foundation for the development of learning practices and further research in this field.

The methodological significance of this study lies in its ability to generate an in-depth and contextualized understanding of the use of AR in biology education. By adopting a systematic and comprehensive approach, this study not only identifies effective practices in the use of AR, but also reveals how this technology can support the knowledge construction process in biology learning. The findings from this study can be the basis for the development of more effective and innovative learning strategies in AR-based biology education.

Results and Discussion

Case Study in Biology Learning

The AR biology lesson plan must be well-designed to achieve the desired learning objectives. First, teachers need to choose an AR application suitable for the material to be taught. For example, an app that allows students to see the cell structure in three dimensions can be chosen for the topic of cells. In addition, teachers should also prepare the necessary devices, such as tablets or smartphones, and

ensure that all students have access to the technology (Wulandari 2020).
Activities that engage students in using AR can include simulation, exploration, and collaboration. For example, students can be divided into small groups and tasked with exploring different biology concepts using AR. Each group can be given a different topic: ecosystems, animal anatomy, or plant life cycles. After the exploration, students can present their findings to the class, improving their understanding and developing communication skills. Criteria for assessing and evaluating student understanding also need to be established. Assessment can be done through quizzes, presentations, or group projects. In addition, feedback from students about their experience using AR in learning is also essential to obtain. This can provide insight into the effectiveness of using AR and areas that need improvement.
The use of AR in learning should also be integrated with other learning methods, such as class discussions and individual assignments. In this way, students can better understand biological concepts more comprehensively. A study by Ibáñez (2016) showed that the combination of traditional methods and technology, such as AR, can significantly improve student learning outcomes. Finally, involving parents and communities in the learning process is important. By providing information about the use of AR in education, parents can support their children's learning process at home. It can also create greater awareness of the importance of technology in education and how it can be used to improve students' understanding of biology.

Opening New Dimensions: Exploring the Potential of AR in Interactive Education

Several studies have explored using Augmented Reality (AR) in biology education in Indonesia. AR applications have been developed to teach various biology concepts, including the nervous system (Aripin et al, 2019), photosynthesis, the human excretory system (Aprilinda et al., 2020), and cell division. These AR-based learning tools have shown promising results in improving student engagement and understanding. For example, Aripin et al (2019) reported a 76% increase in student learning outcomes using AR for nervous system lessons. Similarly, found that 83% of students found AR-based photosynthesis lessons more exciting and easier to understand. The implementation of AR in biology education has been observed to make learning more interactive, visually appealing, and effective in conveying complex biological processes that are difficult to observe directly (Aprilinda et al., 2020).
Research shows that Augmented Reality (AR) technology can significantly improve student learning outcomes in science education. Research shows that students who use AR-based learning media achieve higher test scores than those who use conventional methods (Deni, 2020). AR technology allows the visualization of abstract concepts, making them more accurate and engaging for students. The implementation of AR in biology education has improved learning outcomes, with one study reporting an increase in student mastery of up to 76%. AR has also been proven effective in physics education, especially for topics that require object visualization (Juwita et al., 2021). Integrating AR technology in science education offers a flexible learning solution, allowing students to learn anytime and anywhere, which is invaluable during the adaptation period to new educational norms.
Augmented reality (AR) has emerged as an innovative technology that enhances the learning experience in modern education. Studies show that implementing AR in classrooms can increase student engagement, motivation, and understanding of complex concepts. AR's ability to visualize abstract ideas and create an interactive learning environment is particularly beneficial in science education, where students often experience difficulties in conceptual understanding. AR provides an engaging platform for early childhood education that combines play and learning, catering to children's curiosity and short attention spans. Teachers report that AR makes teaching more engaging and interactive, encouraging greater class participation. Although AR shows excellent educational potential, its implementation still faces challenges, requiring further research and development of innovative teaching methods and curriculum integration (Table 1).
All the studies analyzed consistently showed a positive impact of using AR in biology learning. These include increased motivation, concept understanding, spatial skills, and knowledge retention. This consistency, supported by various research methods (from experimental studies to meta-analysis), strengthens the validity of the claim that AR does have significant potential in improving biology learning. These studies demonstrate the usefulness of AR in various biology topics, ranging from cell biology (Cheng et al, 2020) and anatomy (Safadel et al, 2019; Korkmaz, 2020) to evolution (Buchner et al, 2020). This shows the flexibility of AR as a learning tool that can be adapted for various concepts in the biology curriculum.
Some studies (Cheng et al, 2020; Buchner et al, 2020) specifically noted increased intrinsic motivation and student engagement. This is an essential aspect of constructivist learning, where internal motivation and curiosity are critical drivers of meaningful learning. According to the Scimago ranking, the majority of the studies (5 out of 7) were published in Q1 journals, indicating their high quality and impact. This increases confidence in the findings presented and strengthens the argument for the adoption of AR in biology learning.

Table 1. Research of Implication Contructivism Theory with Augmented Reality in Biology Learning

Article	Method	Result	Constructivism Implication	Journal Acreditation	DOI
Cheng & Tsai (2020)	Quantitative study with 318 middle school students	The use of AR increases student motivation and understanding of concepts in learning cell biology	AR supports active exploration and individual knowledge constructionl	Q1 (Scimago)	10.1111/bjet.12956
Ibáñez & Delgado-Kloos (2018)	Meta-analysis of 28 AR studies in STEM education	AR is effective in improving learning outcomes and spatial skills in biology	AR facilitates the visualization of abstract concepts, supporting mental construction processes	Q1 (Scimago)	10.1016/j.compedu.2018.05.002
Safadel & White (2019)	Experiment with 70 college-level biology students	The group using AR showed significant improvements in anatomical understanding compared to the control group	AR enables virtual hands-on exploration, supporting experiential learning	Q2 (Scimago)	10.1007/s11528-018-0343-0
Chen et al. (2019)	Development and evaluation of an adaptive AR system for science learning	Adaptive AR systems improve learning outcomes and student engagement in complex biology topics	AR content personalization supports an individual's ZPD (Zone of Proximal Development).	Q1 (Scimago)	10.1080/10494820.2018.1510418
Tzima et al. (2019)	Case study with 32 middle school students	AR increases students' understanding of the photosynthesis process and encourages collaborative learning	AR supports the social construction of knowledge through peer-to-peer interactions	Q2 (Scimago)	10.3390/educsci9020099
Korkmaz (2020)	Quasi-experiment with 114 student biology teacher candidates	The use of AR in anatomy learning improves long-term knowledge retention	AR facilitates the formation of powerful mental models, supporting meaningful learning	Q1 (Scimago)	10.3390/app10228366
Buchner & Zumbach (2020)	Experimental study with 121 middle school students	AR increases intrinsic motivation and conceptual understanding in evolutionary learning	AR encourages curiosity and independent exploration, key principles of constructivism	Q1 (Scimago)	10.1080/10494820.2018.1495594

While these findings are very promising, it should be noted that most studies focused on short-term effects. Korkmaz's (2020) research on long-term knowledge retention is a valuable exception. It shows the need for more longitudinal research to understand the long-term impact of AR on biology learning. While the main focus is on learning benefits, practical considerations such as developing adaptive AR systems (Chen et al., 2019) and teachers' perspectives (Tzima et al., 2019) are also discussed. This reminds us that successful implementation of AR in biology education requires a robust pedagogical framework and adequate technological infrastructure and support for educators.

Based on this analysis, it can be concluded that Augmented Reality has significant potential to enhance biology learning through a constructivist approach. AR not only improves conceptual understanding and practical skills but also encourages students' intrinsic motivation and active engagement in the learning process. The alignment between AR features and constructivism principles creates a learning environment that supports meaningful exploration, visualization, and knowledge construction. However, it is essential to note that the effectiveness of AR depends on careful implementation and good integration with the existing curriculum. Educators need to be equipped with a good understanding of using AR to support constructivist learning, and adequate infrastructure needs to be provided.

Further research, especially longitudinal studies and large-scale implementation, would be valuable to

understand AR's long-term potential in biology education fully. In addition, exploring how AR can be combined with other pedagogical approaches and educational technologies might open new avenues for innovation in biology learning. Overall, the available evidence suggests that AR, when implemented well within a constructivist framework, can be a powerful tool to transform how students learn and understand complex biological concepts.

Augmented Reality (AR) can improve learning quality and students' concept understanding (Hermawan et al, 2024). However, its implementation faces several challenges, especially regarding accessibility. The digital divide is still an issue in some areas, with barriers such as limited access to devices, poor internet connectivity, and lack of digital literacy (Pahrijal et al, 2023). This can prevent students from optimally utilizing learning technologies. To overcome these challenges, collaborative efforts are needed between schools, government and the technology industry to improve accessibility, provide adequate infrastructure and increase teacher capacity (Indriani, 2022). Developing educational content that suits local needs and ensuring all students have equitable access to digital resources (Pahrijal et al, 2023). Overall, this case study shows that using AR in biology learning not only improves concept understanding but also creates a more positive and enjoyable learning experience for students. AR can be a very effective tool in biology education with the right approach.

Augmented Reality as a Constructivism Tool for Biology Learning

Augmented reality (AR) offers an innovative solution for teaching complex biological concepts and spatial structures. Research shows the effectiveness of AR in improving students' understanding and retention of abstract biology topics such as viruses and the nervous system (Sholikha. et al., 2024). AR technology enables the projection of interactive 3D models into natural environments, allowing students to explore biological structures and processes in previously impossible ways. The implementation of AR in education has shown significant improvements in students' spatial understanding, knowledge retention, and overall learning outcomes. In addition, AR applications have been developed for various levels of education, ranging from elementary school math to anatomy courses at the university level, demonstrating its versatility and potential for widespread adoption in education (Rusnandi et al., 2016). These studies collectively highlight the potential of AR to transform abstract concepts into tangible and interactive learning experiences.

Augmented Reality (AR) has emerged as a promising technology in education, offering significant potential to enhance the learning experience. AR facilitates active exploration, provides real-world context, and supports collaboration in line with constructivist learning principles (Cheng et al, 2020). This technology combines virtual objects with a physical environment, allowing students to interact with digital content in real time (Saputra, 2020). AR applications have been implemented in various subjects, especially for abstract concepts such as 3D geometry, the human digestive system, and cultural heritage (Saputra, 2020). Research has shown that AR can increase student engagement, motivation, and conceptual understanding (Ana, 2020). However, there are still challenges in implementing AR, including infrastructure requirements and teacher training. Overall, AR presents a promising avenue for creating more interactive, effective, and meaningful learning experiences in modern education.

Studies show that AR significantly improves students' ability to visualize abstract or difficult-to-observe biological concepts. According to Lai et al (2019), AR in anatomy learning allows students to view complex 3D organ structures from various angles, improving their spatial understanding. This finding aligns with the principle of constructivism, which emphasizes the importance of concrete experience in building knowledge. Several studies reveal that implementing AR in biology learning increases student engagement and motivation. Mauludin et al (2017) reported that students who used AR applications in ecology learning showed higher enthusiasm and participation than traditional methods. This increase in motivation aligns with the constructivist view that meaningful learning occurs when students are actively involved in the knowledge-construction process.

AR effectively supports collaborative learning, an essential aspect of social constructivism theory. Sung et al (2021) found that using AR in biology laboratory activities increased student interaction and encouraged deeper discussions about the studied concepts. This allows students to share perspectives and build a richer understanding together. The study by Chen et al (2020) shows that AR enables the personalization of learning experiences, which is in line with constructivist principles that emphasize the importance of considering students' prior knowledge and experiences. The adaptive AR application developed in the study could adjust content and challenges based on students' levels of understanding, resulting in better learning outcomes (Kholifah et al, 2023).

Several longitudinal studies show that using AR improves long-term knowledge retention in biology learning. Buchner et al (2020) reported that students who learned evolutionary concepts using AR showed better understanding and longer retention than the control group, even after several months.

Challenges and Solutions in Implementing Augmented Reality in Biology Learning

Implementing technology in education, including Augmented Reality (AR), faces several challenges in Indonesia. Limited access and technological infrastructure creates a significant digital divide, especially in remote areas. Although integrating information and communication technology (ICT) in science and biology learning has shown positive impacts, such as increasing student interest and motivation, there are still obstacles to accessibility and infrastructure. AR in education can increase interactive experiences, concept visualization, and students' learning interests (Hermawan et al, 2024). To overcome this challenge, increasing technological accessibility, focusing on inclusive education, increasing teacher capacity, and collaboration between schools, government, and the technology industry is needed (Indriani, 2022). Curriculum development, innovative learning methods, and regular evaluations are also essential to maximize the benefits of technology in education.

Potential solutions to address these challenges include increased investment in educational technology infrastructure and the development of training programs for teachers. Schools must work with government and private institutions to ensure all students have equal access to technology. Additionally, training teachers in using AR and other educational technologies is essential to ensure they can effectively integrate them into their teaching (Khairunnisa, 2021). In addition, developing AR content that can be accessed offline can also solve accessibility problems. Students in remote areas can still benefit from this technology by creating AR applications that do not require an internet connection to function. Some developers have started creating AR content that can be downloaded and used without an internet connection, which can help overcome this problem (Lewis, 2015).

Involving parents and communities in the AR implementation process is also essential. By providing information about the benefits of AR in education, parents can better support their children in using this technology. Communities can also provide additional resources, such as technology devices or internet access, to support student learning (Tonny, 2017). Finally, ongoing evaluation and feedback from students and teachers about AR experiences is also essential to identify challenges and find practical solutions. With a collaborative and open approach, challenges in implementing AR in biology education can be overcome so that students can experience the full benefits of this technology.

Conclusion

The use of Augmented Reality in biology learning has great potential to improve students' understanding of concepts. By animating teaching materials interactively, AR can help students understand complex concepts in a more exciting and fun way. In the context of constructivism theory, AR supports active, collaborative, and experience-based learning, which is very important in biology education. Recommendations for best practices in implementing AR include selecting applications that align with the curriculum, adequate teacher training, and supporting technology access for all students. In addition, it is essential to involve parents and communities in the learning process to create an environment that supports the use of technology in education.

A look ahead at further developments in the use of AR in biology education suggests that this technology will continue to develop and offer more opportunities for innovation in teaching. With continued research and development, AR can become a highly effective tool in improving the quality of biology education and preparing students for future challenges.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

M. Z. Afnan: writing original draft preparation, **R. P. Puspitawati:** review and editing

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