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The use of augmented reality in cell structure learning to improve students' conceptual understanding

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ABSTRACT

This study is important due to the need for innovative learning media to help students understand abstract biological concepts effectively. This study aims to determine the effect of utilizing Augmented Reality (AR) in cell structure learning on the improvement of students' conceptual understanding at SMP Negeri 1 Aifat Timur. This study uses a quantitative approach with a quasi-experimental method and a nonequivalent control group design. The research sample consists of two classes, namely the experimental class using AR and the control class with conventional learning. The instrument used was a concept understanding test administered through a pretest and posttest. Data were analyzed using normality tests, homogeneity tests, independent sample t-tests, and N-Gain. The results showed a significant difference between the experimental and control classes with a significance value of 0.000 < 0.05. The average improvement (N-Gain) of the experimental class was 0.63 (moderate), higher than that of the control class at 0.38. These findings indicate that AR effectively enhances students' conceptual understanding. The novelty lies in applying AR as an interactive medium to visualize abstract cell structures at the junior high level, supporting improved biology education quality.

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INTRODUCTION

Science education, especially biology, plays an important role in shaping students' understanding of natural phenomena and developing scientific thinking skills (Purnawati & Yakin, 2025; Maharani, 2025). However, in practice, biology learning still faces various challenges, especially with abstract materials such as cell structure. These materials involve microscopic objects that cannot be directly observed by students, often leading to difficulties in fully understanding the concepts and potentially causing misconceptions (Sokib & Prasetyo, 2025; Indrati & Masing, 2025)

Empirical data from previous studies indicate that students' conceptual understanding of cell structure remains relatively low. For instance, research shows that only about 45%–55% of students achieve the minimum mastery criteria in cell-related topics, while a significant proportion experience misconceptions regarding organelle functions and structures . Additionally, other studies report that students' average scores on concept understanding tests for cell structure are still in the moderate to low category, ranging between 50–60 on a scale of 100 (Herak et al., 2023). These findings highlight the need for more effective learning strategies to improve students' conceptual understanding.

Initial observations at SMP Negeri 1 Aifat Timur indicate that biology learning is still dominated by conventional methods such as lectures and textbooks, with minimal integration of technology-based learning media, particularly Augmented Reality (AR). In practice, teachers have not yet utilized AR or other interactive digital tools to visualize abstract concepts such as cell structure. As a result, the learning process tends to be teacher-centered, and students experience difficulties in understanding the spatial and functional aspects of cell organelles. This is reflected in students' low engagement during lessons and their limited ability to explain cell structure concepts accurately. The absence of AR-based visualization contributes to the gap between abstract biological concepts and students' concrete understanding. This condition aligns with research findings that biology learning is often considered difficult due to the abstract nature of the material and the lack of adequate visual media support (Nurwahyunani et al., 2025) (Rifani Arsyad et al., 2025) (Hisdayu et al., 2023).

Along with the development of digital technology, the integration of technology in learning has become one of the solutions to improve the quality of the learning process (Dewi, 2024) (Chafshah et al., 2024) (Alenezi et al., 2023). One of the rapidly developing technologies is Augmented Reality (AR). AR is a technology that can integrate virtual objects into the real world in real-time, resulting in an interactive and immersive learning experience (Al-Ansi et al., 2023) (Kafilahudin & Akbar, 2024). The use of AR in biology education allows students to observe cell structures in three-dimensional form, thereby helping to bridge the gap between abstract concepts and students' concrete understanding (Agma, 2025).

Various studies show that the use of Augmented Reality in biology learning has a positive impact on students' motivation, engagement, and conceptual understanding (Karim et al., 2026) (Afnan & Puspitawati, 2024). Recent literature studies show that AR is capable of significantly enhancing concept comprehension, learning engagement, and student knowledge retention (Hariyono, 2023). Furthermore, other research also reveals that the trend of using AR in biology education continues to increase during the 2020–2024 period, indicating that this technology is becoming increasingly relevant in supporting 21st-century learning (Muhammad Kautsar & Haryono, 2025). In Indonesia, systematic studies also affirm that AR has become one of the effective innovations in learning media to enhance the quality of biology education (Resti et al., 2024) (Leliavia, 2023).

Nevertheless, the implementation of Augmented Reality in biology learning at the junior high school level, particularly on the topic of cell structure in areas like Aifat Timur, is still relatively limited. This indicates a gap between the development of learning technology and its practical application in the field. Therefore, this research is important to conduct in order to examine the effectiveness of utilizing Augmented Reality in enhancing students' conceptual understanding.

Based on the description, this study aims to determine the effect of utilizing Augmented Reality in cell structure learning on the improvement of students' conceptual understanding at SMP Negeri 1 Aifat Timur. The results of this study are expected to contribute to the

development of innovative technology-based learning media and serve as a reference for teachers in implementing more effective and engaging learning.

RESEARCH METHODS

Research Design

This research uses a quantitative approach with a quasi-experimental method. The design used is the Nonequivalent Control Group Design, which involves two groups: the experimental class and the control class without full randomization. The experimental class is given treatment in the form of learning using Augmented Reality (AR) media, while the control class uses conventional learning. The research design can be presented in Table 1.

Table 1. Research Design

Group	Pretest	Treatment	Postest
Experiment	O1	X (AR)	O2
Control	O1	-	O2

Explanation:
O_1 = Pretest
O_2 = Posttest
X = Learning using Augmented Reality

Population and Samples

The population in this study consists of all eighth-grade students of SMP Negeri 1 Aifat Timur. The research sample was selected using a purposive sampling technique, which involves choosing samples based on specific criteria relevant to the research objectives. The considerations for selecting the sample include: (1) both classes are taught by the same biology teacher, ensuring consistency in teaching methods; (2) the classes have relatively similar academic abilities, as indicated by previous biology scores and school records; (3) the number of students in each class is relatively equal; and (4) both classes have not previously been exposed to Augmented Reality-based learning media. Based on these criteria, class VIII A was selected as the experimental class and class VIII B as the control class, each consisting of 30 students. The use of purposive sampling is intended to ensure that both groups have comparable initial characteristics, thereby increasing the internal validity of the study and minimizing potential bias due to differences in prior knowledge or learning experience.

Instruments

The instruments used in this study consisted of a concept understanding test, observation sheets, and student response questionnaires, each serving different but complementary purposes. The concept understanding test was the primary instrument used to measure students' conceptual understanding of cell structure before and after the treatment. The test consisted of 20 multiple-choice questions based on cognitive indicators (C2–C4). The data obtained from the pre-test and post-test were analyzed using descriptive statistics, N-Gain, and an independent sample t-test to determine the effectiveness of Augmented Reality (AR) in improving students' conceptual understanding.

The observation sheet was used to assess students' learning activities during the implementation of AR-based learning. The observed indicators included student participation, engagement, and interaction during the learning process. The observation data were analyzed using a percentage formula and categorized into levels such as very active, active, moderately active, and less active. The results of the observation were used to support the findings regarding student engagement during AR implementation.

The student response questionnaire was used to measure students' perceptions of the use of AR as a learning medium. The questionnaire consisted of Likert-scale statements covering aspects such as attractiveness, ease of use, and usefulness of AR in learning. The data were analyzed using percentage analysis and interpreted into categories such as very positive, positive, fairly positive, and less positive. The results of this analysis were used to strengthen the interpretation of the effectiveness of AR from the students' perspective.

Before being used, all instruments underwent content validity testing by experts to ensure their relevance to the research objectives. Empirical validity testing was conducted using product-moment correlation, while reliability testing was performed using the Cronbach Alpha coefficient. Additionally, item analysis, including difficulty level and discrimination index, was conducted for the test instrument to ensure the quality of the items.

Procedures

The research procedure is carried out through several interconnected stages. The research began with the preparation stage, which included the development of learning devices, the development and testing of Augmented Reality media, and the preparation of research instruments. Next, at the implementation stage, the researcher administered a pretest to both classes to determine the students' initial abilities. After that, the learning process was carried out according to the treatment of each group, where the experimental class used Augmented Reality media in cell structure learning, while the control class used conventional teaching methods. During the learning process, observations were made on student activities. At the end of the learning process, both classes were given a posttest to measure the improvement in students' conceptual understanding. The final stage is data processing and analysis, as well as drawing conclusions based on the research results obtained.

Data Analysis

The obtained data were analyzed quantitatively to address the research objectives. The analysis began with prerequisite tests, including the normality test using the Shapiro-Wilk and the homogeneity test using the Levene Test, to ensure that the data met the assumptions for parametric statistical analysis. After the assumptions were fulfilled, the hypothesis was tested using an independent sample t-test to determine whether there was a significant difference in conceptual understanding between the experimental class and the control class. Furthermore, the N-Gain test was conducted to measure the improvement in students' conceptual understanding before and after the treatment. The N-Gain values were categorized into three levels: high ($g > 0.7$), medium ($0.3 \leq g \leq 0.7$), and low ($g < 0.3$). All statistical tests were conducted at a significance level of $\alpha = 0.05$. In addition to test data, observational data on student activities were analyzed using percentage calculations based on observed indicators, such as participation, interaction, and engagement during the learning process. The results were then interpreted into categories, including very active, active, moderately active, and less active. Meanwhile, the data from the student response questionnaire were analyzed using a Likert scale approach and converted into percentages to determine students' perceptions of the use of Augmented Reality. The results were categorized into very positive, positive, fairly positive, and less positive. These supporting analyses were used to strengthen the interpretation of the effectiveness of Augmented Reality in enhancing students' conceptual understanding.

RESULTS

The research results were obtained from students' concept understanding tests on cell structure material given before (pretest) and after treatment (post-test). A summary of the test results is presented in Table 2.

Table 2. Descriptive Statistics of Pretest and Posttest Scores

Class	N	Pretest Mean	Posttest Mean	Gain	Category
Experiment	30	52.30	82.40	0.63	Medium
Control	30	51.80	70.20	0.38	Medium

Based on Table 2, it can be seen that the average pretest scores of both classes are relatively the same. However, after the treatment, the experimental class using Augmented Reality experienced a higher increase compared to the control class. To ensure that the differences in learning outcomes between the experimental class and the control class can be analyzed validly, it is necessary to test the basic assumptions in statistical analysis. This prerequisite test aims to determine whether the obtained data meet the criteria for conducting a parametric test. In this study, the prerequisite tests conducted include the normality test to determine whether the data is normally distributed, as well as the homogeneity test to ensure that the variances of the two groups are the same. The results of these prerequisite tests serve as the basis for determining the appropriate advanced analysis techniques to test the research hypothesis. The results of the normality test and the homogeneity test can be seen in Table 3 and Table 4.

Table 3. Normality Test (Shapiro Wilk)

Class	Sig. Pretest	Sig. Posttest	Category
Experiment	0.200	0.176	Normal
Control	0.187	0.165	Normal

Table 4. Homogenitas Test (Shapiro Wilk)

Data	Sig.	Category
Posttest	0.321	Homogen

Based on Table 3 and Table 4, the test results indicate that the data is normally distributed and homogeneous, allowing for the continuation of the hypothesis test.

Table 5. t-test Result

Data	t count	Sig. (2-tailed)	Category
Posttest	3.87	0.000	Signifikan

A significance value < 0.05 indicates that there is a significant difference between the experimental and control classes. Thus, the use of Augmented Reality has an impact on improving students' conceptual understanding. Based on Table 6, the results of the student response questionnaire indicate that the use of Augmented Reality in learning received a very positive response from students, with an average percentage of 85.8%. All assessed indicators fall into the "very positive" category, including attractiveness (88%), ease of use (85%), clarity of material (83%), usefulness in learning (87%), and learning motivation (86%). These findings suggest that Augmented Reality is perceived as an engaging, user-friendly, and beneficial learning medium that helps students better understand the material while also increasing their motivation to learn. Overall, the high percentage across all indicators demonstrates that the implementation of Augmented Reality creates a positive learning experience and supports its effectiveness in enhancing students' conceptual understanding.

Based on Table 7, the results of the observation of student activities show that students were highly engaged during the learning process using Augmented Reality, with an average percentage of 84.2% categorized as "very active." Most indicators fall within the active to very active categories,

including participation in discussions (84%), asking questions (80%), interaction with AR media (89%), group collaboration (85%), and focus during learning (83%). The highest score is observed in students' interaction with AR media, indicating that the technology successfully attracts students' attention and encourages active involvement. These findings suggest that the use of Augmented Reality not only enhances students' conceptual understanding but also promotes active participation and collaborative learning in the classroom.

Table 6. Results of Student Response Questionnaire on the Use of Augmented Reality

Indicator	Percentage (%)	Category
Attractiveness	88%	Very Positive
Ease of Use	85%	Very Positive
Clarity of Material	83%	Very Positive
Usefulness in Learning	87%	Very Positive
Learning Motivation	86%	Very Positive
Mean	85.8%	Very Positive

Table 7. Student Activity Observation Results

Indicator	Percentage (%)	Category
Participation in discussions	84%	Very Active
Asking Questions	80%	Active
Interaction with AR Media	89%	Very Active
Group Collaboration	85%	Very Active
Focus During Learning	83%	Very Active
Mean	84.2%	Very Active

DISCUSSION

The research results show that the use of Augmented Reality (AR) in cell structure learning has a significant impact on improving students' conceptual understanding. This is evident from the difference in average posttest scores between the experimental and control classes, as well as the statistical test results that indicate significance.

The improvement in concept understanding in the experimental class occurred because AR was able to visualize cell structures in an interactive three-dimensional form. This visualization helped students understand the parts of the cell that were previously abstract to become more concrete. This finding is in line with research by Alenezi et al. (2023), which states that AR can enhance conceptual understanding through real-time visualization of complex objects. Moreover, the use of AR also enhances student engagement in the learning process. Students become more active, interested, and motivated to learn. This is supported by the research of Indria Permana et al. (2024), which states that AR can enhance students' motivation and participation in biology learning.

The N-Gain test results show that the improvement in the experimental class falls into the moderate category (0.63), but is higher compared to the control class. This shows that although conventional methods still provide improvement, the use of technology such as AR yields more optimal results. These findings are in line with Indrati & Masing (2025), who state that the integration of technology in biology education can significantly enhance learning effectiveness.

Furthermore, the results of this study also reinforce the concept of 21st-century technology-based learning, which emphasizes the use of interactive media to enhance the quality of education. AR as a learning medium is capable of combining visual, audio, and interactive elements, thereby creating a more meaningful learning experience. This is in line with the findings of (Arshad et al.,

2023), which states that AR technology plays a crucial role in enhancing the quality of education through innovative and interactive learning.

Thus, it can be concluded that the use of Augmented Reality in biology learning, particularly on the topic of cell structure, has proven effective in enhancing students' conceptual understanding. The implementation of this technology can serve as an alternative solution to address students' learning difficulties with abstract material.

CONCLUSION

Based on the research results, it can be concluded that the use of Augmented Reality in cell structure learning significantly affects the improvement of students' conceptual understanding at SMP Negeri 1 Aifat Timur. This is evidenced by the higher average learning outcomes and improvement (N-Gain) in the experimental class compared to the control class, as well as supported by significant statistical test results. These findings affirm that the integration of Augmented Reality technology can transform abstract concepts into more concrete ones through interactive three-dimensional visualization, thereby providing a more meaningful and effective learning experience. The novelty of this research lies in the application of Augmented Reality to cell structure material at the junior high school level, which is still limited, particularly in the context of learning in the Papua region, thus making a tangible contribution to the development of technology-based learning media. Therefore, it is recommended that teachers utilize Augmented Reality technology as an alternative innovative learning medium to enhance the quality of biology education, and further research can develop the application of this technology to other biology topics or different educational levels..

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