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THE INFLUENCE OF AUGMENTED REALITY-BASED FLASHCARDS ON THE UNDERSTANDING OF THE CONCEPT OF GRADE V STUDENTS ON THE MATERIAL OF FAUNA DIVERSITY IN INDONESIA

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Abstract
The integration of technology in learning is constantly evolving to improve student understanding. One of the challenges in teaching science in elementary schools is presenting abstract concepts, such as faunal diversity, in a way that is engaging and easy to understand. Augmented reality offers a solution by providing an immersive visual learning experience. This study aims to assess the effect of augmented reality flashcards on understanding the concept of faunal diversity in fifth grade students. This study used an experimental method with a nonequivalent control group design, students were divided into two groups, where the experimental group used augmented reality flashcards and the control group with conventional methods. Data was collected through pretest and posttest, analyzed using paired sample t-test, independent t-test, effect size, and N-Gain. The results showed a significant increase in the understanding of students who used augmented reality flashcards (Sig. 0.004 <0.05) with an effect size of 2.08 (large category). N-Gain analysis showed a higher increase in comprehension in the experimental group (0.57) compared to the control group (0.36). This finding confirms that augmented reality flashcards can be an effective learning tool for teachers in teaching abstract science concepts.
Keywords: *Augmented reality; Flashcards; Concept Understanding; Fauna Diversity*

Abstrak
Integrasi teknologi dalam pembelajaran terus berkembang untuk meningkatkan pemahaman siswa. Salah satu tantangan dalam pengajaran sains di sekolah dasar adalah menyajikan konsep abstrak, seperti keanekaragaman fauna, dengan cara yang menarik dan mudah dipahami. *Augmented Reality* menawarkan solusi dengan memberikan pengalaman belajar visual yang imersif. Penelitian ini bertujuan menilai pengaruh *flashcard augmented reality* terhadap pemahaman konsep keanekaragaman fauna pada siswa kelas lima. Penelitian ini menggunakan metode eksperimen dengan desain nonequivalent control group, siswa dibagi menjadi dua kelompok, Dimana kelompok eksperimen yang menggunakan *flashcard augmented reality* dan kelompok kontrol dengan metode konvensional. Data dikumpulkan melalui pretest dan posttest, dianalisis menggunakan uji-t sampel berpasangan, uji-t independen, effect size, dan N-Gain. Hasil menunjukkan peningkatan signifikan pada pemahaman siswa yang menggunakan *flashcard augmented reality* (Sig. 0.004 < 0.05) dengan *effect size* sebesar 2.08 (kategori besar). Analisis N-Gain menunjukkan peningkatan pemahaman yang lebih tinggi pada kelompok eksperimen (0,57) dibandingkan kelompok kontrol (0,36). Temuan ini menegaskan bahwa *flashcard augmented reality* dapat menjadi alat bantu pembelajaran yang efektif bagi guru dalam mengajarkan konsep sains abstrak.
Kata Kunci: Augmented reality; Flashcard; Pemahaman Konsep; Keanekaragaman Fauna

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Introduction

Science education plays a crucial role in fostering students' conceptual understanding. At the elementary level, grasping scientific concepts is essential for developing logical and critical thinking skills. One of the fundamental topics in elementary science is fauna diversity in Indonesia, which is categorized into three distinct regions: Asiatic, Transitional, and Australasian. Understanding this topic poses challenges as it involves numerous details about species characteristics, distribution, and uniqueness in each region. Since elementary school lays the groundwork for students' comprehension and interest in science, instructors play a critical role in science education. In the research conducted by Gusti and Komariah (2023) it is mentioned that elementary school science instruction aims to develop students' curiosity, critical thinking, and problem-solving skills in addition to teaching scientific principles. To help students make connections between science and daily life, teachers can create engaging, contextual, and exploration-based learning experiences.

The evolution of the digital era has led to substantial transformations across various aspects of life, including the education sector. Technology that continues to develop allows learning methods to be more interactive and innovative. In education, technology helps visualize complex concepts, making learning materials more interesting and easier to understand through various forms of visual representation, such as images, animations, simulations, and interactive videos. With technology, students do not only rely on text or verbal explanations but can also see direct illustrations of the concepts being studied. This is particularly useful for understanding abstract material or topics that require spatial comprehension, such as science and biology. In addition, technology-based visualization increases student engagement, making the learning process more effective and meaningful. Therefore, technological advances need to be optimally utilized to improve learning effectiveness.

Conventional teaching methods which primarily rely on textbooks and teacher lectures, are often inadequate in helping students build a deep understanding of the material. Therefore, adopting innovative and interactive learning approaches is essential. The advancement of digital technology has transformed various aspects of education, making learning more engaging and effective. By leveraging technology, complex concepts can be visualized more clearly through animations, simulations, and interactive models, allowing students to better grasp abstract ideas. Augmented Reality technology in particular, facilitates a more immersive learning experience by blending virtual elements with real-world environments. Based on research conducted by Koumpouros (2024) it was found that Augmented Reality has significantly improved user perceptions of time and space and makes it possible to visualize the connection between the real and virtual worlds in a cooperative manner.

Immersion technologies provide students with a sense of the practical applications of the knowledge they acquire in the classroom by simulating realistic situations and offering authentic depictions of real-world work settings. In the research conducted by Udeozor et al (2023) states that these technologies also enable teachers to evaluate students based on their cognitive abilities to complete challenging assignments. Cognitive skills play a critical role in students' ability to apply knowledge in science education. Conceptual understanding in elementary school is influenced by both general and specific cognitive abilities, as students are at varying developmental stages in comprehending scientific concepts. Problem-solving skills enable students to relate learned concepts to real-world situations. Strong cognitive comprehension depends on a student's ability to connect, evaluate, and apply knowledge in various contexts.

Research by Chaturvedi et al (2022) indicates that understanding is not merely about acquiring isolated pieces of information but also about internalizing ideas through deep comprehension, hands-on experiences, and active engagement.

The rapid development of information and communication technology has also led to innovations in education. Digital technology is increasingly being utilized to improve the quality of learning, one of which is through AR-based media that provides a more interactive and engaging learning experience. Augmented Reality combines the real world with virtual elements in one display. According to Hidayat and Khotimah (2019), Augmented Reality is a feature that integrates systems in real-time. This technology enhances learning by presenting virtual information in a dynamic space, aligning with research by Dixon et al (2013), which highlights how Augmented Reality-based games create an engaging approach for children. In education, Augmented Reality transforms abstract material into more concrete and interactive content. This technology enables students to view three-dimensional objects via digital devices, making learning more engaging and effective. Traditional, non-interactive teaching methods often result in low conceptual understanding. One major cause is the lack of media that supports realistic concept visualization. Augmented Reality-based flashcards offer a solution by incorporating both images and text while also presenting 3D visual models. Students can interact dynamically with learning materials, leading to a deeper conceptual understanding.

Some studies show that flashcards are categorized as two-dimensional graphic media. Research by Asyhar (2012), indicates that Augmented Reality-based flashcards integrate images and animations accessible through devices such as smartphones or tablets. In this study, Augmented Reality-based flashcards were utilized via mobile scanning technology. To access the Augmented Reality-based learning experience, students use their device cameras to scan codes, which then display digital content in real-time. In a study conducted by Çelik & Yangın Ersanlı (2022) it was found that one of Augmented Reality's primary benefits is its ability to overlay digital content onto the real environment, allowing students to interact with learning materials more dynamically . For instance, in vocabulary learning, students can scan markers to view 3D representations and hear the pronunciation of words. This interactive feature enriches the learning experience by bridging the gap between static images and active engagement.

Several studies have demonstrated the effectiveness of Augmented Reality in enhancing conceptual understanding. Research by Turan and Atila (2021) indicates that Augmented Reality-based learning media is an educational innovation that supports students with learning difficulties in understanding science material. Accordiing to Syam et al (2021) further emphasize that Augmented Reality appeal as a teaching tool stems from its ability to provide a blended learning experience that merges virtual and real-world elements, making classroom environments more engaging. This technology also allows students to learn independently, explore complex concepts more comprehensively, and engage in enjoyable, personalized learning experiences.

The application of Augmented Reality in science education enhances students' retention of taught concepts, particularly for materials requiring clear visualization. Research by Pulson et al (2025) has demonstrated that incorporating virtual reality into education accelerates the learning process, reduces comprehension time, and enhances subject understanding. According to Xiong, J., & Wu, S. T (2021) unlike traditional teaching panels, Augmented Reality and Virtual Reality expand on 3D digital imagery and promote more interactive human-computer interactions). The primary distinction between Augmented Reality and Virtual Reality is that

Augmented Reality overlays digital content onto real-world environments, whereas Virtual Reality immerses users entirely in virtual spaces. According to Di Fucio et al (2024) students require adequate support to maximize participation in their education.

Curiosity is an important aspect in character education. According to Aeni (2014) curiosity can foster an open attitude towards new knowledge and encourage critical thinking. In the context of technology-based learning, Augmented Reality has the potential to stimulate curiosity by integrating interactive visual aspects, thus encouraging students to be more active in the learning process. However, in Indonesia, the implementation of Augmented Reality in learning still faces various challenges, such as limited technological infrastructure, educator readiness, and diverse student characteristics. Therefore, this study seeks to examine the effect of using Augmented Reality-based flashcards on the conceptual understanding of fifth grade students on the material on fauna diversity in Indonesia. The main focus of this study is to understand how the use of Augmented Reality-based flashcards can improve students' conceptual understanding in experimental classes compared to classes that do not use the media. Thus, this study tests the hypothesis that the use of Augmented Reality-based flashcards has an effect on students' conceptual understanding, which is significantly different compared to students who do not use them.

Research Methods

The research method used in this study is the experimental method. According to Sugiyono (2013) the experimental method is applied in controlled conditions to examine the effect of one treatment on another variable. This study employs a Nonequivalent Control Group Design, where both the experimental and control groups underwent a pretest before the treatment and a posttest after the treatment to measure the improvement in students' conceptual understanding of science, particularly after using Augmented Reality-based flashcards. The learning tool utilized in this study was Augmented Reality-based flashcards, which integrate two- or three-dimensional materials into a real-world setting. According to Mustaqim (2017) this media enhances students' engagement, helps them focus, and facilitates better comprehension of the material being taught. Traditional learning methods often lead to student disengagement and suboptimal comprehension, while Augmented Reality offers a more interactive and immersive learning experience aligned with modern technological advancements.The following table provides a description of this research design:

Table 1. Research Design

Class	Pretest	Treatment	Posttest
Experiment	O1	X	O2
Control	O3	-	O4

To ensure the validity and reliability of the pretest and posttest, the instrument underwent expert validation before administration. Subject matter experts evaluated the content validity to ensure alignment with the learning objectives. Additionally, reliability testing was conducted using Cronbach's Alpha to determine internal consistency, ensuring that the test items accurately measured students' conceptual understanding before and after the intervention. The pretest was conducted at the beginning of the study to assess students' prior knowledge of Indonesia's faunal diversity. Afterward, the control group was taught using conventional methods, while the experimental group used Augmented Reality-based flashcards. A posttest was administered to measure the extent of conceptual improvement, and the results were analyzed to determine differences between the two groups.

This study employed a purposive sampling technique in selecting participants, meaning the experimental and control groups were chosen based on specific criteria. However, the use of nonprobability sampling and a nonequivalent control group design introduces the possibility of selection bias, which could affect the internal validity of the study. To minimize this bias, an equivalence test was conducted before the intervention to ensure that both groups had comparable baseline knowledge. Additionally, efforts were made to maintain consistency in instructional materials, learning duration, and environmental conditions to reduce potential confounding variables.

The research primarily relied on quantitative data collected through pretests and posttests, which were analyzed using various statistical methods, including descriptive analysis, normality and homogeneity tests, paired sample t-tests, independent sample t-tests, N-Gain calculations, and effect size measurements. Descriptive analysis was conducted to summarize the characteristics of the research data, while normality and homogeneity tests were used to verify whether the data met statistical assumptions before further analysis. Paired sample t-tests were employed to compare pretest and posttest scores within the same group, while independent sample t-tests were used to examine differences in learning outcomes between the experimental and control groups. The calculation of N-Gain helped measure the level of improvement in conceptual understanding, and the effect size analysis determined the magnitude of the influence of Augmented Reality-based flashcards on students' comprehension of the topic.

Although this study provides strong numerical evidence of the effectiveness of Augmented Reality-based flashcards in enhancing students' conceptual understanding, it does not explore qualitative aspects such as students' learning experiences, engagement levels, or perceptions of the media used. Future research could incorporate qualitative methods, such as interviews or classroom observations, to provide deeper insights into the mechanisms behind students' conceptual improvement and further validate the impact of Augmented Reality-based learning tools.

Results and Discussion

This study aims to determine the impact of using augmented reality-based learning materials on grade V students' understanding of the concept of Indonesian fauna diversity. The experimental class, which uses augmented reality-based flashcards, and the control class, which use conventional teaching methods, make up the two groups of the study's sample. The research employed a nonequivalent control group design and an experimental methodology. Both groups were given pretests and posttests as research instruments to measure concept understanding before and after treatment. Numerous statistical techniques were used to analyze the data, including paired sample t-test to measure differences in concept understanding before and after treatment in the experimental group, independent sample t-test to compare concept understanding between experimental and control classes, and descriptive analysis to see the distribution of student learning outcomes data. Additionally, the effect size test was used to ascertain the extent to which the use of augmented reality media influences students' concept knowledge, and the N-Gain calculation was performed to assess the efficacy of improving concept understanding in each group. Descriptive analysis of the experimental class's pretest and posttest scores yielded the following findings:

Table 2. Descriptive Statistics of Experimental Class Pretest and Posttest Data

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Pretest Experiment	31	20	70	47.10	11.603
Postest Experiment	31	40	100	76.45	16.237
Valid N (listwise)	31				

Table 2 presents the results of descriptive statistics of students' conceptual understanding before and after using Augmented Reality flashcards in the experimental group. The data in this table were obtained from students' pretest and posttest scores. Before using Augmented Reality flashcards, the average pretest score was 47.10, with the highest score being 70 and the lowest score being 20. After the treatment, the posttest results showed a significant increase, with an average score of 76.45, while the lowest and highest scores increased to 40 and 100, respectively. This increase in scores indicates that learning with Augmented Reality-based flashcards helps students better understand the concepts taught. However, before conducting further analysis, it is important to ensure that the data meets certain statistical requirements. Therefore, tests were conducted to check whether the data were normally distributed and whether the variances between groups were similar. This test helps determine whether the statistical analysis used later will produce reliable and valid conclusions. Table 3 presents the results of the normality tests for the experimental class.

Table 3. Test Results of Normality of Pretest and Posttest of Experimental Classes

Experimental Class	Statistic	df	Sig.
Pretest	.938	31	.071
Postest	.942	31	.096

These scores were obtained from students in the experimental group who participated in learning activities using Augmented Reality flashcards. Normality tests were conducted to determine whether the data followed a normal distribution. The results of the normality test analysis using Shapiro-Wilk show that the pretest data in the experimental class has a statistic of 0.938 with a Sig value. 0.071, while the posttest data has a statistic of 0.942 with a Sig value. 0.096. Because both significance values are greater than 0.05, it can be concluded that the pretest and posttest data in the experimental class are normally distributed. To determine whether the variance of students' conceptual understanding scores in the experimental class was uniform, a homogeneity test was conducted. This test ensures that statistical comparisons between pretest and posttest scores are valid. As shown in Table 4

Table 4. Test Result of Homogenity of Pretest and Posttest of Experimental Classes

Variable		Sig.
Hasil Pemahaman Konsep	Based on Mean	0.03

The homogeneity test results based on the mean yielded a significance value (Sig.) of 0.03. Since this value is below 0.05, it indicates that the variance of pretest and posttest scores is not homogeneous. Despite this, further analysis using the paired sample t-test can still be performed, as this test does not strictly require homogeneity of variance when analyzing differences within the same group.

After conducting the homogeneity test, the next step is to analyze whether there is a significant difference in students' conceptual understanding before and after using Augmented

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Reality (AR) flashcards. This is done using the Paired Sample t-Test, which compares the means of two related samples—in this case, the pretest and posttest scores of the experimental class. The following are the results of the paired sample t-test :

Table 5. Paired Sample t-Test Results

Paired Samples Correlations				
		N	**Correlation**	**Sig.**
Pair 1	**Pretest & Postest**	31	.580	.001

Based on the results of the paired sample t-test, a significance value (Sig. 2-tailed) of 0.001 <0.05 was obtained indicating that H_0 was rejected and H_1 was accepted, which means there is a significant difference between the pretest and posttest results. Thus, it can be concluded that the use of Augmented Reality-based flashcards has a significant effect on improving students' conceptual understanding.

After obtaining the results of the paired sample t-test, which indicate a significant difference between pretest and posttest scores in the experimental class, the next step is to calculate the effect size. This is done to determine the magnitude of the impact that the use of Augmented Reality flashcards had on students' conceptual understanding. The effect size calculation was performed using Cohen's d formula for paired sample t-tests. This formula compares the mean difference between pretest and posttest scores with the pooled standard deviation of both scores. In this study, the effect size was calculated using Cohen's effect size calculator, resulting in a Cohen's d value of 2.08. According to Cohen's interpretation guidelines, an effect size greater than 0.8 is considered large, meaning that the use of Augmented Reality flashcards had a strong impact on students' conceptual understanding.

Before conducting the Independent Samples t-Test to determine whether there was a significant difference between the experimental and control groups after the posttest, it is essential to first examine the descriptive statistics of both groups' pretest scores. This step provides an overview of the initial conditions of students' conceptual understanding in both groups before the treatment was applied. The following table presents the pretest data for both the experimental and control classes:

Tabel 6. Descriptive Statistics of Experimental and Control Class Pretest Data

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Pretes Eksperimen	33	20	70	47.88	13.171
Pretes Kontrol	31	20	70	47.10	11.603

The results of the descriptive statistical analysis in Table 6 were obtained from the pretest scores of students in the experimental and control groups before receiving any treatment or intervention. The analysis shows that both groups have similar characteristics, with a minimum score of 20 and a maximum score of 70. The mean pretest score in the experimental group was 47.88 with a standard deviation of 13.171, while the control group had a mean pretest score of 47.10 with a standard deviation of 11.603.

Since the pretest scores of both groups appear similar, further hypothesis testing is needed to determine whether there is a statistically significant difference between them. Before conducting this test, assumption tests were carried out, including the normality test, which checks whether the data is normally distributed, and the homogeneity test, which ensures that

the variance of both groups is equal. The following are the results of the pretest normality test for the experimental class and control class.

Table 7. *Data from Pretest Normality Test Results*

Class	Shapiro-Wilk		
	Statistic	df	Sig.
Experiment Pretest	.938	31	.071
Control Pretest	.938	33	.061

The results of the Shapiro-Wilk normality test show that the pretest scores in the experimental class (Sig. 0.071) and the control class (Sig. 0.061) have a significance value greater than 0.05, which means that the data in both groups follow a normal distribution. After confirming that the pretest data in both the experimental and control classes follow a normal distribution, the next step is to test the homogeneity of variance. The homogeneity test aims to determine whether the variance of the two groups is equal, which is an important assumption for conducting further comparative statistical tests. The results of the homogeneity test are presented in Table 8.

Table 8. *Pretest Homogeneity Test Result Data*

Varibel		Sig.
Concept Understanding Results	Based on Mean	0.493

The results of the homogeneity test, as shown in Table 8, indicate that the significance value based on the mean is 0.493. Since this value is greater than 0.05, it can be concluded that the variance of the pretest scores in the experimental and control classes is homogeneous. This means that both groups have similar variability in their pretest scores, allowing for further comparative analysis using parametric statistical test. The next step is to conduct an Independent Samples t-Test. This test aims to determine whether there is a significant difference in the initial conceptual understanding between the two groups before implementing the Augmented Reality flashcard intervention. The results of the Independent Samples t-Test for the pretest scores are presented in Table 9.

Tabel 9. Independent Sample t Test Result Data Pretest

Test	Sig. (2-tailled)	Result	Description
Independent Sample t Test	0.802	H_0 Retrieved	There was no significant difference between the average pretest scores of the experimental and control classes.

Table 9 presents the results of the Independent Samples t-Test for the pretest scores of the experimental and control classes. The significance value (Sig. 2-tailed) obtained was 0.802, which is greater than 0.05. This result indicates that H_0 is accepted, meaning there is no statistically significant difference between the average pretest scores of the experimental and control classes. In other words, both groups have relatively the same level of conceptual understanding before the application of Augmented Reality flashcards. After confirming that the initial conceptual understanding of both groups is equivalent, the next step in the analysis is to examine the posttest results. Descriptive analysis of the posttest scores is presented in table 10

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Tabel 10. Descriptive Statistics of Posttest Data of Experimental and Control Classes

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Posttest_Experiment	31	40	100	76.45	16.237
Posttest_Control	33	40	90	67.88	13.638
Valid N (listwise)	31				

Table 10 presents the descriptive statistics of the posttest scores for both the experimental and control classes. The results show that the posttest scores in the experimental class range from 40 to 100, with a mean of 76.45 and a standard deviation of 16.237. Meanwhile, the control class's posttest scores range from 40 to 90, with a mean of 67.88 and a standard deviation of 13.638. The higher mean score in the experimental class suggests that students who used Augmented Reality flashcards tend to have better conceptual understanding compared to those in the control class. However, to determine whether this difference is statistically significant, further hypothesis testing is required. Prior to conducting an Independent Samples t-Test to compare the posttest scores of both groups, assumptions of normality and homogeneity of variance must be checked. The following are the results of the posttest normality test for the experimental class and control class.

Tabel 11. *Posttest Normality Test Result Data*

Class	Shapiro-Wilk		
	Statistic	Statistic	Sig.
Experiment posttest	.153	.942	**.096**
Posttest control	.148	.939	**.061**

Table 11 presents the results of the Shapiro-Wilk normality test for the posttest scores in both the experimental and control classes. The results show that the significance value for the experimental class is 0.096, while for the control class it is 0.061. Since both significance values are greater than 0.05, it can be concluded that the posttest data in both groups follows a normal distribution. After ensuring that the posttest data in the experimental and control classes follow a normal distribution, the next step is to test the homogeneity of variance. The homogeneity test aims to determine whether the variances of the two groups are the same, which is an important assumption for conducting further comparative statistical tests. The results of the homogeneity test are presented in table 12:

Table 12. Posttest Homogeneity Test Result Data

Varibel		Sig.
Concept Understanding Results	Based on Mean	**0.205**

Table 12 presents the results of the posttest homogeneity test for the experimental and control classes. The significance value (Sig.) obtained is 0.205. According to the decision-making criteria for the homogeneity test, if Sig. > 0.05, then H_0 is accepted, indicating that the variance between the two groups is homogeneous. In this study, since 0.205 > 0.05, it can be concluded that the posttest data on students' conceptual understanding meet the assumption of homogeneity. Consequently, the data fulfill the statistical requirements for conducting further

analysis using the Independent Samples t-Test. The results of the Independent Samples t-Test for posttest scores are presented in table 13.

Table 13. Independent Sample t Test Results

Test	Sig. (2-tailled)	Result	Description
Independent Sample t Test	0.02	H_1 Retrieved	There is a significant difference between the average posttest scores of the experimental and control classes.

Based on the results of the independent sample t-test, the Sig. (2-tailed) value = 0.02. Since $0.02 < 0.05$, H_0 is rejected and H_1 is accepted, indicating a significant difference between the posttest mean scores of the experimental and control classes. These results suggest that after receiving treatment in the form of Augmented Reality -based flashcards in the experimental class and conventional teaching methods in the control class, there was a significant improvement in students' conceptual understanding of science in the group using AR media compared to the control group. To measure the effectiveness of using AR-based flashcards, an N-Gain analysis was conducted. This analysis aims to classify students' conceptual understanding into low, medium, and high categories, based on the improvement from pretest to posttest scores. The following table presents the results of the N-Gain calculation for both groups.

Tabel 14. N-Gain Value of Experimental and Control Classes

Class	Number of Students	Highest Score	Lowest Score	Average
Experiment	31	1.00	0.00	0.57
Control	33	1.00	0.00	0.36

Based on the N-Gain value table for the experimental and control classes, it can be observed that the average N-Gain of the experimental class is 0.57, while the average N-Gain of the control class is 0.36. According to the N-Gain score classification, the experimental class falls within the moderate category ($0.3 \leq g \leq 0.7$). Although the control class has a lower N-Gain value, it also falls within the moderate category. These results indicate that the experimental class showed greater improvement in conceptual understanding than the control class. The use of Augmented Reality (AR)-based flashcards significantly enhances students' understanding of scientific concepts, particularly in learning about Indonesia's fauna diversity.

The results of this study indicate that the use of Augmented Reality-based flashcards has a significant effect on students' conceptual understanding in science learning. Students in the experimental group, who used Augmented Reality flashcards, showed higher posttest scores compared to the control group. This suggests that Augmented Reality can facilitate deeper engagement and understanding by providing an interactive and immersive learning experience. This finding is in line with research conducted by Khoirunnisa (2024), which showed that Augmented Reality-based flashcards are very interesting and can increase students' interest in learning. In addition to increasing motivation, Augmented Reality-based media can also improve learning outcomes by making abstract concepts more real. However, several factors must be considered when interpreting these results, such as students' previous familiarity with digital devices, the role of teacher facilitation, and the possibility of cognitive overload. Augmented Reality media presents 3D images that blend with the real world, helping students visualize and interact with abstract concepts more concretely, This aligns with the findings of Hajirasouli & Banihashemi (2022), who argue that Augmented Reality can transform

traditional learning methods by allowing students to engage directly with real-world representations.

Compared to conventional learning approaches, According to Lestari (2023) Augmented Reality provides advantages such as interactivity, visualization, and contextualized learning experiences. However, research by Hamdani et al (2019) argues that traditional hands-on experiments remain superior for developing critical thinking skills, suggesting that Augmented Reality should be integrated alongside rather than as a replacement for conventional methods. The positive impact of Augmented Reality flashcards on students' conceptual understanding observed in this study is not an isolated finding. Several previous studies, both national and international, have reported similar results. In a study by Ikhya & Anggraini (2020) found that Augmented Reality flashcards stimulate students' curiosity and foster a deeper learning experience by making abstract concepts more real. According to Yulianto et al (2023), science learning tools that use augmented reality claim that by providing realistic 3D object representations, augmented reality can improve student comprehension and engagement by enabling more tangible interactions with scientific topics.

Beyond national research, findings from international studies also support the role of Augmented Reality in education. In a study by Radu (Koumpouros, 2024) found that Augmented Reality significantly improved conceptual understanding and motivation across a range of subjects by providing an immersive and interactive learning experience. However, his study emphasized that the effectiveness of Augmented Reality depends on the complexity of the content being taught. While Augmented Reality has been shown to be useful for abstract concepts, simpler topics may not require the technology. This suggests that Augmented Reality should be applied selectively, ensuring that its integration is aligned with the learning objectives and needs of specific students.

Conclusion

The findings of this study highlight that augmented reality flashcards have an impact on improving students' conceptual understanding compared to conventional teaching methods. Students who used Augmented Reality flashcards demonstrated a deeper understanding of concepts, suggesting that the interactive and visual nature of Augmented Reality technology plays a significant role in improving learning outcomes. This supports the growing body of research advocating the integration of Augmented Reality into educational environments, particularly for subjects that require strong visualization, such as science and geography. However, this study has several limitations. The sample size was limited to a specific group of students, which may affect the generalizability of the results. In addition, potential bias may arise from differences in students' prior knowledge and familiarity with digital learning tools. The implementation of Augmented Reality -based learning also presents challenges, including the need for adequate technological infrastructure and teachers' readiness to integrate Augmented Reality into the curriculum effectively.

Future research could explore the implementation of Augmented Reality -based learning across different subjects and levels of education to assess its broader impact. Investigating how Augmented Reality affects long-term retention and critical thinking skills could also provide valuable insights into its role in deeper learning processes. Furthermore, research involving more diverse samples could help validate the findings and refine best practices for Augmented Reality integration. From a practical perspective, educators can maximize the benefits of Augmented Reality -based flashcards by ensuring they are used as a supplemental tool, not as a

complete replacement for traditional instruction. Teachers should receive adequate training to effectively incorporate Augmented Reality into lesson plans, balancing interactive elements with meaningful discussions and hands-on activities. By strategically integrating Augmented Reality into the curriculum, educators can create more engaging and effective learning experiences for students.

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