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The Impact of Augmented Reality-based Learning Media on Primary Students' Retention of Human Sensory System Concepts

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Abstract

The use of Augmented Reality (AR) in education contexts has great potential to enhance students' learning experiences and retention for abstract scientific content. This research was conducted to find out whether AR-based learning media is effective in increasing the retention of elementary school students on the five human senses. The study used a quantitative one-group pretest-posttest design with 52 4th-grade students of two Islamic elementary schools located in Pandeglang, Indonesia. AR media was applied to present 2D and 3D interactive visuals for introducing science content. Data were collected from pre-test, post-test, and documents, then analyzed by using a paired sample t-test in SPSS 16. A statistically significant difference is found between posttest and pretest scores ($p < 0.05$), indicating that the retention of AR media among students was effective. The AR media-using students showed a higher level of conceptual understanding and memory for the topic of the five senses. In this paper, we stress the potential of AR technology as a transforming tool, shedding new light on how science teaching can be transformed into an innovative and efficient learning model. It also contributes to the growing body of research on educational technology in primary education, especially in the Indonesian context. The findings provide significant implications for educators, curriculum designers, and education policy makers in balancing the introduction of the latest digital technologies into the primary classroom to enhance students' learning.

INTRODUCTION

Science in elementary school lays the foundation for children's scientific knowledge, understanding what they read, and the skills they need to be critical thinkers. However, science teaching in elementary schools remains challenging, particularly with abstract concepts such as the five human senses. For example, it is difficult for students to internalize materials if traditional (text-based) methods are employed, and their understanding of concepts and knowledge acquisition becomes quite restricted in this manner (Hasanah et al., 2023; Suryanti et al., 2024). Non-interactive and context-free traditional media can disconnect learners, leading to a lack of long-term memory formation and knowledge transfer (Angkur,2025).

Despite the prevalent traditions of frontal teaching and the application of static pictures in science education, namely curriculum work, textbooks tend to be obstacles, as such measures do not support active learning. Both modes of presentation are used as sensory stimulants, and without them, the students are deprived of understanding complex scientific concepts (Pamorti et al., 2024; Sidiq et al., 2021). This is particularly evident in investigations of biological systems (e.g., sensory organs), for which visually relevant or tactually accessible information can have a significant impact on students' ability to connect form and function.

In this age of digital learning transformation, technology-enhanced language labs have been gaining increasing attention. AR, through the combination of virtual and real objects in a physical environment, creates interactive, visual, and immersive experiences that encourage participation and greater cognitive processing (Sandoval-Henríquez et al., 2025; Tene et al., 2024). Within the science learning field, AR has been seen as an interesting technology for bringing out-of-sight processes and abstract structures into view, enabling students to engage in phenomena using means that are not available when working with conventional media (Klopfer et al., 2009; Tene et al., 2024).

Although AR has been commonly researched for secondary and tertiary education, AR in primary schools is understudied, particularly in the Indonesian context (Sandoval-Henriquez et al., 2025). The majority of research has focused on the influence of AR on conceptual understanding and motivation, whereas retention, as a measure of learning success, is relatively under-investigated (e.g., Tene et al., 2024). Moreover, very few educational studies have been conducted on AR in science and social studies teaching at the elementary classroom level.

This study is essential to address these gaps by investigating the effectiveness of AR as an instructional medium for knowledge retention among elementary students for primary learning (regarding race relations and especially the human sense system). By examining the implementation of AR in the teaching process in Social Science and Natural Science, this study provides a new approach to analyzing how immersive technologies are employed to improve retention and comprehension of primary school learners (Alkhabra et al., 2023; Gargrish et al., 2021). What makes it innovative is the dual-subject curriculum use (science and social studies), which has been underrepresented in prior AR literature.

The strong theoretical foundation of this study is the Cognitive Theory of Multimedia Learning, which claims that the coordinated presentation of visual and verbal texts is more effective than their presentation in a syncopated way (Zhang & Wang, 2021; Mayer, 2009). AR interactive factors, such as 3D visualization, animation, and real-time interaction, are consistent with dual coding theory and cognitive load theory, which favor deeper learning and knowledge memory. In addition, a constructivist view of learning is promoted through AR because students have the chance to learn through hands-on experiences and by customizing their learning design to continuously enhance their previous knowledge (Cai et al., 2022). Based on these theories, we investigate how AR technology can support cognitive and affective engagement that are important in enhancing learning consolidation and retention (Wen et al., 2024). It is thus expected that augmented reality could reduce superfluous cognitive load, support germane processing, and enhance retention of learning performance in young children.

This study aimed to examine the effectiveness of augmented reality (AR) learning media in enhancing the retention levels of fourth-grade students in Indonesian state elementary schools during science instruction. This research contributes to the advancement of educational technology by providing empirical evidence on the use of AR as a pedagogical tool in primary education. It is essential to offer guidance to teachers, media producers, and policymakers to maximize the effective use of these tools in science learning. This encompasses the entire process, from assessment to promoting immersive digital technologies in science teaching, and developing a comprehensive understanding over time that aligns with performance outcomes.

METHODS

This study used a quantitative pre-experimental research design and a one-group pre-test-post-test approach, which is typically utilized to determine the treatment effectiveness of an intervention in instances where randomization and control groups are not feasible (Creswell & Creswell, 2018). This design was considered appropriate to monitor the influence of AR-media learning on student retention in IPAS elementary school students. The subjects for the research were 52 fourth-grade students aged between 9 and 10 years old from two Islamic elementary schools located in Pandeglang Regency in Banten Province, Indonesia.

The first group of participants (n = 27) was composed of students from Public Islamic Elementary School (MIN) 2 Pandeglang, while the second group (n = 25) was from MIN 3 Pandeglang. Both schools were intentionally selected for their willingness to integrate augmented reality (AR) into their teaching practices. Approval for the study was obtained from the research office of the institution, along with consent from the school authorities and the parents or guardians of the students. Participants were informed about the voluntary and anonymous nature of their participation, and no personal data was collected.

The tool used to assess student retention was a 20-item marks test designed to evaluate human reasoning, derived from Bloom's Revised Taxonomy. The test comprised mainly multiple-choice and short-answer questions, aligned with the national IPAS curricula. The content validity of the instrument was established through feedback from two science educators and one elementary school teacher, which led to necessary revisions. An initial pilot test was conducted with a separate group of students (n=20) from another school, yielding an alpha reliability estimate of 0.82, thus confirming strong internal consistency (Taber, 2018). Participants underwent an intervention for two weeks, including three learning sessions with traditional teaching methods and exploration in AR through the Assemblr Edu mobile application. AR media also combined 2D and/or 3D interactive models of sensory organs viewed by mobile devices with QR codes. The learning process involved the following sequence for a session: introduction and motivation - use of AR for exploration, group discussion, and reflection.

Pre- and post-test data were collected before and after the AR intervention, respectively. Student scores are expressed as mean and standard deviation. The normality of the data was assessed using the Shapiro-Wilk test, and the homogeneity of variances was evaluated using Levene's test. The difference between scores was tested for statistical significance using a paired-sample t-test. In addition, relative gains (N-gain) were calculated and compared to determine how much learning increased. All statistical analyses were performed using SPSS (version 16.0), and $p < 0.05$ was regarded as statistically significant.

RESULTS

1. Augmented Reality-Based Learning Intervention

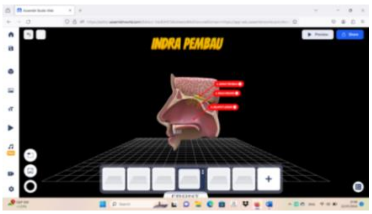
The AR-based learning intervention was integrated into the fourth-grade Integrated Science and Social Studies curriculum, specifically targeting the topic of the five human senses. The intervention was conducted over three instructional sessions within two weeks, each lasting for 70 minutes. The sessions were delivered to two classes: MIN 2 Pandeglang and MIN 3 Pandeglang.

Each session followed the Merdeka Curriculum's learning framework, emphasizing student-centered exploration, the use of digital media, and project-based learning activities. The teaching process combined traditional instruction and mobile-based AR experiences through Assemblr Edu, a platform that enables students to view 3D models by scanning QR codes embedded in their worksheets. The structure of the media is shown in Figure 1.

Slide pertama

Slide kedua

Slide ketiga



Slide keempat

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Figure 1. Example of AR Media Displayed via Mobile Device

In each session, students actively participated in observing 3D models projected onto physical environments, responded to teachers' guiding questions, recorded their observations on structured worksheets, and collaborated in small groups to discuss their findings. This learning model aims to promote higher-order thinking skills (HOTS), particularly analysis, application, and conceptualization. AR media functioned as both instructional support and engagement enhancer, making abstract anatomical and physiological content more tangible for students.

The learning process consists of several stages: (1) introduction: students and the teacher start with a prayer together, followed by an attendance activity; (2) apperception: teacher asks the students to look at their friends' faces, then answer questions related to what they observe; (3) core activity: teacher explains the learning objectives, followed by an explanation of the parts of the organs on the face. Students are actively involved in answering the teacher's questions related to the material. The instructional structure is presented in Table 1.

Table 1. Instructional Structure

Session	Topic	Learning Activity	AR Component
1	Sense of Sight and Hearing	Observation and discussion of facial features; identification of organ functions	3D models of the eye and ear, with animation on parts
2	Sense of Smell and Taste	Exploration through sensory-based experiments with fruits and spices	Interactive 3D models of the nose and tongue
3	Sense of Touch	Touch-based group activity using various textured objects	3D model of the skin with layers and nerve structures

2. Descriptive Analysis of Student Retention

Retention was measured using a 20-item test administered before and one week after the intervention. The test focused on students' ability to recall definitions, identify sensory organs, explain their functions, and interpret their everyday sensory experiences. The pre- and post-tests were implemented directly through face-to-face methods with fourth-grade students of MIN 2 Pandeglang and MIN 3 Pandeglang. The test instrument was given in the form of a number of questions to 27 students from class IV MIN 2 Pandeglang and 25 students from class IV MIN 3 Pandeglang. The descriptive analysis revealed a clear improvement in students' retention scores, as shown in Table 2.

Table 2. Retention of MIN 2 and MIN 3 Pandeglang students

No.	Schools	Pre-test	Post-test
1.	MIN 2 Pandeglang	55,50	79,20
2.	MIN 3 Pandeglang	55,20	83,60
	Mean	**55,35**	**81,40**

Table 2 shows the average pre- and post-test student scores for MIN 2 and MIN 3 Pandeglang, which were used as indicators to measure the Augmented Reality (AR) learning intervention effect on students' retention. The pre-test mean of MIN 2 Pandeglang was 55.50, which increased in the post-test to 79.20, meaning a gain score of 23.70 points with augmented reality-facilitated instruction. Likewise, the students of MIN 3 Pandeglang experienced an improvement from a pre-test mean of 55.20 to the post-test mean of 83.60, with the gain difference being 28.40 points for this group as well." The average score for both schools was 55.35 in the pre-test and 81.40 in the post-test, indicating that AR intervention implementation led to a significant improvement in retention among the students.

The findings indicate that students from both schools experienced a significant improvement in learning through AR-based media, with MIN 3 Pandeglang achieving a slightly higher average gain. This suggests that augmented reality (AR) can greatly enhance knowledge retention and conceptual understanding of Earth Sciences, particularly when complemented by lessons that engage the human sensory system. Additionally, another positive outcome of this experiment was the heightened attention and engagement observed during AR-based classroom activities. Students demonstrated increased enthusiasm, curiosity, and a greater willingness to participate in reading sessions compared to traditional classrooms. Teachers also noted a decrease in off-task behavior and an increase in questioning among lower-achieving students during class discussions.

3. The Impact of Augmented Reality-based Learning Media on Primary Students' Retention of Human Sensory System Concepts

To verify the assumptions for the parametric analysis, the Shapiro-Wilk test was applied to assess the normality of the data. The results indicated that some datasets did not follow normal distribution ($p < 0.05$). However, Levene's test showed that the variance between groups was homogeneous ($p > 0.05$), permitting the use of paired sample t-tests for further analysis.

A paired sample t-test was performed to determine the statistical significance of the difference between the means of the pre- and post-tests. The t-test values are presented in Table 3.

Table 3. Paired Samples t-Test Results

Group	t-value	df	Sig. (2-tailed)
MIN 2 Pandeglang	8.854	24	0.000
MIN 3 Pandeglang	7.386	26	0.000

Table 3 presents the results of the paired samples t-test, which aims to determine if there are any significant differences in pre- and post-test scores among students of MIN 2 Pandeglang and MIN 3 Pandeglang following AR-based learning. Meanwhile, for MIN 2 Pandeglang, the results of the analysis obtained t-counts equal to 8.854 with df = 24 and p-values <0.000. Similarly, for MIN 3 Pandeglang, the t value was 7.386 with a degree of freedom of 26 and a level of significance of = 0.000. Since the p-values of both groups were less than 0.05, it can be concluded that the differences in pre- and post-test measures were statistically significant. That is, AR-based instructional intervention positively and significantly influenced students' learning retention of the five senses in both School A and School B. These findings provide significant statistical evidence that AR incorporation in science learning has beneficial effects, positively impacting abstract conceptual memory and comprehension enhancement through the Intervention.

4. Effectiveness Analysis Based on N-Gain Score

Normalized gain (N-gain) scores were computed for each school to assess the effectiveness of the intervention. The N-gain score, as a normalized measure of the increase in scores (see below), is applied extensively in educational research. The n-gain of both groups is presented in Table 4.

Table 4. N-Gain Score Analysis

School	Mean Pretest	Mean Posttest	Maximum Score	Mean of N-Gain	Effectiveness Category
MIN 2 Pandeglang	55,50	79,20	100	0,53	Moderate
MIN 3 Pandeglang	55,20	83,60	100	0,63	Moderate
Overal mean	**55,35**	**81,40**	**100**	**0,58**	**Moderate**

As shown in Table 4, the effectiveness of the AR-based learning intervention can be seen from the average N-gain of the students in MIN 2, MIN 3, and Pandeglang. N-gain is the fraction of learning that was improved relative to the potential and yields a normalized measure of instructional efficiency. At MIN 2 Pandeglang, the average score before the test was 55.50, which increased to 79.20. For a maximum score of 100, the resulting mean N-gain was 0.53 (which belonged to the effectiveness category of "moderate").

Furthermore, the average score of students at MIN 3 Pandeglang in the pre-test was 55.20, and in the post-test was 83.60, with an average N-gain value of p = 0.63, which indicates moderate effectiveness. While both schools showed modest increases, MIN 3 Pandeglang showed a slightly larger improvement. The average N-gain across the two schools was 0.58, indicating that the AR-based intervention had a moderate to high level of effectiveness in enhancing students' retention performance in the five senses of science learning. The results suggest that the use of AR media in students' learning has a positive effect, and the implementation of technology-enhanced instruction should be considered as a significant strategy for improving memory retention in students' performance in elementary science.

DISCUSSION

1. Interpretation of Research Findings

The findings of the study revealed that elementary school learners could effectively remember concepts related to the human sensory system employing AR-based teaching media integration. The magnitudes of the differences between the post- and pre-test scores ($p<0.05$) strongly contribute to empirically solidifying the predicted effectiveness of this intervention. This support is in line with the premise of the Cognitive Theory of Multimedia Learning, which states that students learn more effectively when verbal and visual information are presented simultaneously through two channels (Aldeeb et al., 2024; Buchner et al., 2022). This befits the AR affordance to embed interactive 2D/3D visualization in formal instruction (Lin & Yu, 2023; Mansour et al., 2025) by reducing the extraneous cognitive load while promoting germane processing, which is essential for schema construction and long-term memory registration. This positive influence is attributed to the constructivist paradigm, where AR enables students to manipulate and interact with virtual representations of sensory receptors as well as explore, which facilitates them to apply their prior knowledge on a meaningful personal level.

Such an enhancement in retention and understanding is also supported by the qualitative part of the study and observed through students' interest during the AR class. This increased engagement may be linked to the framework of three dimensions (Behavioral, Emotional, and Cognitive) proposed by Fredricks et al.

(2004), where behavioral, emotional, and cognitive engagement are crucial to successful learning. The interactive and immersive nature of AR enhances students' activation and orientation (behavioral), pleasure and significance (emotional), mental effort in dealing with complex anatomical information, invested time, and performance quality of tasks (cognitive) (see, for example, Drljević et al., 2022; Lin & Yu, 2023). The results also appear to correlate with Vygotsky's (1978) ZPD, as when students engaged in dialogue about their learning, they shared AR models and collectively constructed meaning and scaffolded one another's understanding through cooperative discourse (Greenwood & Wang, 2018; Hadjistassou et al., 2019). This suggests that AR does not need to be limited to individual learning and can also support sociocultural learning environments.

The results of the present study are consistent with those of previous studies conducted in various international settings. For example, AR has been shown to increase the overall instructional effectiveness (ES g = 0.717) on general learning, such as knowledge retention or memory recall, in a large-scale meta-analysis with results consistent with those of Turkey and European studies (Lin & Yu, 2023; Xu et al., 2022). Furthermore, beyond physics achievement, critical thinking and practical skills are dimensions facilitated through AR and can be considered additional evidence for the robustness of the current study results (Alkhabra et al., 2023). Collaborative and immersive AR environments also afford collaborative problem-solving experiences and peer learning, recently referred to as embodied and collaborative science learning (Alzahrani, 2020; Mansour et al., 25).

Nevertheless, not all studies have demonstrated successful results of implantation. For instance, certain studies have emphasized that AR can be a generator of extraneous cognitive load when content is not designed as such and at the level at which students do not possess the required digital competences (Alzahrani, 2020; Buchner et al., 2022; Thees et al., 2020). This is a timely reminder that access does not always equal effective learning, something that good instructional design and careful attention to new media should promote and reinforce. In the current study, this problem was addressed by applying a guided additive AR approach with a carefully designed learning progression.

2. Pedagogical and Policy Implications

The findings of this study are significant for educators, curriculum planners, and governments, especially in Indonesia. In terms of educational practice, teachers need to transition from traditional decontextualized media in classrooms and integrate AR-scaffolding sequences that involve exploration and investigation inquiry (Dhar et al., 2021; Zhang et al., 2022). "Instead of a teacher showing a 2D diagram of the eye on a whiteboard, they can use Augmented Reality to project an AR model which students can explore physically by rotating and zooming that object, or look around the cornea, lens, and retina in space." For instance, when learning about parts of the human eye, teachers can go beyond just presenting two-dimensional diagrams and instead showcase it in an interactive three-dimensional experience. Such visual and interactive methods of learning help make conceptual facts tangible and more understandable, resulting in better retention, and are especially useful for science education (Basumatary & Maity, 2023). It is further important to implement AR technology in combination with physical activities and real-life situations. For instance, when practicing taste, students who understand the AR model of the tongue could attempt to view their own tongues operating by biting into different parts of a fruit or spice and noting how those interactions work, to see what they "See" in that model." By allowing students to integrate their theoretical learning and practical experience, our multisensory teaching utilizes both sides of the brain.

In terms of teacher education, this study highlights the need for focused training modules on the pedagogical use of AR. This training ought not only to provide the pedagogical skills to use a given AR platform (such as Assemblr Edu) but also to address the instructional design techniques that integrate AR technologies with both learning objectives and assessment methodologies from an existing curriculum (Lampropoulos et al., 2022; Sırakaya & Alsancak Sırakaya, 2020). By introducing such skills, we can ensure that AR-enabled technology is more than just a complementary technology; it will eventually become a revolution in developing an effective instructional tool (Basumatary & Maity, 2023; Zulfiqar et al., 2023).

At the policy level as well, the authors would argue for writing AR-compliant learning outcomes and digital literacy into science curricula. This is in line with the objectives of the Merdeka Curriculum, which emphasizes student-centered learning as well as emerging digital technology (Faqih & Jaradat, 2021; Zhang et al., 2022). To achieve equal access, the policy must provide appropriate technology infrastructure to bridge the digital divide between cities and towns in Indonesia's schools (Koumpouros, 2024).

3. Limitations

While this work yields important insights, our interpretation of its results needs to be tempered by certain limitations. A one-group pre-test–post-test design without a control group is also a major limitation in explaining the causal relationship between AR intervention and retention scores. Furthermore, the sample size was relatively small and from two schools in only one region; therefore, the results may not be generalizable elsewhere. The limited length of the intervention (two weeks) also precluded the measurement of retention.

Based on these limitations, future research should employ experimental or quasi-experimental designs with larger and more diverse samples and control groups to improve the generalizability of the findings. Long-term follow-up studies are required to determine whether the gains in knowledge retention and conceptual transfer following AR instruction can be sustained over time. In addition, combining mixed methods will allow interviewing as well as surveying students and teachers, providing richer qualitative data to the quantitative results for a more complete understanding of student engagement from the perspective of this study. Owing to the fast development in AR technology, new kinds of AR platforms, such as markerless or AI-supplemented Augmented Reality, can be expanded and may have potential applications in AR for pedagogy in primary education.

CONCLUSION

This study provides strong empirical evidence that using Augmented Reality (AR)-based learning media significantly improves the retention of fourth-grade students in Indonesian elementary schools. By merging real and virtual elements in an interactive, real-time manner, AR media with 2D and 3D visuals make it easier for students to understand and remember abstract concepts related to the human sensory system. The results of the paired sample t-test showed a statistically significant improvement in post-test scores, with a p-value of 0.000 ($p < 0.05$) for both schools, confirming the positive impact of the intervention on student retention.

This research contributes to the field of educational technology by providing new insights into the pedagogical value of AR in primary education, a context that has been largely underexplored, especially within Indonesia's dual-subject curriculum. It also offers practical recommendations for educators and policymakers to effectively integrate innovative digital tools to foster long-term learning and align with the objectives of the Merdeka Curriculum. The findings highlight AR's potential of AR not only to enhance learning outcomes but also to promote higher-order thinking skills (HOTS) and increase student engagement and curiosity. Despite the study's limitations, such as its pre-experimental design and small sample size, the results suggest that AR is a viable and effective strategy for transforming conventional science instruction into a more engaging and impactful learning experience for young students.

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