Biological Augmented Reality Media for Improving Deaf Students' Understanding of the Human Immune System

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Abstract: This study aims to measure the effectiveness of the Biological Augmented Reality (BAR) learning media in improving understanding of the "Human Immune System" Material among deaf junior high school students. The Research employed an experimental method with a one-group pre-test-post-test design, involving six deaf students from SLB X. Participant criteria included diagnosed hearing impairments, junior high school age, basic literacy skills, and the absence of severe cognitive impairments. The procedure began with a pre-test consisting of multiple-choice questions to assess prior knowledge. Subsequently, students participated in learning sessions using BAR media, designed to present three-dimensional visualizations and interactive features to facilitate understanding of abstract concepts. A post-test was then administered to evaluate changes in students' comprehension. Data from the pre-test and post-test were analyzed using the nonparametric Wilcoxon test to identify significant differences. The results revealed a significant improvement in students' understanding after using the BAR media. The media's visualization and interactivity not only enhanced learning engagement but also helped students process information more effectively. This study recommends BAR media as an innovative learning alternative, particularly for deaf students, to address verbal communication barriers and support education.

Abstrak: Penelitian ini bertujuan mengukur efektivitas media pembelajaran Biological Augmented Reality (BAR) dalam meningkatkan pemahaman materi "Sistem Kekebalan Tubuh Manusia" pada peserta didik tunarungu tingkat SMP. Metode eksperimen dengan desain one-group pre-test-post-test digunakan, melibatkan enam peserta didik tunarungu di SLB X. Kriteria peserta mencakup keterbatasan pendengaran terdiagnosis, usia jenjang SMP, kemampuan literasi dasar, dan tidak memiliki gangguan kognitif berat. Prosedur dimulai dengan pemberian pre-test berupa tes pilihan ganda untuk mengukur pengetahuan awal. Setelah itu, pembelajaran dilakukan menggunakan media BAR yang menyajikan visualisasi tiga dimensi dan fitur interaktif guna mempermudah pemahaman konsep abstrak. Setelah pembelajaran, post-test dilakukan untuk mengukur perubahan pemahaman peserta. Data pre-test dan post-test dianalisis menggunakan uji statistik non-parametrik Wilcoxon untuk melihat perbedaan signifikan. Hasil menunjukkan peningkatan signifikan pada pemahaman peserta didik setelah menggunakan media BAR. Visualisasi dan interaktivitas media ini tidak hanya meningkatkan daya tarik belajar, tetapi juga membantu peserta memproses informasi lebih baik. Penelitian merekomendasikan media BAR sebagai alternatif pembelajaran inovatif, khususnya bagi peserta didik tunarungu, untuk mengatasi keterbatasan komunikasi verbal dan mendukung pembelajaran.

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A. Introduction

Science education, particularly biology instruction, faces persistent challenges in explaining abstract concepts such as the human immune system, especially for students with hearing impairments or who are deaf. Deaf students experience limitations in receiving auditory information, which often leads to difficulties in understanding complex biological processes that rely heavily on verbal explanations and abstract reasoning (Susetyo et al., 2021; Knoors & Marschark, 2014). Marschark et al (2015) further confirmed that the academic achievement of deaf students is significantly influenced by communication factors and educational support system. In current practice, science instruction for deaf students at the junior high school level is still largely dominated by conventional approaches, such as written lectures and static visual materials. These methods do not adequately accommodate deaf learners' visual and kinesthetic learning styles, resulting in a shallow conceptual understanding of essential biological topics such as the immune system.

The urgency of this issue highlights the need for instructional media that can present biological content in a more visual, interactive, and contextual manner. One promising approach to addressing this challenge is the use of biological, augmented-reality-based learning media. Augmented Reality enables the visualization of biological structures and processes in three dimensions and interactively, allowing learners to observe abstract concepts more concretely (Azuma, 1997). Previous studies have shown that AR-based media can enhance learners' attention, retention, and conceptual understanding, particularly for students who face barriers to verbal communication (Subagya et al., 2023; Akayır & Akayır, 2017). A systematic literature review by Permana (2024) further indicated a rising trend in the application of augmented reality within biology education, particularly for visualising abstract biological concepts. Moreover, AR has been shown to bridge sensory input limitations among deaf students by providing realistic visual simulations that closely resemble real-world biological phenomena (Rusli, 2022). In addition, previous research has explored the use of interactive digital concept maps as instructional media for the immune system topic, demonstrating positive effects on students' conceptual understanding (Rahayu, 2020).

In response to this need, the present study proposes the development and implementation of Biological Augmented Reality learning media specifically designed for the human immune system. This topic was selected due to its high level of abstraction and its crucial role in supporting students' health literacy. Despite its importance, the immune system remains one of the most difficult biology topics for deaf students to comprehend when taught using conventional instructional strategies.

Compared with previous Research, which has largely focused on the application of AR for regular students or on outcomes such as motivation and engagement (Garzón & Acevedo, 2019; Ibáñez & Delgado-Kloos, 2018), this study explicitly targets deaf learners. Research specifically examining the impact of AR on deaf students' conceptual understanding, particularly in complex biological topics such as the human immune system, remains scarce (Braun et al., 2018). A decade-long systematic review by Jdaitawi & Kan'an

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(2021) confirmed that AR technology has consistently demonstrated positive learning outcomes for students with special disabilities, yet studies specifically targeting deaf learners in science education remain limited. Susilawati (2023) identified that inclusive culture and institutional support are key factors, yet the availability of adaptive learning media remains insufficient. Kurz et al (2015) demonstrated that deaf children's science content learning is significantly affected by the mode of instructional delivery. Similarly, Saptono et al (2023) reported positive reception of AR in inclusive education settings. This reveals a clear Research gap, namely the limited number of empirical studies that combine AR technology with the specific learning needs of deaf students at the junior high school level.

The novelty of this Research lies in the development and empirical testing of Biological Augmented Reality learning media that are specifically tailored to accommodate the visual learning characteristics of deaf students, including visual design, textual narration, and interactive features. his design approach is informed by Zamakhsyari et al (2022), who recommended integrating visual elements, minimal textual explanations, and interactivity to align with the learning characteristics of students with special needs. Furthermore, this study employs a pre-experimental approach with a one-group pre-test-post-test design to measure conceptual understanding as the primary learning outcome. This aspect has rarely been examined in prior AR-based studies involving students with hearing impairments. Bower et al (2014) emphasized that AR has the potential to reduce cognitive overload by providing perfectly situated scaffolding in education, yet its application for learners with special needs remains underexplored. Saputri et al (2024) developed AR-based learning media specifically designed for deaf elementary school students and reported positive impacts on learning engagement and outcomes, further reinforcing the potential of AR for this population.

Based on the identified Research gap and novelty, this study is guided by the following Research question: Does the use of Biological Augmented Reality learning media significantly improve deaf junior high school students' understanding of the human immune system?. Accordingly, the objective of this study is to examine the effectiveness of BAR learning media in enhancing deaf students' conceptual understanding of the human immune system. The findings are expected to contribute to the development of adaptive and inclusive learning media in science education and to enrich the field of educational technology for students with special needs, particularly in supporting visual and interactive biology instruction.

Theoretically, this Research is grounded in visual constructivist learning theory, as proposed by Piaget (1954) and Bruner (1966), which emphasises that learning becomes more meaningful when students actively construct knowledge through direct experience and visualization (Kurniawati et al., 2021). Özer et al (2023) provided further theoretical evidence supporting the suitability of constructivist approaches for special education settings, reinforcing the role of active knowledge construction through visual experience. Augmented Reality, which integrates virtual objects into the real environment, provides

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strong support for experience-based visual learning. Supporting this perspective, Raharjo (2020) reported that students with special needs demonstrate significant improvements in cognitive performance after engaging with interactive, technology-based learning media.

B. Method

This study employed a quantitative approach using a one-group pre-test post-test experimental design to examine the effectiveness of Biological Augmented Reality (BAR) learning media in improving deaf junior high school students' understanding of the human immune system. The participants consisted of six deaf students selected through purposive sampling based on specific criteria, including diagnosed hearing impairment, enrollment in grade IX, basic reading literacy skills, the ability to understand visual instructions, and willingness to participate fully in the learning and evaluation process. The study was conducted at SLB X in Bandung City.

The learning intervention was implemented through structured learning sessions using BAR media designed to present three-dimensional visualizations and interactive representations of the human immune system. The media allowed students to explore immune organs, immune response mechanisms, and basic concepts of pathogen defence through visual interaction. Before the intervention, a pre-test was administered to assess students' initial conceptual understanding. After the learning sessions were completed, a post-test was conducted to measure changes in students' understanding following the use of the BAR media.

Data collection involved conceptual understanding tests in the form of pre-test and post-test, as well as observations of students' learning activities during the intervention. The instrument used was a multiple-choice test designed to measure students' conceptual understanding of the human immune system, including the identification of immune system components and basic immune processes. The test items were reviewed to ensure their relevance to the learning objectives and content validity.

Data analysis was conducted using descriptive quantitative techniques to compare pre-test and post-test scores and to describe changes in students' conceptual understanding. Improvement in learning outcomes was further examined through gain score analysis. To determine whether the observed differences between pre-test and post-test scores were statistically significant, the Wilcoxon Signed Rank Test was used as a nonparametric test, given the small sample size and the data's characteristics.

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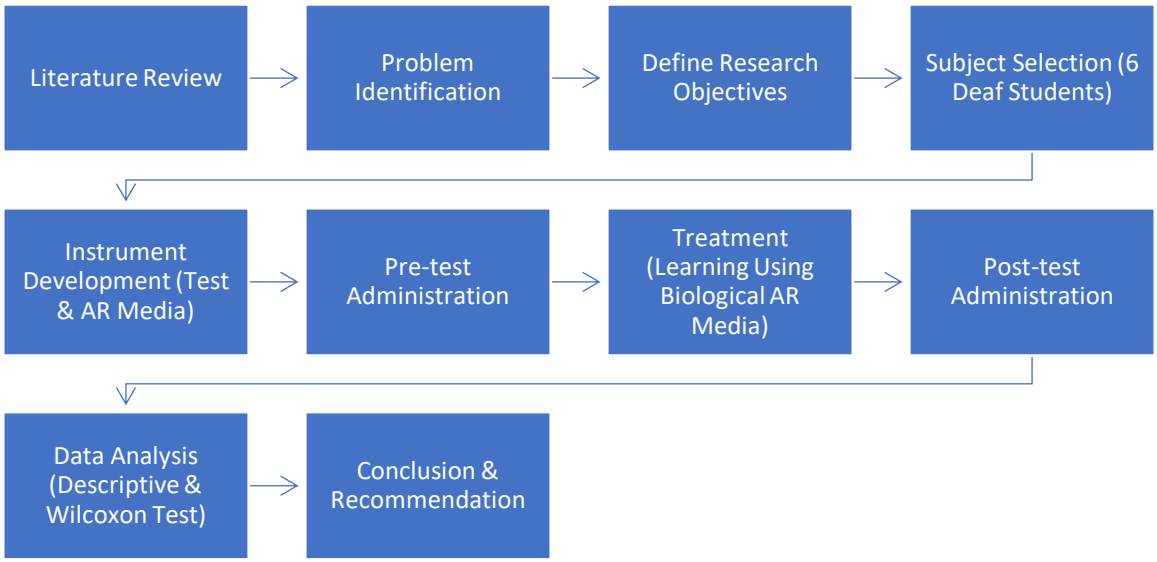

Figure 1. Research Flow of the Study

Figure 1 illustrates the overall Research procedure, consisting of four sequential stages: pre-test administration, BAR-mediated learning intervention, post-test administration, and data analysis using the Wilcoxon Signed Rank Test.

C. Result

The study found that deaf students' understanding of the topic "*The Human Immune System*" improved after using the Biological Augmented Reality (BAR) learning media. The average pre-test score was 44.17, while the average post-test score increased to 83.83, with an average score difference of 39.67. Data analysis using the Wilcoxon Signed Rank Test showed significant results, indicating that the use of BAR media significantly enhanced students' understanding.

Table 1. Data Analysis Results

Name	Score Pre-test	Score Post-test	Difference	Ranking
A	40	85	45	5
B	50	90	40	4
C	45	80	35	3
D	35	75	40	4
E	50	88	38	2
F	45	85	40	4

Based on observations during the learning process, students responded positively to the BAR media. They appeared enthusiastic and actively engaged throughout the lessons, such as by exploring the 3D models, following the mechanisms of the immune system, and answering interactive questions within the media. Some students were even able to explain

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basic concepts, such as phagocytosis and antibody production, with the support of the media's visualizations.

Table 2. Wilcoxon Test Result

		N	Mean Rank	Sum of Ranks
Post_Test - Pre_Test	Negative Ranks	0^a	.00	.00
	Positive Ranks	6^b	3.50	21.00
	Ties	0^c		
	Total	6		

a. Post_Test < Pre_Test
b. Post_Test > Pre_Test
c. Post_Test = Pre_Test

Based on Table 2, the Negative Ranks indicate a negative difference between the biology learning outcomes in the pre-test and post-test. The values of Negative Ranks for N, Mean Rank, and Sum of Ranks are all 0, indicating that none of the students experienced a decrease in scores from pre-test to post-test.

Positive Ranks represent a positive difference between the pre-test and post-test scores. The value of N for Positive Ranks is 6, indicating that all 6 students increased their biology scores. The Mean Rank indicates the average increase in scores (3.50), and the Sum of Ranks represents the total of positive rankings (21).

Ties refer to whether or not there are any identical scores between the pre-test and post-test. Based on Table 2, the value for ties is 0, indicating that there were no identical scores between the pre-test and post-test.

Table 3. Wilcoxon Test Result

	Post_Test - Pre_Test
Z	-2.226^b
Asymp.Sig. (2-tailed)	.026

a.Wilcoxon Signed Ranks Test
b.Based on negative ranks

The next SPSS output is shown in Table 3, which presents the results of the Wilcoxon test. As observed, the Asymp. Sig. (2-tailed) The value is 0.026, which is smaller than the 5% significance level (0.05). This indicates a significant difference in the biology learning outcomes between the pre-test and post-test. In other words, the use of the Biological Augmented Reality (BAR) media had a statistically significant effect on students' understanding of the topic *"The Human Immune System."*

D. Discussion

The findings of this study clearly address the Research question and confirm that the use of Biological Augmented Reality learning media significantly improves deaf students'

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conceptual understanding of the human immune system. This result is consistent with the Research objective, which aimed to examine the effectiveness of BAR media in supporting biology learning for deaf junior high school students. The improvement observed between pre-test and post-test scores indicates that BAR media provides meaningful learning support for students who experience limitations in accessing auditory information.

The effectiveness of BAR media stems from its strong visual representation and interactive features, deliberately designed to align with the learning characteristics of deaf students. Biological concepts related to the human immune system involve abstract and dynamic processes that are difficult to understand through conventional text-based instruction or static images. Through three-dimensional visualisation and interactive exploration, BAR media allows students to observe immune structures and processes more concretely, thereby reducing cognitive abstraction and facilitating deeper conceptual understanding. This finding supports Mayer (2005) cognitive theory of multimedia learning, which emphasises that learning becomes more effective when information is presented through integrated visual representations. Aboud (2025) similarly reported that AR significantly improved mathematics learning outcomes among deaf elementary students in Saudi Arabia, confirming the cross-disciplinary effectiveness of AR for this population. For deaf students, visual elements serve as the primary channel for knowledge construction, making AR-based visualisation particularly effective.

The results of this study are consistent with previous Research by Radu (2014), Wu et al (2013), and Raharjo (2020), which reported positive effects of augmented reality-based learning media on students' conceptual understanding in science education. While Garzón & Acevedo (2019) meta-analysis confirmed positive AR effects primarily among regular students, the present findings extend this evidence to deaf learners, suggesting that such benefits are transferable across diverse student populations. These findings are also consistent with Jdaitawi & Kan'an (2021) review, extending their conclusions by providing specific evidence for deaf learners in biology education. Nugraheni et al (2024) also demonstrated that AR-based applications effectively improved sound understanding among hearing-impaired students in Central Java, further supporting the applicability of AR for students with hearing impairments. Compared with Rahayu (2020) digital concept maps, BAR media offers the additional advantage of three-dimensional visualisation, which may account for the larger gain scores observed in this study.

Observational data collected during the learning process further support the quantitative findings, showing increased student engagement and active participation when using BAR media. This is consistent with Yusnita (2021), who reported that innovative learning approaches significantly enhance student learning activities and outcomes.

From a theoretical perspective, these findings reinforce the role of visual constructivist learning in inclusive science education by demonstrating how AR-based media can support knowledge construction through visual experience and interaction. This empirically validates Özer et al (2023) theoretical framework, demonstrating that constructivist visual learning is not only theoretically suitable but also practically effective

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for improving deaf students' conceptual understanding in biology. From a practical perspective, the results indicate that BAR media can serve as an effective instructional alternative for teaching abstract biological topics to deaf students. This study also contributes to the AR-in-biology research trajectory identified by Permana (2024), specifically by providing empirical data on deaf learners — a population underrepresented in that body of literature.

E. Implication

Theoretically, this study contributes to the development of inclusive learning theory by strengthening the role of visually based constructivist learning in science education for students with special needs, particularly deaf learners. The findings provide empirical support for multimedia learning theory by demonstrating that conceptually complex biological content can be more effectively understood when delivered through well-designed visual and interactive media. By focusing on conceptual understanding rather than solely on motivation or engagement, this study extends existing theoretical perspectives on augmented reality-based learning within inclusive educational contexts. This aligns with the findings of Akayır & Akayır (2017), who identified enhanced learning achievement as one of the most consistent advantages of AR in education.

Practically, the results suggest that Biological Augmented Reality learning media can be adopted as an effective instructional alternative in biology classrooms for deaf students, especially when teaching abstract and dynamic topics such as the human immune system. Teachers are encouraged to integrate AR-based media into instructional planning to support visual exploration and active learning. In addition, educational institutions and curriculum developers are encouraged to invest in and develop adaptive learning technologies that align with the visual learning preferences of students with hearing impairments to support inclusive classroom practices.

Socially, this study highlights the potential of technology-assisted learning to promote more equitable access to quality science education for students with hearing impairments. The social significance of this study is reinforced by Susilawati (2023) finding that adaptive learning media remains insufficient; the present study addresses this gap by providing BAR media as a concrete solution for inclusive science classrooms. By integrating adaptive technologies such as BAR media, schools can better accommodate deaf students' communication needs and promote equitable participation in science learning.

F. Limitation and Suggestion for Further Research

This study has several limitations that should be considered when interpreting the findings. First, the relatively small sample size limits the generalizability of the results to a broader population of deaf students. Future studies are therefore encouraged to involve larger, more diverse samples across different educational settings to strengthen external

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validity and provide more comprehensive evidence of the effectiveness of AR-based learning media.

Second, the learning intervention was conducted over a relatively short period, which may not fully capture the long-term impact of Biological Augmented Reality learning media on students' conceptual understanding. Further Research is recommended to employ longitudinal designs to examine learning retention and the sustainability of conceptual gains over extended periods of instruction.

Third, this study focused primarily on cognitive outcomes related to conceptual understanding. While these outcomes are essential, they do not fully represent the complexity of the learning process. Future Research should explore additional dimensions, such as students' learning motivation, attitudes toward AR-based media, and levels of engagement, to obtain a more holistic understanding of the impact of augmented Reality in inclusive science education.

Finally, future studies may also compare AR-based learning media with other instructional approaches or include control groups to examine their relative effectiveness further. Such Research designs would contribute to a deeper understanding of how and under what conditions augmented Reality can most effectively support learning for deaf students in science education.

G. Conclusion

This study concludes that the Research objective has been successfully achieved, as the use of Biological Augmented Reality learning media significantly improved deaf students' conceptual understanding of the human immune system. The findings indicate that AR-based instruction, which emphasises visual representation and interactivity, provides effective learning support for deaf students by accommodating their visual learning preferences and reducing reliance on auditory explanations.

The results of this study demonstrate that Biological Augmented Reality learning media can serve as an effective instructional alternative for teaching abstract and complex biological concepts within inclusive science education. By providing empirical evidence on the cognitive impact of AR-based biology learning media for students with hearing impairments, this study contributes to the advancement of educational technology Research. It supports the development of adaptive learning strategies for students with special needs.

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