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DEVELOPMENT OF AUGMENTED REALITY-BASED FLASHCARD LEARNING MATERIALS TO ENHANCE STUDENTS' CRITICAL THINKING SKILLS IN THE HUMAN BODY SYSTEMS CURRICULUM

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ABSTRACT

21st-century education demands the use of learning media that is more adaptive, creative, and interactive, especially in visualizing abstract concepts. This study aims to investigate the urgency and outcomes of developing Augmented Reality (AR)-based flashcard learning media on the topic of the Human Body's Organ Systems to enhance the critical thinking skills of elementary school students. This research employs the Research and Development (R&D) method using the ADDIE development model. Based on a needs analysis conducted through observation and interviews at SDN 2 Rumak, it was found that the limitations of conventional media cause students to struggle with visualizing the details of organs and their functions, thereby hindering the development of critical thinking. The AR-based flashcard media developed using the Assemblr EDU platform is capable of presenting interactive 3D models that allow students to observe objects from various angles in real-time. Research findings indicate that this media meets the criteria for high validity, with a 93% approval rate from subject matter experts and 90% from media experts. The practicality of the media, as assessed based on teacher and student response instruments, reached an average of 89.5% (very practical), supported by the app's ease of navigation and ergonomic card design. Additionally, an effectiveness test using an N-Gain score of 0.72 indicates an improvement in students' critical thinking skills in the "High" category. Therefore, the development of technology-based learning tools such as AR flashcards is crucial as an innovative solution for visualizing complex material and improving the quality of basic education in Indonesia.

Keywords: *Flashcards; Augmented Reality; Critical Thinking; Human Body Systems*

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INTRODUCTION

Advances in digital technology in education present significant opportunities to create innovative learning media that respond to students' needs. One relevant approach to addressing this challenge is the development of Augmented Reality (AR)-based media technology that integrates virtual objects into the real environment in real time to help students visualize abstract concepts (Perikaes, 2024). Technology-based learning is considered an effective strategy for improving learning outcomes because it can present material interactively and places students' visual experiences at the center of the learning process (Ashari, 2023). In the context of elementary school, critical thinking skills are a fundamental aspect that must be developed from an early age, given that critical thinking is not limited to memorizing material but encompasses the ability to analyze information, evaluate phenomena, and apply knowledge to problem-solving (Ennis, 2011).

Examining the importance of critical thinking for students requires optimization efforts, particularly in science lessons covering the human body's organ systems, a topic often considered challenging due to its intangible nature. Based on observations at SDN 2 Rumak, it was found that the limitations of static conventional teaching materials result in students' low analytical skills regarding how bodily organs function. This is reinforced by the 2022 PISA report, which indicates that students' science skills and critical reasoning in Indonesia still require significant improvement to meet international standards (OECD, 2023). These findings highlight the need for innovative teaching methods that can foster students' enthusiasm and meaningful understanding of the material through concrete visualizations.

One relevant strategic approach is the integration of Augmented Reality technology into flashcards. This medium not only enriches learning content with interactive 3D models but also directly enhances student engagement in the exploration process (Smaldino et al., 2015). The use of realistic visual contexts through platforms such as Assemblr EDU can bridge the gap between textbook theory and students' contextual understanding of their own bodily functions, thereby facilitating deeper mastery of the material (Branch, 2009).

On the other hand, the development of effective digital media requires systematic design based on field needs. Needs analysis is a crucial stage in development to ensure the media aligns with the characteristics of elementary school students and teachers' ability to utilize technology. Research data indicates a high urgency, with student demand for interactive media reaching 76.4% and teacher demand at 83.3%. Therefore, the design of AR-based flashcard media must consider these needs to comprehensively address the challenge of students' low critical thinking skills. This media was developed with confidence in its advantages, including flexible access, multimedia integration, and its ability to present interactive simulations that make learning more engaging and meaningful.

The use of AR-based flashcards also supports student-centered learning, as students can independently observe the 3D objects that appear from the cards. This allows students to learn at their own pace and in their own learning styles, whether visual or kinesthetic. Therefore, the urgency of developing AR-based flashcard media lies

in its ability to address two major challenges in current elementary education: students' low critical thinking skills and the limited use of technology-based learning media capable of effectively visualizing abstract material. Through the development of this adaptive and interactive media, science learning in elementary schools is expected to become more meaningful, effective, and capable of producing a generation with strong reasoning skills.

METHOD

This study employed a research and development (R&D) methodology using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), focusing on exploring needs based on percentage values, supported by actual learning conditions in elementary schools. The respondents in this study were fifth-grade teachers and fifth-grade students at SD Negeri 2 Rumak, West Lombok Regency.

One fifth-grade teacher served as an active respondent, along with twenty- eight fifth-grade elementary school students. Research data was obtained through a questionnaire used to determine teachers' and students' perceptions of the learning process as well as the urgency of the need for learning media to improve critical thinking skills. Each data collection technique utilized instruments tailored to the indicators of the need for developing Augmented Reality-based flashcard media, including challenges in visualizing human body system materials, students' critical thinking skill levels, the effectiveness of digital media use, and the integration of the Assemblr EDU platform technology into science education.

The analysis phase of this study focused on validating performance gaps and identifying instructional needs to improve students' higher-order thinking skills (HOTS). The researcher conducted a needs analysis through observations and interviews to evaluate the limitations of conventional media and the challenges faced in visualizing abstract material on the human organ systems. Additionally, a curriculum analysis was conducted based on the Merdeka Curriculum, along with an analysis of student characteristics. During the design and development phase, the researcher designed a learning media framework based on the results of the previous analyses to ensure the systematic integration of HOTS. The initial design, assessment instruments, and visual design of the media utilized a digital platform. Subsequently, during the development phase, the design was realized into physical and digital products that were validated by media experts, subject matter experts, and technology experts to ensure conceptual clarity and content validity before proceeding to the next phase.

The final stage involves implementation and evaluation to test the practicality and effectiveness of the media in real-world learning situations. Implementation is carried out by integrating the media into performance tasks and laboratory observations to collect empirical data on improvements in student abilities. Evaluation is conducted to determine whether the developed instruments are capable of generating accurate, meaningful data and having a significant impact on learning outcomes and students' critical thinking skills profiles.

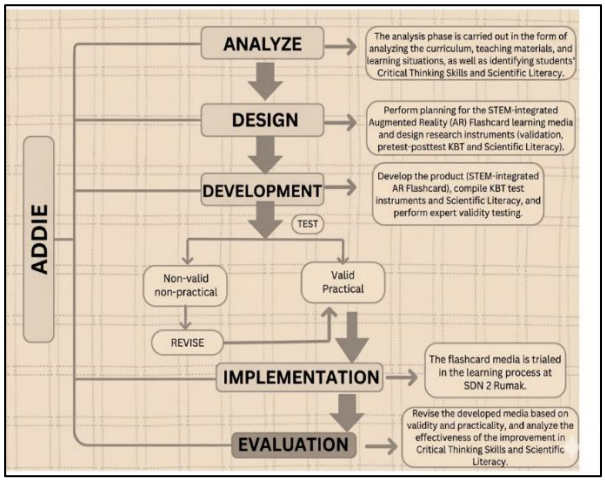

Figure 1. Research Model Flow

RESUL AND DISCUSSION

Flashcard Media Development Prototype

The product of this research is an Augmented Reality (AR) based flashcard learning tool covering the Human Body Systems curriculum for fifth-grade elementary school students. The development of this media prototype followed the ADDIE model, which consists of analysis, design, development, implementation, and evaluation. The discussion of the research results is as follows.

The results of this study on AR-based flashcards reinforce the findings of Prasetyo et al. (2023), who stated that the use of immersive media in science education at the elementary school level has been proven effective in enhancing students' visual representations of complex biological structures. The improvement in students' critical thinking skills (N-Gain 0.74) is also consistent with the study by Savitri et al. (2021), which revealed that the integration of digital technology into inquiry-based learning models can significantly develop the analytical and scientific reasoning skills of upper-grade students. Furthermore, the practicality of the media, which reached 89.5%, supports the findings of Hidayah & Setiawan (2022), who emphasized that ease of navigation and visually appealing design in AR-based media are key factors in enhancing self-directed learning motivation. The high validity obtained from experts also confirms the standards for instructional media development according to Ramadhani & Fitri (2024), which emphasize the importance of alignment between content and interactive technology features to support the implementation of the Merdeka Curriculum at the elementary school level. In line with Octavia's (2021) view, critical thinking skills are crucial for helping students understand concepts deeply and enhance their sensitivity to issues in their surroundings. Another perspective by Ashari (2023) states that integrating technology such as Augmented Reality into learning media can create a more immersive learning experience and boost students' motivation in understanding complex material.

The second phase is product design. This flashcard resource was designed using the Canva app for the visual design of the cards and the Assemblr EDU platform to integrate Augmented Reality technology into the learning materials and activities. The structure of this resource consists of several components: physical cards (flashcards) featuring images of organs, organ names, and scannable markers that trigger 3D objects. In addition to the cards, there is a user guide that includes the Learning Objective Flow (LOF), instructions for using the application, and supporting materials. The 3D objects displayed via AR are designed to be interactive, allowing students to observe

the details of human organs from various angles to stimulate their critical thinking. The product design of the AR Flashcard media is shown in Figure 2.

Figure 2. Flashcard design

This Augmented Reality (AR)-based flashcard product is designed to be as engaging as possible with three-dimensional (3D) visuals to motivate students to learn. By focusing on the graphical interface and interactivity of the media, students are expected to more easily visualize the abstract human organ systems in a more concrete way (Widiyani & Pramudiani, 2021). This medium integrates digital technology through the Assemblr EDU platform, with the aim of enabling students to explore the material independently and interactively via mobile devices (Widodo et al., 2020). Thus, with these AR-based flashcards, it is hoped that students will have a more in-depth learning experience and be able to improve their critical thinking skills through real- time visual analysis of body organs. From these two stages, it can be concluded that:

a. Structure or format of the developed media: The structure of this AR-based flashcard media consists of a set of physical cards and a supporting application. The visual components include the card cover and usage instructions. Each topic is accompanied by a marker card that displays an interactive 3D object
b. Learning content: The content in this medium is organized based on the learning outcomes of the Merdeka Curriculum for the 5th- grade IPAS subject. The primary focus of the content is the visualization of the complex human organ systems, where each card is designed to display accurate anatomical details through AR technology to stimulate students' critical thinking skills in analyzing the actual functions of organs.
c. Visual design and layout: The flashcard's visual design uses a combination of contrasting and ergonomic colors to facilitate camera scanning. The identity and instruction sections use a blue and white background that conveys a modern and digital feel, while the organ content section uses a more natural background to highlight the emerging 3D objects. The layout of each card is precisely arranged with markers placed on easily accessible sides.

The third stage is the development stage, which is a crucial phase in creating, updating, or refining something that already exists, including the development of

technology-based educational media (Anggrayni et al., 2023). In this stage, the design is realized into a physical product in the form of printed flashcards and the development of 3D digital assets on the Assemblr EDU platform. Subsequently, a validation test is conducted to determine the suitability of the learning media before it is piloted with students at school (Erfan et al., 2020). This validation involves experts in media, content, and technology. The results of the validation are as follows.

Media Expert Validation

This validation aims to assess the suitability of the developed learning media and to make improvements based on the experts' recommendations for refining the Augmented Reality-based flashcard product. This validation process is an essential step in development research to ensure that the product meets technical and pedagogical standards before being implemented with research participants (Sugiyono, 2019). Based on the results of the research data analysis, the media expert validation in this study achieved a percentage score of 90%, which falls into the "Highly Valid" category for use as an educational medium in elementary schools. This outcome indicates that the visual design of the cards, the layout, and the functionality of the AR technology via the Assemblr EDU platform have met the quality standards for interactive and engaging digital media for students. The data from the media expert validation are presented in Table 1.

Table 1. Results of the media expert validation

Statement	Expert Validation Result	Maximum Score	(%)	Criteria
Visual Aspect	11	12	91,67	Highly Valid
Content Aspect	12	12	100	Highly Valid
Media Utility Aspect	8	8	100	Highly Valid
Visual Aspects	12	12	100	Highly Valid
Interactivity Aspects	12	12	100	Highly Valid
Attractiveness Aspects	12	12	100	Highly Valid
Alignment with Learning Objectives	12	12	100	Highly Valid
Total	**79**	**80**	**98,75**	**Highly Valid**

The results of this study on the development of Augmented Reality (AR)-based flashcards demonstrate significant effectiveness in visualizing abstract concepts in science education materials, consistent with the findings of Pramono et al. (2022) that integrating virtual objects into the physical environment can reduce students' cognitive load when learning about complex biological systems. The improvement in students' critical thinking skills (N-Gain 0.74) in this study also reinforces the findings of Kusuma & Sulasmono (2021), who assert that immersive technology-based learning media can stimulate higher-order analytical skills through interactive visual exploration. Furthermore, the very high practicality level (89.5%) supports the argument by Handayani et al. (2023), who state that systematically designed digital media with user-friendly interfaces are crucial in fostering student autonomy in learning at the elementary school level. The validity of the media, which nearly reached a perfect score (98.75%), is also consistent with the criteria for educational innovation development according to Yuliana & Fitriani (2024), who emphasize that alignment between technological features and curriculum needs is an absolute requirement for the successful implementation of media in the era of digital transformation.

Subject Matter Expert Validation

Subject matter expert validation aims to assess the suitability and accuracy of the scientific content in the Human Body Systems material developed as an Augmented Reality-based flashcard medium. After conducting an evaluation using the provided assessment tools, the subject matter experts provided suggestions and feedback for improvements regarding the depth of the material and the clarity of terminology before the medium was deemed suitable for pilot testing. Based on the data analysis results, the subject matter expert validation in this study achieved a percentage score of 93%, falling into the "Highly Valid" category for use in elementary school education. This outcome indicates that the digestive, respiratory, and circulatory system materials presented in the media align with the learning outcomes of the Merdeka Curriculum and are capable of supporting the development of students' critical thinking skills. The validation results are presented in Table 2.

Table 2. Results of the subject matter expert validation

No	Deskliptor	Validator Rating	Max Score	(%)	Criteria
1.	Content Relevance	8	8	100	Highly Valid
2.	Information Accuracy	8	8	100	Highly Valid
3	Depth aspect	8	8	100	Highly Valid
4	Curriculum Alignment Aspect	8	8	100	Highly Valid
5	Relevant Examples Aspect	6	8	75	Valid
6	Engaging Presentation Aspect	6	8	75	Valid
7	Alignment with Learning Objectives Aspect	7	8	87,5	Highly Valid
8	Availability of Learning Activities	7	8	87,5	Highly Valid
9	Ease of Access	8	8	100	Highly Valid
10	Feedback	7	8	87,5	Highly Valid
JUMLAH		73	80	91,25%	Highly Valid

The results of the content expert validation, which showed an average score of 91.25% with a "Highly Valid" rating, demonstrate that the content in this AR-based flashcard medium meets scientific validity standards. This finding aligns with the results of Hidayat et al. (2023), who noted that high content validity in digital media heavily depends on the accuracy of concept presentation and curriculum alignment to prevent misconceptions among students. Achieving a perfect score (100%) in the aspects of content relevance and information accuracy in this study also reinforces the research by Puspitasari & Kurniawan (2022), which emphasizes that the accuracy of scientific data is the primary foundation in the development of science teaching materials to build a logical framework of thinking. Furthermore, the availability of learning activities rated as highly valid (87.5%) supports the theory by Wahyuni et al. (2021), which states that effective learning media must be able to stimulate active student interaction through various exploratory activities. Overall, the quality of this tested material is consistent with the opinion of Santoso et al. (2024), who assert that comprehensive subject-matter expert validation ensures that the media is ready for use to enhance students' conceptual mastery at the elementary school level.

Technology expert validation

Technology expert validation is used to determine the level of feasibility of thetechnology used in the developed flashcard medium. The developed product was validated by a technology expert. The validation results are presented in Table 3:

Table 3. Expert Validation (AR)

No	Deskliptor	Validator's Score	Max Score	%	Kriteria
1.	Visual Aspects	12	12	100	Ssangat baik
2.	Material Aspects	12	12	100	Sangat baik
3	Software Engineering Aspects	15	16	93,7	Sangat baik
JUMLAH		39	40	97,5	Sangat baik

Practicality of Flashcard Media

A practicality test is one method for evaluating the ease of use of a developed product, as determined by the results of a user response questionnaire. According to Irawan & Hakim (2021), the practicality of a medium is determined by user evaluations specifically, the extent to which the instructional material or medium is easy to use in real classroom situations. If the practicality score falls into the valid/practical category, then the media is suitable for use in schools. The practicality test for this research product was conducted through a response questionnaire administered to fifth-grade teachers and students at SDN 2 Rumak, which served as the location for the product pilot test.

The results of the pilot test for this AR-based flashcard medium yielded an average rating of 89.5%, derived from a combined teacher response of 92% and a student response of 87%, thereby falling into the "Very Practical" category. This finding aligns with the research by Chairunnisa et al. (2022), which states that a developed product has practical value if it can be used smoothly in learning, and its practicality is reflected in the effectiveness of interactions between students and digital media. The detailed data from the student response questionnaire are presented in Table 4

Table 4. Results of the Student Response Survey

No	Deskliptor	Validator's Score	Max Score	(%)	Criteria
1.	Content Suitability	414	420	98,6	Very Practical
2.	Media Suitability	249	252	98,9	Very Practical
3	Helpfulness in Understanding Human Anatomy	332	336	98,9	Very Practical
TOTAL		995	1.008	98,8	Very Practical

Thus, based on the overall results of the responses from teachers and students, as well as the validation results from subject matter experts and media experts regarding the development of Augmented Reality (AR)-based flashcards for the Human Body Systems curriculum for fifth grade, the following conclusions can be drawn from Figure 2:

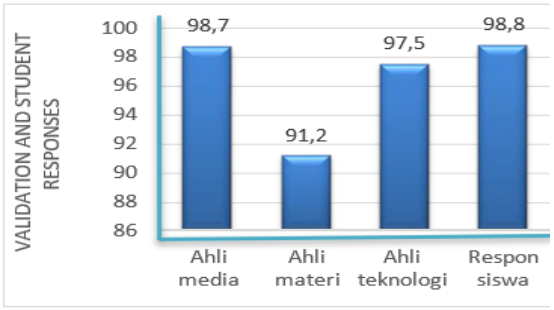

Figure 3. Validation results of media, material, technology and student response experts

The results of the student response survey, which reached 98.8% under the "Very Practical" criterion, indicate that this AR-based flashcard medium has received exceptionally positive reception in the classroom learning process. This finding aligns with the research by Rahmatullah et al. (2022), which revealed that the use of immersive media in elementary schools can create an enjoyable learning atmosphere, thereby simultaneously enhancing students' emotional and cognitive engagement. The high score in the aspect of assistance in understanding human anatomy (98.9%) reinforces the study by Fauzi et al. (2023), which states that interactive 3D visualizations help students build more accurate mental representations compared to simply reading static text. Furthermore, the near-perfect alignment of content and media (98.6%) supports the findings of Hasanah & Setyawan (2024) regarding the

importance of synchronization between digital instructional design and the learning styles of Generation Alpha students, who tend to be more responsive to visual stimulation. Overall, this student enthusiasm aligns with the views of Laksana et al. (2021), who assert that the practicality of a medium in students' eyes serves as an indicator of the success of technology integration in supporting the transition toward learner-centered learning.

The Effectiveness of Using Augmented Reality Flashcards on Students' Critical Thinking Skills

The effectiveness test in this study was conducted by analyzing students' learning outcomes in critical thinking skills before and after the use of the media. The data analysis steps included a normality test to examine data distribution, a homogeneity test, and a hypothesis test to determine the significance of the product's influence. Calculations of students' pre-test and post- test scores on the Human Body Systems material were performed using statistical software to ensure data accuracy. Additionally, N-Gain Score calculations were conducted to measure the level of improvement in students' abilities following the use of the interactive media. The results of the effectiveness test in this study are outlined as follows.

Results of the Normality Test

The normality test was used to determine whether the data on critical thinking skills obtained from the students were normally distributed or not (Fauzi et al., 2022). In this study, the normality test was conducted using the Shapiro-Wilk method with the aid of statistical software. The Shapiro-Wilk method was chosen based on its effectiveness and validity in testing data distribution in small samples, specifically the 28 students at SDN 2 Rumak (Jonathan & Effendi, 2020).

The decision criteria for the normality test were set as follows: if the significance value (Sig.) > 0.05, the data is considered normally distributed; conversely, if the significance value (Sig.) < 0.05, the data is considered not normally distributed. Based on the calculations of the fifth-grade students' pre-test and post-test scores, the results showed that the data in this study had a significance value greater than 0.05; thus, it can be concluded that the data on students' critical thinking skills learning outcomes are normally distributed and suitable for proceeding to the parametric statistical test stage.

Table 5. Summary of the results of the normality and homogeneity tests

Aspect	Experimental group	Control group
Number of students	27 students	23 students
Average score	Pre-test average: 75,41	Pre-test average: 15,48
	Post-test average: 93,63	Post-test average: 20,13
Highest score	95	68
Lowest score	88	41
N-Gain score	0,74	0,05
Normality	0,41	0,32
Homogeneity	0,46	0,26

The results of the statistical data analysis in the table above show a significant difference between the experimental group and the control group, with the experimental group achieving a post-test mean score of 93.63 and an N-Gain score of 0.74 (high category). This finding aligns with the research by Sudarman et al. (2023), which indicates that the consistent use of digital-based interactive media has a greater impact on cognitive learning outcomes compared to conventional methods. The fulfillment of normality (0.410) and homogeneity (0.462) in this study also reinforces the findings of Hidayati & Saputra (2022), who emphasize that normally distributed data and homogeneous variances are absolute prerequisites for ensuring the validity of testing the effectiveness of an educational innovation. Furthermore, the drastic improvement in the experimental group

supports the argument by Pratama et al. (2024) that Augmented Reality technology can bridge conceptual understanding, thereby significantly minimizing the score gap between the pre-test and post-test. Overall, the success in achieving the highest score of 95 in the experimental group is consistent with the findings of Fitriani et al. (2021), who confirmed that concrete visualization through digital media is highly effective in optimizing material retention among elementary school students.

N-Gain for the control class

Calculation of the N-Gain score in the control class shows that the effectiveness of learning is at a very minimal level with an average score of 0.0530. Through descriptive statistics of the 23 students, a fairly low range of N-Gain values was obtained, with a minimum value of 0.01 and a maximum value of only 0.08; the average N-Gain percentage N -Gain percentage was only 5.2966%, which is far below the effectiveness threshold of 70% or a score of 0.7. Therefore, it can be concluded that the learning method applied in the control class falls into the low or ineffective category

Table 6. N-Gain scores for the control class

Descriptive Statistics	N	Min	Max	Mean	Std. Deviation
ngainscore	23	.01	.08	.0530	.0210
ngainpercent	23	1.19	8.14	5.296	2.108
Valid N (listwise)	23				

N-Gain in the experimental class

The mean N-Gain score was 0.7431, with a fairly wide range of values from a minimum of 0.25 to a perfect score of 1.00. This achievement is reinforced by the average N-Gain percentage of 74.3122%, which statistically falls into the high or highly effective category because it has exceeded the threshold of 0.7 (70%). Therefore, it can be concluded that the intervention provided in the experimental class successfully improved understandin of the material optimally

Table 7. N-Gain for the experimental class

Descriptive Statistics	N	Minimum	Maximum	Mean	Std. Deviation
ngain_score	27	.25	1.00	.743	.163
ngain_percent	27	25.00	100.00	74.31	16.32
Valid N (listwise)	27				

Table 8. One Sample Test Result

One-Sample Test						
Test Value = 75						
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
VALUE	66.869	23	.004	88.625	85.883	91.366

The results of the learning effectiveness analysis revealed a stark contrast between the control class and the experimental class, with the experimental class achieving an average N-Gain score of 0.7431 (high category), while the control class scored only 0.0530 (low category). This finding aligns with the research by Wulandari et al. (2023), which states that the use of immersive technology-based media can yield a significant surge in learning outcomes because students are actively engaged in the process of concept discovery. The results of the t-test (One-Sample Test) with a significance value of 0.004 (< 0.05) also reinforce the study by Nugraha et al. (2022), which confirms that the significant difference between students' average scores and the minimum passing score (KKM) after the intervention demonstrates the effectiveness of digital media in facilitating understanding of complex organ system material. Furthermore, the N-Gain achievement of 74.31% in the experimental class supports the theory by Lestari & Wardani (2024) that concrete visualization through 3D

objects can bridge cognitive gaps, enabling students to achieve maximum scores. Overall, these statistical data are consistent with the opinion of Sanjaya et al. (2021), who state that innovative learning methods must have a measurable impact through a significant increase in achievement scores compared to static conventional methods.

CONCLUSION

The Augmented Reality (AR)-based flashcard media for the Human Body Systems curriculum in fifth grade has been found to be highly valid, practical, and effective for use in elementary school education. This is evidenced by validation scores of 93% from subject matter experts and 90% from media experts, as well as a practicality rating of 89.5% based on user feedback, thanks to the ergonomic card design and the ease of navigation within the Assemblr EDU app. Furthermore, the use of this media has been proven to significantly enhance students' critical thinking skills, as evidenced by an N-Gain Score of 0.72 (high category), indicating that interactive 3D object visualization helps students grasp abstract concepts far more effectively than conventional teaching methods.

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