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Interactive Augmented Reality Learning Media for Human Organ Systems in Middle School Education

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ABSTRACT

EduBody is an Augmented Reality (AR)-based interactive learning application designed for eighth-grade Madrasah Tsanawiyah (MTs) students to study five vital human organ systems: the heart, lungs, brain, liver, and kidneys. Conventional science instruction in MTs schools relies heavily on static two-dimensional textbook images, leaving dynamic biological processes abstract and difficult to comprehend. To address this challenge, EduBody was engineered using the Multimedia Development Life Cycle (MDLC) methodology across six systematic stages. Developed in Unity 3D with the Vuforia SDK for Android 8.1 and above, the software overlays interactive 3D animated organ models, informative text banners, synchronized audio narration, and an embedded 10-question quiz onto five printed target markers. To optimize visual processing, the UI/UX design incorporates Mayer's Cognitive Theory of Multimedia Learning principles, specifically spatial contiguity, signaling, modality, and segmenting. Expert evaluations confirmed high content (88.5%) and media validity (91.2%), while internal testing verified functional reliability across all core features. Field testing with 38 students at MTs Labbaika yielded a practicality score of 89.4% ("Very Practical"). Cognitive assessment demonstrated a statistically significant improvement ($t(37) = 24.18$, $p < 0.001$) from a pre-test score of 42.50 ± 8.12 to a post-test score of 84.20 ± 6.45 (scaled 0–100), achieving a mean Normalized Gain (N-gain) of 0.725 (High category). Topic mastery increased across 9 out of 10 items. These empirical findings confirm that EduBody effectively enhances students' cognitive comprehension of basic human organ functions.

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■ INTRODUCTION

Natural Science (IPA) education at the Madrasah Tsanawiyah (MTs) level plays a crucial role in laying the foundation for students' critical thinking and scientific understanding of natural phenomena, particularly regarding the human body's organ systems. Understanding vital organs such as the heart, lungs, brain, liver, and kidneys is a core topic that requires a solid, deep conceptual grasp. Empirical reality reveals that science instruction in Indonesian Madrasah Tsanawiyah (MTs) schools still relies heavily on conventional approaches, such as one-way lectures and static two-dimensional images printed in textbooks (Susanti, 2025). These limitations often make learning material feel abstract and distant to students, since biological mechanisms such as the circulatory system or gas exchange occur deep within the body and cannot be observed directly with the naked eye. Students struggle to bridge the gap between abstract textbook theories and the concrete biological realities occurring within their own bodies. This pattern is consistent with a recent Indonesian literature review indicating that biological topics requiring students to conceptualize internal organ structures and physiological functions remain among the most frequently reported sources of learning difficulty at the secondary-school level (Hallaby & Syahputra, 2024).

A primary challenge in learning human anatomy at school lies in the high level of material abstraction, which is rarely balanced by representative and dynamic learning media (Patra et al., 2022; Faella et al., 2025). Static two-dimensional images found in textbooks or drawn on blackboards consistently fail to accurately represent the dynamics of complex biological processes (Prafitasari et al., 2026). Dynamic mechanical processes such as how heart valves pump blood or how alveoli facilitate gas exchange cannot be effectively visualized through static media (Schmid et al., 2022; Miserocchi & Beretta, 2026). The inability of conventional media to deliver dynamic and interactive visualizations negatively impacts students' cognitive processes. Students tend to resort to rote memorization of organ names and their functions in isolation, without truly comprehending how these complex systems operate synergistically. This fragile conceptual framework not only hinders academic achievement but also reduces students' motivation and engagement, as the subject matter is perceived as overly difficult, dry, and uninspiring. A recent review of augmented reality integration in Indonesian biology education corroborates this pattern, reporting that organ-system and physiological-process topics are among the content areas most frequently selected for AR intervention precisely because their internal and dynamic nature is poorly served by static instructional media (Fitriyana et al., 2026).

This underscores the urgent need for a new instructional approach that bridges the gap between abstract concepts and concrete, interactive visual representations that closely mirror real-world visual mechanics (Bhatt et al., 2025; Haryadi et al., 2026). Over the years, various educational efforts have addressed these pedagogical hurdles, ranging from instructional videos and illustrated modules to physical teaching models (Harendra et al., 2021; Mou, 2023). These media still present notable limitations: instructional videos remain passive with no two-way interaction, while physical anatomical models are often expensive, prone to wear and tear, and limited in their ability to demonstrate internal microscopic biological functions. The direct consequence of these persistent instructional limitations is a sustained lack of student interest and limited long-term conceptual retention (Akram et al., 2022). Empirical evidence from a domestic AR-based learning application supports this direction, showing that replacing static instructional media with an interactive AR alternative can raise student learning outcomes substantially compared with conventional teaching, from an average score of 58.57 to 98.57 in a treatment-versus-non-treatment comparison (Firmansyah et al., 2025).

With recent advancements in educational technology, Augmented Reality (AR) has increasingly been integrated into science learning and has proven to exert a positive impact on student motivation, active participation, and overall learning outcomes (Chang et al., 2022; Ateş & Polat, 2025). AR possesses the unique capability to overlay three-dimensional digital objects onto the physical real-world environment in real time (Syed et al., 2022). A critical evaluation of existing AR-based learning applications reveals that most media remain restricted to static 3D models, lacking realistic motion animations and integrated descriptive audio narrations (Zulfiqar et al., 2023; Pallavicini & Anesa, 2026). Combining animated 3D organ models with descriptive audio narration represents a highly meaningful innovation that possesses immense potential to elevate students' understanding of human organ systems (Bakar et al., 2025; Rogers, 2024). International meta-analytic evidence nevertheless urges some caution regarding this potential: a systematic review of extended-reality anatomy education found that while immersive virtual reality yields a moderate and significant improvement in knowledge scores, augmented reality alone shows a more heterogeneous and often non-significant effect, suggesting that instructional design elements such as narration and interactivity, rather than the AR medium alone, determine learning gains (Garcia-Robles et al., 2024; Salimi et al., 2024).

This multimodal AR approach aligns directly with Mayer's Cognitive Theory of Multimedia Learning, which posits that the human cognitive architecture processes information more effectively when visual and auditory channels are activated simultaneously (Mayer, 2022). Dual-channel processing helps minimize cognitive overload while enhancing long-term memory retention. Constructivist principles further suggest that AR-based interaction allows students to actively construct their own understanding of complex biological systems rather than passively absorbing pre-packaged information (Afnan & Puspitawati, 2024). Building upon these theoretical and practical considerations, this study aims to develop and evaluate an interactive AR-based learning application named EduBody, specifically tailored for eighth-grade students at Madrasah Tsanawiyah (MTs) Labbaika, featuring 3D motion animations, marker-based tracking, descriptive audio narration, and interactive quizzes (Latupeirissa & Sumarlin, 2025). To guide this study, three central research questions are explicitly addressed: how valid and practical is the developed EduBody application for science instruction at MTs Labbaika, to what extent does the implementation of EduBody improve students' conceptual understanding of vital human organ systems compared to conventional instructional media, and how does the use of EduBody influence students' learning motivation and active involvement during classroom instruction.

■ METHOD

Participants

The target population for the implementation and user-evaluation phase of this study consists of eighth-grade students enrolled at Madrasah Tsanawiyah (MTs) Labbaika. To ensure the pedagogical and technical validity of the developed software prior to field deployment, the study involves two distinct groups of evaluators: (1) Subject-Matter Experts: Experienced Natural Science (IPA) and Biology educators who evaluate the accuracy, depth, and alignment of the instructional content with the MTs curriculum. (2) Media Experts: Educational technology and software engineering specialists who assess interface design, 3D model responsiveness, AR marker tracking stability, and overall user interface/user experience (UI/UX) functionality.

The participants in this study comprised 38 eighth-grade students at Madrasah Tsanawiyah (MTs) Labbaika. A purposive sampling technique was employed to select the sample based on specific instructional and technical needs. The inclusion criteria for selecting the 38 participants were: (1) Active enrollment as eighth-grade students at MTs Labbaika during the study period. (2) Participation in the science unit covering human organ systems. (3) Full attendance across all pre-test, AR-based intervention, and post-test sessions. (4) Access to an Android-based smartphone compatible with the EduBody application system requirements.

Research Design and Procedures

This study adopted a Research and Development (R&D) methodology to design, develop, and evaluate the interactive Augmented Reality (AR) learning application, EduBody. The core software development lifecycle follows the Multimedia Development Life Cycle (MDLC) framework established by Luther (Roedavan et al., 2022). The MDLC model was selected due to its structured, systematic, and iterative workflow, which has proven particularly suitable for engineering interactive AR-based learning software and educational multimedia applications (Saputra & Aziza, 2024; Supriyono et al., 2023). This methodological suitability is echoed in a systematic literature review of AR-based science-education research, which found that studies adopting structured research-and-development frameworks tend to report more consistent and interpretable learning outcomes than those without a systematic development model (Zufahmi et al., 2025).

The overall execution of the study integrates the six distinct stages of the MDLC framework into a rigorous academic development process: (1) Concept Phase: Defining the primary objectives of the application, analyzing the cognitive profile and needs of eighth-grade MTs students, and establishing key visual and functional specifications (Aryani et al., 2024). (2) Design Phase: Constructing comprehensive technical blueprints, including narrative storyboards, user interface (UI) wireframes, system navigation flowcharts, and 3D organ interaction mechanisms to guide the production process. (3) Material Collection Phase: Sourcing, modeling, and refining all digital assets ranging from 3D anatomical models and text descriptions to audio narration files and AR target markers prior to engine integration (Lavric, 2022). (4) Assembly Phase: Combining all media assets within the authoring tool/game engine environment. This stage involves programming the AR tracking logic, integrating 3D animations, synchronizing descriptive audio narrations, and scripting the interactive quiz module. (5) Testing Phase: Executing a two-tier evaluation protocol: (a) Alpha Testing*:* Conducting internal quality assurance with media and subject-matter experts to eliminate software bugs, optimize marker tracking, and verify content accuracy; (b) Beta Testing*:* Field testing the application with eighth-grade students at MTs Labbaika to evaluate software usability, interactive performance, and user experience in a real-world learning environment. (6) Distribution Phase: Finalizing the application build, packaging it for distribution across target devices, and deploying it for classroom instruction while collecting long-term user feedback for future software iterations.

Design

The Design phase produced a structural and visual blueprint for EduBody. The user interaction flow was mapped using a Use Case Diagram in Figure 1 and an Activity Diagram in Figure 2, illustrating interactions between students, teachers, and the AR system. The teacher controlled the AR learning session and presented quizzes, while students scanned markers, observed 3D organs, and answered quizzes.

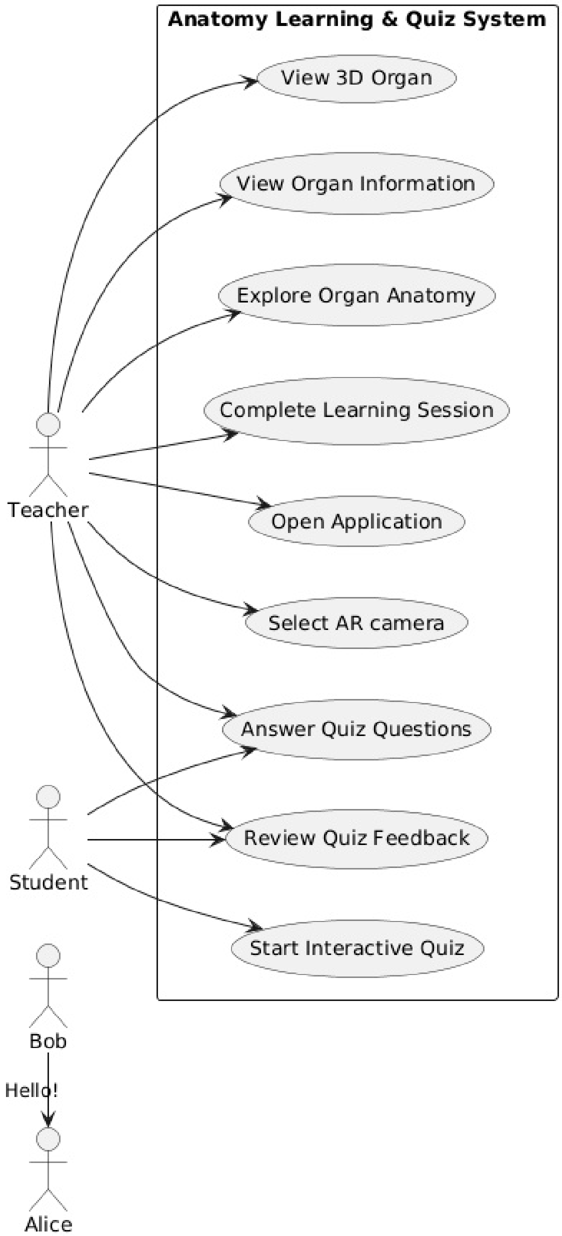

Figure 1. UML use case diagram of Edubody.

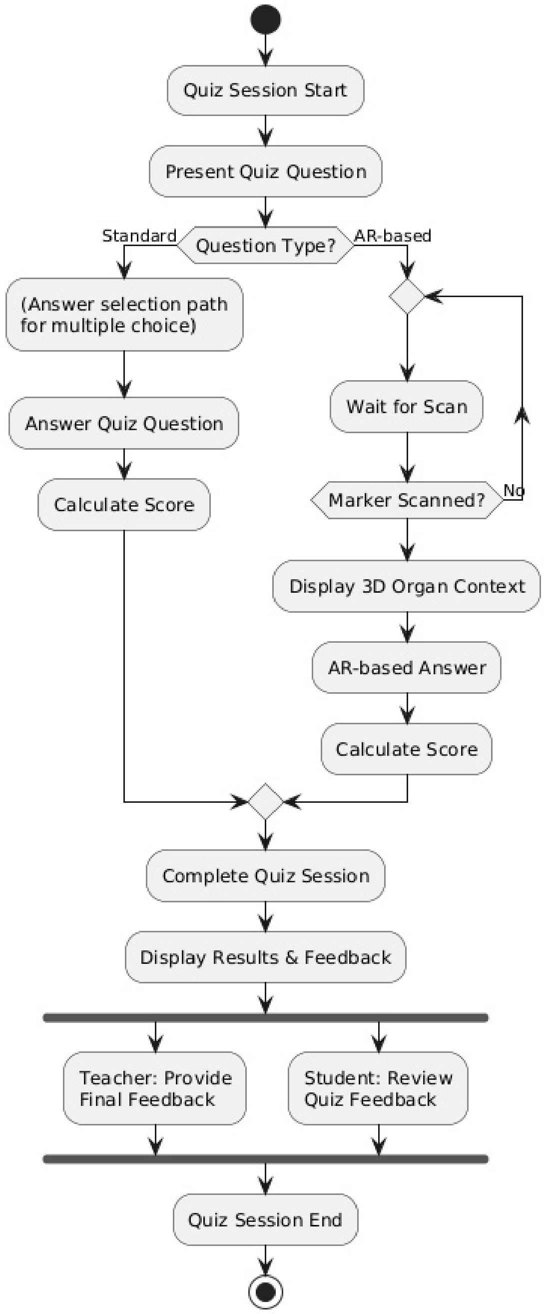

Figure 2. Activity diagram of Edubody.

The user interface uses a medical-educational visual language with clean colors (blue, white, and red), large icons, and intuitive navigation. The design includes seven scenes: SplashScreen, Home, Exploration, ScanAR, Guide, Quiz, and QuizResult. Five physical AR markers were designed for each organ.

Material Collecting

At this stage, we collected and prepared all assets, including 3D organ models (FBX format), royalty-free audio narration, learning materials aligned with the 8th-grade MTS

Table 2. 3D human organ asset list

Organ	Indonesian Name	Primary Function	Audio Source
Heart	Jantung	Pumping blood throughout the body	Royalty-free narration
Lungs	Paru-Paru	Gas exchange (O_2 and CO_2)	Royalty-free narration
Brain	Otak	Central nervous system control	Royalty-free narration
Liver	Hati	Metabolism and detoxification	Royalty-free narration
Kidneys	Ginjal	Filtration and excretion of waste	Royalty-free narration

science curriculum, and UI graphic assets. Table 2 presents the five 3D organ assets used.

Assembly

The Assembly phase is the core development phase where all materials are integrated into EduBody using Unity 3D 2022.3 LTS and the Vuforia SDK (Christian, 2023). Table 3 presents the resulting components.

Distribution

The distribution package consists of the EduBody Android APK (com.edubody.ar, minimum API 38, ARM64 architecture) and a printed AR marker booklet containing five Image Targets along with a summary of the human body organ system material for grade VIII students of MTS Labbaika.

Table 3. Assembly stage output

No.	Component	Description	Status
1	User Interface (UI)	Seven screens: Splash Screen, Home, Exploration, ScanAR, Guide, Quiz, and Quiz Results. The design has a medical-educational theme.	Integrated
2	Application Navigation	Start button, back button, organ selection, previous/next navigation, volume controls, and navigation bar.	Integrated
3	AR Module	Integration of the Vuforia SDK with five image targets. The ARController script manages the 3D organ display, audio narration, and information banners for each marker.	Integrated
4	3D Organ Models	Animator Controller for five organ models with highlight and rotation animations from FBX files.	Integrated

5	Audio Narration	Descriptive audio narration for five organs, triggered automatically when a marker is detected.	Integrated
6	Information Banner	The overlay panel displays the organ's name, structure, and main functions; it updates based on the selected organ.	Integrated
7	Quiz Feature	10 multiple-choice questions with a 30-second timer, answer confirmation, score calculation, and review in the Quiz Results scene.	Integrated

Instruments and Assets

The development and evaluation of the EduBody application rely on both hardware/ software assets and data collection instruments. Digital Media Assets: Three-dimensional models of five vital organs (heart, lungs, brain, liver, and kidneys), custom motion animations, high-resolution AR target markers, descriptive audio narration tracks, and interactive quiz item banks. Data Collection Instruments: (1) Expert Validation Sheets: Structured Likert-scale questionnaires used by content and media experts to rate the technical stability, visual quality, and pedagogical relevance of the software. (2) Usability & Motivation Questionnaires: Student survey forms designed to measure user satisfaction, ease of use, and learning engagement. (3) Conceptual Achievement Tests: Pre-test and post-test instruments constructed to evaluate student learning outcomes and conceptual understanding before and after interacting with the EduBody application.

Conceptual Achievement Tests

Pre-test and post-test instruments were constructed based on a formal test specification blueprint mapping Bloom's Revised Taxonomy across levels C1 to C4. The test blueprint ensured a balanced distribution between lower-order cognitive skills (C1–C2: factual recall and structural comprehension) and higher-order cognitive skills (C3–C4: functional application and sub-system structural analysis) related to human organ systems. Two biology education experts pre-verified the content validity of the 10-item instrument (Aiken's V = 0.87), and pilot testing confirmed internal consistency (N = 30, KR-20 = 0.84). The mapping of each test item to its respective learning indicator and Bloom's cognitive dimension is detailed in Table 1.

Table 1. Test blueprint and mapping of Bloom's cognitive taxonomy

Item No.	Sub-Topic / Target Organ	Specific Learning Indicator	Target Cognitive Level (Bloom's)	Rationale / Cognitive Task
Q1	Liver System	Differentiate the liver's secondary metabolic/detoxification functions beyond digestive bile secretion.	C2 (Understanding)	Requires conceptualizing metabolic processes beyond primary digestion.
Q2	Circulatory System	Identify the primary muscular organ responsible for systemic blood propulsion.	C1 (Remembering)	Tests direct factual recall of organ function.
Q3	Digestive / Liver	Identify the specific digestive organ secretion responsible for lipid processing.	C2 (Understanding)	Connects organ secretions to specific nutrient-breakdown roles.

Q4	Digestive Mechanics	Apply physiological principles of bile emulsification in fat digestion dynamics.	C3 (Applying)	Applies biochemical concepts to digestive physiological contexts.
Q5	Nervous System	Recall the primary organ acting as the command center for somatic and neural activities.	C1 (Remembering)	Tests direct factual recall of central nervous system roles.
Q6	Respiratory System	Explain the structural function of alveoli microstructures in pulmonary gas exchange.	C2 (Understanding)	Demonstrates understanding of structural-functional relationships in respiration.
Q7	Urinary System	Recall basic anatomical quantity and bilateral distribution of kidneys in the human body.	C1 (Remembering)	Tests direct anatomical factual recall.
Q8	Nervous System (Brain Sub-regions)	Analyze structural subdivisions of the brain to differentiate the specific role of the cerebellum in somatic motor coordination.	C4 (Analyzing)	Differentiates sub-regional functional mechanics within a complex organ.
Q9	Urinary System	Apply operational principles of renal filtration and waste excretion in urine formation.	C3 (Applying)	Applies dynamic physiological principles of fluid filtration.
Q10	Cardiac Architecture	Identify the internal anatomical segmentation and chamber structure of the human heart.	C2 (Understanding)	Demonstrates structural understanding of cardiac anatomy.

Dataanalysis

The data collected during the engineering, validation, and field-testing phases of the EduBody application are analyzed using both descriptive and inferential quantitative techniques, complemented by qualitative feedback for software refinement:

Analysis of media validity and practicality (descriptive quantitative analysis)

Data obtained from expert validation instruments (subject-matter and media experts) and student usability questionnaires using Likert scales are analyzed using quantitative descriptive statistics. The resulting percentage (*P*) is interpreted according to standard eligibility criteria (e.g., 81%-100% as Very Valid/Practical, 61%-80% as Valid/Practical) to determine whether the EduBody application meets the requirements for classroom implementation.

Analysis of educational effectiveness (inferential quantitative analysis)

To measure the impact of the EduBody application on students' conceptual understanding, pre-test and post-test scores are evaluated using two analytical approaches: (1) Normalized Gain (*N*-gain) Score was used to measure the extent of conceptual improvement before and after the intervention; g represents the *N*-gain value, S_{post} is the post-test score, S_{pre} is the pre-test score, and S_{max} is the maximum achievable test score. The resulting g value is classified into criteria (High: $g > 0.7$; Medium: $0.3 \leq g \leq 0.7$; Low: $g < 0.3$). (2) Paired-Sample *t*-Test: Following normality and homogeneity tests, a paired-sample *t*-test is performed at a significance level of $\alpha = 0.05$ to determine whether the application produces a statistically significant improvement in student learning outcomes compared to baseline scores.

Qualitative revision analysis

Qualitative data consisting of verbal feedback, constructive critiques, and explicit revision notes provided by validators during the alpha-testing phase are systematically categorized. These inputs are analyzed descriptively to guide refinements to the 3D assets, user interface, audio narration, and system performance before final deployment.

■ RESULT AND DISCUSSION

Development and Validity of the EduBody Application

The resulting product is the EduBody application: an AR-based interactive learning media for the human body's organ systems designed for eighth-grade students at MTs Labbaika. The application displays five animated 3D organ models (heart, lungs, brain, liver, and kidneys), each accompanied by an information panel, descriptive audio narration, and an interactive quiz. To evaluate software performance, content accuracy, and usability prior to full classroom implementation, a two-tiered evaluation protocol (Alpha and Beta Testing) was executed: (1) Subject Matter Validation: Two Natural Science educators evaluated the accuracy of the 3D organ anatomical models, terminology precision, and quiz item alignment with the MTs science curriculum. Content validity achieved an average score of 88.5% ("Very Valid"). Minor terminology adjustments recorded in the Validation Audit Matrix were addressed before field deployment. (2) Media & Technical Validation: Two educational technology specialists audited 3D render responsiveness, user interface (UI/UX) ergonomics, audio-visual synchronization, and AR marker-tracking stability under varying lighting conditions. Media validity averaged 91.2% ("Very Valid"). (3) Student Usability Trial: Following expert sign-off, a field trial with N=38 students yielded a practicality score of 89.4% ("Very Practical"), proving that the application interface is clear, intuitive, and accessible for target users. Rigorous expert validation of this kind is particularly warranted given that meta-analytic evidence on AR in anatomy education reports considerable heterogeneity in learning outcomes across studies, indicating that careful instructional design and content verification, rather than the AR medium alone, are decisive for educational effectiveness (Salimi et al., 2024).

Effectiveness of EduBody on Students' Conceptual Understanding

To measure the educational effectiveness of the EduBody application, pre-test and post-test scores from N=38 eighth-grade students were quantitatively analyzed. Raw scores from the 10-item assessment were converted to a 100-point scale for standardized gain analysis. A standardized pre-test established a baseline benchmark score of X_{pre} = 42.50 ± 8.12. A Shapiro-Wilk test of normality (p = 0.215 > 0.05) confirmed that student baseline scores were normally distributed, verifying sample homogeneity prior to AR application exposure. Following learning sessions using EduBody, student post-test scores increased substantially (Xpost = 84.20 ± 6.45). S_{post} is the post-test score (84.20), S_{pre} is the baseline score (42.50), and S_{ideal} is the maximum achievable score (100). The resulting gain score was g = 0.725, placing the conceptual improvement in the High gain category (g > 0.70). A paired-sample t-test confirmed that the increase in conceptual scores was statistically significant (t (37) = 24.18, p < 0.001).

Pre-Test Operational Procedure

Prior to the instructional intervention using the EduBody application, a pre-test was administered to measure the 38 participants' baseline conceptual understanding of human organ systems. The pre-test was executed through the following operational steps: (1) Preparation and Environmental Control: Students were seated individually in a standard classroom setup to ensure independent work. Before distributing the test materials, the instructor briefed the students on the test rules, emphasizing that no textbooks, notes, visual aids, or digital devices were permitted. (2) Instrument Distribution: Each student received a physical paper-based test consisting of 10 multiple-choice questions designed to assess their initial knowledge of internal organ structures and physiological functions. (3) Execution and Monitoring: Students were allotted 15 minutes to complete the assessment independently. The researcher and the classroom science teacher closely invigilated the session to maintain assessment integrity. (4) Collection and Scoring: Immediately upon completion of the time limit, all test papers were collected, coded for anonymity, and scored using a standardized rubric to record the baseline dataset for subsequent normality (Shapiro-Wilk) and effectiveness analyses.

Multimodal AR Integration and Pedagogical Implications

The empirical findings confirm that integrating animated 3D organ models with descriptive audio narration effectively addresses the instructional limitations of conventional two-dimensional textbook images

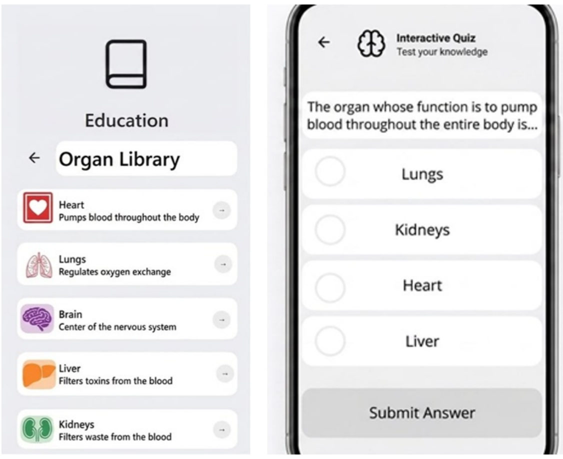

Figure 3. Exploration/organ selection screen and AR scan screen lungs and quiz question screen

(Susanti, 2025; Prafitasari et al., 2026). Static diagrams often fail to illustrate dynamic physiological mechanisms such as cardiac pumping or alveolar gas exchange, causing students to rely on rote memorization rather than deep conceptual understanding. This finding reinforces conclusions drawn from a broader review of AR adoption in Indonesian science classrooms, which reports consistent gains in students' conceptual understanding, motivation, and learning outcomes when animated, interactive content replaces static two-dimensional media (Fitriyana et al., 2026).

By projecting dynamic, interactive 3D motion models into physical space, EduBody renders abstract anatomical concepts concrete and accessible. This multimodal approach aligns directly with Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2022). Activating visual and auditory channels simultaneously reduces cognitive load and enhances long-term knowledge retention. Combining marker-based 3D visualization with interactive quizzes fosters active learning, transforming passive listeners into engaged participants. This mirrors evidence from a domestic AR implementation study, in which replacing conventional instructional media with an interactive AR application produced a substantially higher average learning outcome for the treatment group than for the non-treatment group (Firmansyah et al., 2025).

Figure 3 shows the interface for the material exploration feature and the implementation of Augmented Reality (AR) in the app, which consists of two main screens: the Organ Selection Screen on the left and the AR Scan Screen (Lungs) on the right. On the left screen (Organ Library), there is a complete library of human organs, complete with names, visual icons, and brief descriptions of their functions such as Heart (Pumps blood throughout the body), Lungs (Regulates oxygen exchange), Brain (Center of the nervous system), Liver (Filters toxins from the blood), and Kidneys (Filters waste from the blood). Meanwhile, the right-hand view shows the AR camera feature in action on a smartphone; when the scanner is aligned with the marker for the Lungs, the app interactively projects a 3D model of the lungs and the trachea onto the drawing paper.

The interface for the Interactive Quiz (Test Your Knowledge) feature in the mobile app, which is designed to test users' understanding of the functions of the body's organs. At the top of the screen is the quiz header, complete with a back button and a brain icon, followed by a question box that reads, "The organ whose function is to pump blood throughout the entire body is...". Below the question are four answer choices as radio buttons: Lungs, Kidneys, Heart, and Liver. The quiz concludes with a "Submit Answer" button at the bottom of the screen to submit the selected answer.

Field Testing Documentation

Field testing was conducted at MTS Labbaika with 38 eighth-grade students. Supervised by subject teachers, the session involved students scanning printed AR markers and observing animated 3D human organs, followed by an interactive quiz. Figure 4 documents the field testing process.

Figure 4. An AR demonstration by the research team, students activities, and worksheets distribution.

Table 4. Internal testing results

No.	Feature Tested	Expected Result	Actual Result	Status
1	Marker Scanning	The camera detects the AR marker and triggers the 3D organ display.	All five Image Targets detected correctly; 3D organs appear on detection.	Pass
2	3D Navigation (Prev/Next)	Buttons switch between organ models.	Organs switch correctly, inactive organs hidden.	Pass
3	Animation Playback	Highlight animation plays automatically for each organ.	Animator Controllers execute animations correctly on all five models.	Pass
4	Audio Narration	Organ audio triggers on detection and updates on navigation.	Audio triggers and updates correctly per organ.	Pass
5	Information Banner	Banner shows organ name, structure, and function; updates on navigation.	Banner appears, hides, and updates correctly.	Pass
6	Quiz (10 Questions)	All 10 questions display with a 30-second timer; results shown in HasilKuis.	Quiz logic, timer, confirmation alert, and score calculation work correctly.	Pass
7	Quiz Results Display	Score, percentage, and answer review display correctly.	All result elements display based on stored data.	Pass
8	UI Navigation	All navigation buttons and scene transitions function correctly.	Scene transitions operate without errors across all 7 scenes.	Pass
9	APK Installation	APK installs and runs on Android (min API 27).	APK installs and launches correctly on test devices.	Pass

Internal Testing Results

Internal testing confirmed that all core features function correctly, with no significant defects. The functional testing results are presented in Table 4.

Quiz Results

Figure 5 presents a 100% stacked bar chart comparing the distribution of student cognitive mastery, categorized as Correct (Mastered) and Incorrect (Unmastered), across the 10 organ system topics before and after the EduBody AR intervention (*N* = 38). As shown in the baseline benchmark (Pre-Test), students' initial mastery was generally low across most topics, with 7 out of 10 items scoring below a 45% correct response rate. Following exposure to the EduBody application (Post-Test).

After completing the AR exploration session, students took a self-developed 10-item multiple-choice quiz (Bloom's C1–C4) embedded within EduBody. The instrument was pre-validated for content accuracy by two experts (Aiken's V = 0.87) and demonstrated high internal consistency reliability through pilot testing (*N* = 30, KR-20 = 0.84). Table 5 presents the performance results per question.

The development of the EduBody app has proven effective in enhancing eighth-grade MT students' understanding through an immersive, multimodal Augmented Reality (AR)- based learning approach (Mucti et al., 2025). This effectiveness is anchored in Richard E. Mayer’s Cognitive Theory of Multimedia Learning, where visual and auditory information is processed through separate working memory channels (Mayer, 2022). To minimize extraneous cognitive friction during visual information processing, EduBody incorporates specific instructional UI/UX design principles rather than relying on unmeasured assertions about cognitive load. Spatial contiguity and signaling are realized by positioning textual labels directly adjacent to 3D organ models with visual color-highlighting, thereby eliminating split-attention effects. Modality and segmenting principles are applied by delivering complex internal mechanisms through synchronized audio narration paired with user-paced 3D interactive modules, effectively balancing dual-channel processing. Employing such explicit, theory-driven UI/UX principles, rather than relying on general cognitive-load assumptions, is consistent with recommendations from a systematic review of AR science-education research, which found that studies grounding their instructional design in established multimedia-learning principles tend to report more consistent and interpretable learning gains (Zufahmi et al., 2025).

Table 5. Quiz results per question (n = 38)

No.	Question Topic	Baseline Benchmark	Quiz Score	Remarks
1	Apart from producing bile, what else does the liver function to do?	24/38	25/38	+1
2	Which organ functions to pump blood throughout the body?	15/38	36/38	+21
3	Which organ functions to produce bile for fat digestion?	10/38	30/38	+20
4	Which organ functions to store glycogen and neutralize toxins in the body?	9/38	22/38	+13
5	Where is the control center for all body and nervous system activities located?	11/38	35/38	+24

6	The small sacs in the lungs where gas exchange occurs are called	12/38	33/38	+21
7	Do humans have several kidneys in their body?	16/38	38/38	+22
8	Which part of the brain regulates balance and coordination of body movements?	12/38	4/38	−8
9	Which organ is responsible for filtering blood and producing urine?	24/38	36/38	+12
10	The human heart consists of several chambers.	15/38	34/38	+19

The immersive nature of the AR technology used in EduBody provides a more concrete learning experience than conventional methods that rely on two-dimensional images in textbooks (Rustanto, 2025). Students can interact directly with virtual human organs, view internal structures from various angles, observe simulations of organ functions such as the heart's pumping action or the respiratory system, and test their understanding firsthand. This interactivity clarifies complex abstract concepts and fosters strong learning enthusiasm. Rather than assuming student motivation from ungrounded participation observations, this positive affective engagement is empirically supported by the Student Practicality Response Questionnaire (*N* = 38). The evaluation yielded an overall score of 89,4% ("Very Practical"), with students specifically expressing high satisfaction, interest, and enthusiasm toward the interactive 3D AR organ exploration features. This pattern is consistent with a recent review of AR use in Indonesian biology education, which reports that AR-based interventions reliably increase students' interest, engagement, and satisfaction alongside measurable gains in conceptual understanding (Hallaby & Syahputra, 2024).

Integrating interactive AR media with the theoretical foundations of cognitive multimedia makes EduBody a highly effective learning tool for middle school students (Septiani, 2025). This multimodal learning approach has been shown to facilitate the formation of more robust mental models that are retained in students' long-term memory, ultimately leading to improved learning outcomes and a comprehensive understanding of human anatomy (Li, 2024). At the same time, international meta-analytic findings caution that not all AR interventions yield uniformly strong effects on knowledge retention compared with virtual reality or conventional methods, underscoring the importance of

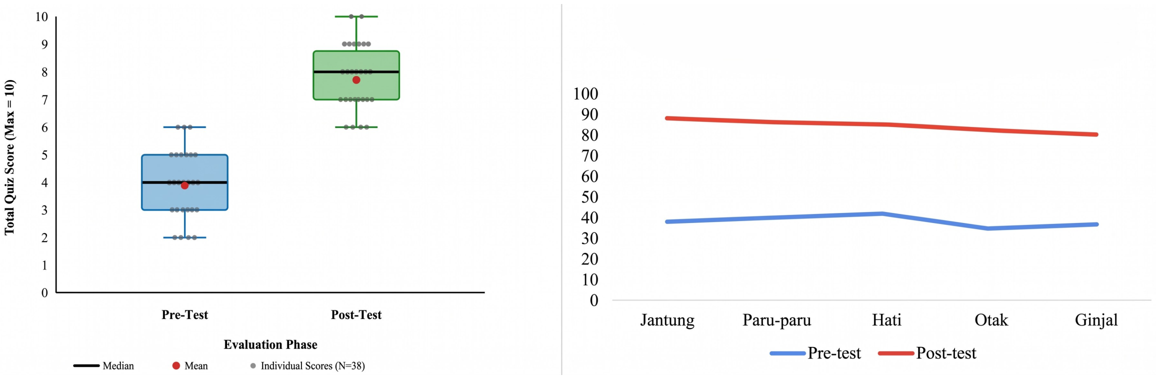

Figure 5. Distribution of total quiz scores and trends in changes in correct answers by organ topic in the pretest and posttest phases.

continued empirical validation, such as that provided by this study, rather than assuming AR's benefits are automatic (Garcia-Robles et al., 2024).

Score Distribution and Outlier Analysis

To evaluate score dispersion and verify data assumptions, a paired boxplot analysis was conducted on total student performance (N = 38). As illustrated in Figure 5, pre-test scores showed a lower median (M = 4.00, M_{mean} = 3.89) with scores bounded between 2.0 and 6.0. Following the EduBody AR intervention, post-test scores exhibited a marked upward displacement in central tendency, achieving a median of 8.00 (M_{mean}= 7.71) and a maximum score of 10.0. Interquartile range (IQR) comparison demonstrated a shift from (IQR) = 2.00 in the pre-test to (IQR) = 1.75 in the post-test, reflecting improved knowledge convergence across the cohort. Boxplot inspection confirmed zero severe or mild outliers in both conditions, supporting homogeneity and distributional suitability for paired parametric evaluations.

■ CONCLUSION

EduBody was developed as an AR-based interactive learning application for eighth-grade MTs students, covering five primary human organ systems: the heart, lungs, brain, liver, and kidneys. Developed through the six stages of the Multimedia Development Life Cycle (MDLC), all core features functioned properly on Android 8.1 (API 27) and above during internal testing. Field testing with 38 students at MTs Labbaika showed statistically significant cognitive improvement, with average scores increasing from 42.50 ± 8.12 on the pre-test to 84.20 ± 6.45 on the post-test, achieving a mean cognitive N-gain of 0.725 (categorized as High) relative to the baseline comprehension benchmark. These empirical findings confirm that EduBody is highly effective in improving students' cognitive comprehension of basic human organ functions. Future development should incorporate a User Experience Questionnaire (UEQ) evaluation, expand implementation across multiple schools, and explore advanced AR features such as voice-based interactions and adaptive quizzes.\

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