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BloodFlowAR: Development of an Augmented Reality Application as a Visual Learning Medium for the Human Blood Circulation System

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ABSTRACT

The human blood circulation system is one of the most abstract and challenging topics for elementary school students, as it involves internal organs and processes that cannot be directly observed. Traditional teaching methods such as textbooks and two-dimensional diagrams are often insufficient to provide meaningful understanding. This study aims to develop BloodFlowAR, an Android-based augmented reality (AR) application built in Unity, designed as an interactive visual learning medium for Grade 5 elementary students. The development followed the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). The application enables students to visualize the blood circulation system in three dimensions by scanning a marker card, displaying animated 3D models of the heart, blood vessels, and blood flow direction in real time. Data were collected through expert validation questionnaires (media and material validators), practicality questionnaires (teacher and student responses), and learning outcome tests (pretest and posttest). The validity test results showed that the media validator gave a score of 92.5% and the material validator gave 95.0%, both categorized as very valid. Practicality test results showed teacher responses of 90.6% and student responses of 91.7%, both categorized as very practical. The media's effectiveness was evaluated using the N-Gain formula, which produced a value of 0.37, categorized as moderate improvement. These results indicate that BloodFlowAR is valid, practical, and moderately effective as a visual learning medium for the human blood circulation system at the elementary school level.

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INTRODUCTION

The rapid advancement of information and communication technology has significantly transformed education, enabling more interactive, visual, and meaningful learning experiences (Alam & Mohanty, 2023). In elementary science education, students are expected to develop a foundational understanding of natural phenomena, including human body systems. Several topics in life science education remain particularly challenging to teach and learn because of their abstract and invisible nature (Jones & Burrell, 2022).

Among these topics, the human blood circulation system consistently challenges Grade 5 elementary school students. The circulatory system involves complex, dynamic processes that occur inside the body and cannot be directly observed, making it difficult for students to visualize how blood flows, the role of the heart chambers, the distinction between oxygenated and deoxygenated blood, and the function of different types of blood vessels

(Hasanah, 2022). Conventional learning approaches that rely on textbooks and static two-dimensional illustrations are often insufficient to convey these dynamic biological processes in an engaging and comprehensible manner (Munib et al., 2025).

Augmented reality (AR) is an emerging technology that superimposes digital content, such as three-dimensional models, animations, and text, onto the real-world environment through a device camera, enabling learners to interact with virtual objects as if they were present in their physical surroundings (Dargan et al., 2023; Pallavicini & Anesa, 2026). Unlike virtual reality, AR does not require dedicated hardware and can run on widely available Android smartphones and tablets, making it an accessible and cost-effective solution for Indonesian schools (Friani & Nishida, 2025). Several studies have demonstrated the positive impact of AR-based learning media on student engagement, comprehension, and learning outcomes in science subjects (Latif et al., 2024; Sattar et al., 2025).

Previous studies have reported that augmented reality learning media can significantly improve students' understanding of the human blood circulation system and offer high practicality for classroom implementation. Preliminary empirical data collected from Grade 5 elementary school students revealed a critical learning gap during pre-research observations. Based on initial formative assessment data on the human circulatory system, only 35% of students met the Minimum Mastery Criterion, and the overall class average score remained low at 62.5 (out of 100). As a result, 65% of students failed to reach the passing standard because they struggled to visualize dynamic circulatory processes through static textbook diagrams. Most existing AR educational applications for biology are designed for secondary or higher education levels and are not specifically tailored to the vocabulary, visual style, and cognitive level of elementary school students (Akbar et al., 2024; Barmaki et al., 2023). An intervention using age-appropriate AR media is urgently needed to address this learning gap.

This study aims to develop BloodFlowAR, a marker-based augmented reality application for Android built using the Unity game engine, designed specifically for Grade 5 elementary school students in Indonesia. The development process follows the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), which provides a systematic and structured framework for producing valid, practical, and effective educational media (Martatiyana et al., 2023; Adeoye et al., 2024). The application features an animated 3D model of the human blood circulation system, interactive organ information, and a quiz feature for self-evaluation (Castellano, 2024).

Czok et al. (2023) formulate a framework based on seven design parameters (such as interactivity, complexity, and game elements) to analyze and design Augmented Reality (AR) applications in Science and Engineering education. The study emphasizes the importance of creating didactics-driven AR applications that prioritize pedagogical value and concept comprehension rather than purely technology-driven ones that merely rely on fancy 3D visuals. Based on this pedagogical imperative, this study addresses the following research questions: (1) How is a marker-based AR application for learning the human blood circulation system developed for Grade V elementary school students? (2) How valid is the developed AR application based on media and subject-matter expert evaluations? (3) How practical is the application according to teacher and student responses? (4) How effective is the application in improving student learning outcomes? Consequently, the objectives of this research are: (1) To develop a marker-based AR application for learning the human blood circulation system targeted at elementary school students; (2) To evaluate the validity of the application through expert validation by media and material validators; (3) To assess the practicality of the application through teacher and student response questionnaires; and (4) To measure the effectiveness of the application on student learning outcomes using the N-Gain formula. This research contributes to the development of AR-based educational technology that makes abstract biological concepts more tangible, engaging, and accessible for young learners.

■ LITERATURE REVIEW

Many studies have explored integrating augmented reality into educational settings at various levels. Conducted a comprehensive review of AR in education identified that AR applications demonstrated significant advantages in improving spatial understanding, engagement, and knowledge retention in science subjects (AlGerafi et al., 2023). A systematic review covering 68 studies concluded that AR consistently enhanced student motivation and learning outcomes; the authors noted that technical difficulties and lack of teacher training remained persistent barriers to adoption.

Friani & Nishida (2025) reviewed AR case studies across multiple educational levels and highlighted that while most AR implementations focused on secondary and higher education, elementary applications remained underrepresented in the literature. This observation aligns with Hasanah (2022), who systematically reviewed AR game-based learning in K-12 education and found that most studies targeting elementary students focused on mathematics and language arts rather than life sciences. These findings indicate a notable research gap in AR-based biology learning media for elementary school contexts (Stanič & Špernjak, 2025).

In biology education specifically, Akbar et al. explored the use of AR for learning human body systems at the middle school level and found that AR-based instruction produced statistically significant improvements in conceptual understanding compared to traditional methods. Liu et al. (2024) reported that elementary students exposed to AR science learning media achieved higher academic scores and demonstrated greater intrinsic motivation than those in control groups. Both studies were conducted outside the Indonesian educational context, limiting their direct applicability to local curriculum requirements and student characteristics.

Several studies have examined AR-based learning media for elementary science using marker-based and simulation approaches. Nikimaleki & Rahimi (2022) investigated marker-based AR in elementary science classes and demonstrated that students using AR achieved significantly higher posttest scores than counterparts using conventional methods. Alpariji (2025) further reported that AR applications specifically designed for young learners featuring simplified interfaces, child-appropriate visual design, and age-suitable terminology produced superior engagement and learning outcomes compared to adult-oriented adaptations. Despite these contributions, none of the reviewed studies specifically address the human blood circulation system topic at the Grade V elementary level with a validated ADDIE-based development process.

The research gap addressed by this study can be summarized as follows: (1) the absence of a validated, specifically designed AR application for the blood circulation system topic in the Indonesian Grade V elementary school context, (2) the lack of rigorous ADDIE model-based development with dual expert validation in existing related AR media and (3) limited empirical effectiveness evidence using the N-Gain framework in this subject domain and target population. BloodFlowAR is developed to address these gaps directly by combining a structured ADDIE development process with field-based empirical validation involving real elementary school students.

■ METHOD

Research design and procedures

This study employs the Research and Development (R&D) method, which is a systematic research approach designed to develop new products or improve existing ones while testing their feasibility (Umar et al., 2023). This research used the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Martatiyana et al., 2023). This model was selected because it provides a structured, iterative process that ensures the resulting product is theoretically valid, practically usable, and effective in improving student learning outcomes.

Analyze

The analysis phase comprised a needs assessment and a curriculum analysis to establish the foundation for application design. The needs assessment was conducted through direct classroom observations, semi-structured interviews with the science teacher, and preliminary student questionnaires. The findings indicated that students engage more actively and comprehend abstract concepts more effectively when supported by interactive visual media. A curriculum analysis was conducted based on the Grade 5 science curriculum to ensure the application content aligns with the relevant learning objectives and competency indicators.

Design

At the design stage, the overall structure and user interface of the BloodFlowAR application were planned. A storyboard was developed to map the flow from the splash screen and main menu to the AR view, organ information popups, and quiz feature. The 3D model specifications for the heart, arteries, veins, capillaries, and animated blood flow particles were outlined. The marker card design, featuring a unique recognizable pattern, was also created at this stage. The target user interface was designed to be simple, colorful, and appropriate for the reading level and attention span of Grade 5 elementary school students.

Development

The development stage involved realizing the design into a functional application. BloodFlowAR was built using the Unity game engine with the Vuforia SDK integrated for marker-based AR tracking. Three-dimensional models of the heart and blood vessels were imported and animated using Unity's Animator component. Particle systems simulated blood flow direction, with red particles representing oxygenated blood and blue particles representing deoxygenated blood. C# scripts handled marker detection, popup display logic, and quiz functionality. After completing the initial build, the application was submitted to expert validators for review. Validation was conducted by a media expert and a material expert using structured questionnaire instruments. Revisions were made based on validator feedback prior to field implementation.

Implementation and Research Participants

The implementation stage involved deploying the application in a real learning context with 29 Grade 5 students selected via purposive sampling. The participants met specific inclusion criteria: (1) actively enrolled in Grade 5, (2) capable of operating Android-based mobile devices, and (3) present during all pretest, intervention, and posttest sessions. To ensure baseline homogeneity in students' prior knowledge, all participants shared the same standardized educational background, having completed identical Grade 4 foundational science materials with comparable prior academic scores. The application was installed on Android devices and used by the 29 students during a science lesson on the blood circulation system. Prior to the learning session, students completed a pretest to measure their initial understanding of the topic. After using the BloodFlowAR application for approximately 15 minutes, students completed a posttest consisting of 10 multiple-choice questions covering the same material. Teacher and student practicality questionnaires were also distributed during this stage to gather feedback on the application's usability and appeal.

The implementation stage involved deploying the application in an intact learning context with an accessible population of 29 Grade 5 elementary school students (N = 29). To address sampling accuracy and avoid misclassifying basic operational prerequisites as purposive selection criteria, total sampling (saturated sampling) was adopted for this intact class. All enrolled students present during the intervention were included as participants, thereby eliminating selection bias within the target class and reflecting authentic classroom dynamics.

Evaluation

The evaluation stage involved analyzing all collected data. The application's effectiveness was measured by comparing pretest and posttest scores using the N-Gain formula (Fathurohman et al., 2023). Expert validation scores and practicality questionnaire scores were analyzed using the percentage formula to determine the application's validity and practicality categories.

Instrument

Data were gathered using three types of research instruments: (a) expert validation questionnaire sheets completed by the media validator and material validator; (b) practicality questionnaire sheets completed by the classroom teacher and students; and (c) pretest and posttest instruments consisting of 10 multiple-choice questions on the human blood circulation system (Ratnawati et al., 2026). The 10-item test instrument was self-developed based on the Grade 5 science learning indicators and underwent a preliminary try-out with non-sample Grade 5 students. Its content validity was confirmed by subject-matter experts, while item validity and internal consistency reliability were statistically verified (Cronbach's $\alpha > 0.70$). The validity and practicality data were calculated using the following percentage formula (Martatiyana et al., 2023).

The criteria for the validity and practicality of the developed learning media are categorized into four distinct levels based on the percentage score range. Learning media achieving a score range of 81%–100% are classified as Very Valid or Very Practical. A score range of 61%–80% falls under the Valid or Practical category. Meanwhile, scores ranging from 41%–60% are categorized as Less Valid or Less Practical, and any percentage score ≤ 40% indicates that the media is Invalid or Impractical. The effectiveness of the application was evaluated using the N-Gain formula to measure the improvement in student learning outcomes before and after using BloodFlowAR.

The improvement level of student learning outcomes based on the Normalized Gain (N-Gain) values is classified into three distinct categories. Learning outcomes are categorized as High Improvement if the obtained N-Gain value is greater than 0.7 (N-Gain > 0.7). The improvement is considered Moderate Improvement when the N-Gain value falls within the range of 0.3 to 0.7 (0.3 ≤ N-Gain ≤ 0.7). An N-Gain value of less than 0.3 N-Gain < 0.3) indicates a Low Improvement in learning outcomes.

The thematic concept map in Figure 1 categorizes expert validators' qualitative feedback into three primary themes to guide the

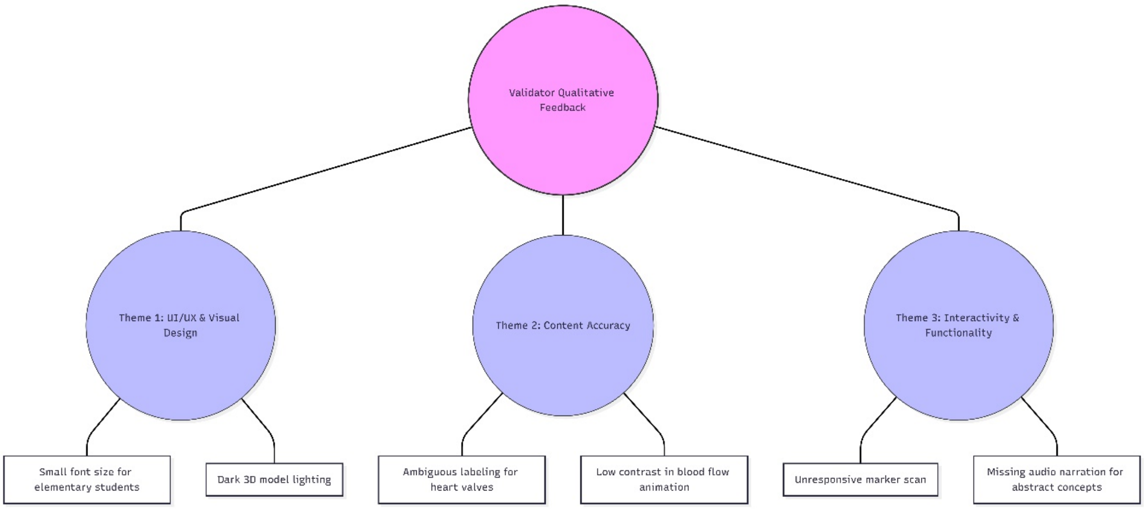

Figure 1. Thematic map of qualitative feedback and revision categories from expert validators

iterative revision of the BloodFlowAR application. UI/UX & Visual Design addresses aesthetic and visual accessibility adjustments, specifically increasing the font size for elementary students and improving dark 3D model lighting to ensure optimal readability. Content Accuracy focuses on pedagogical precision by correcting ambiguous labeling for heart valves and improving the low-contrast blood flow animation to clearly differentiate oxygenated and deoxygenated blood streams. Interactivity & Functionality targets technical optimizations, including fixing unresponsive marker scanning and incorporating missing audio narrations to help young learners better grasp abstract biological concepts.

Data analysis

The collected data were analyzed using both descriptive quantitative and inferential/gain analysis methods. For the validity and practicality analysis, percentage scores obtained from the expert validation sheets and participant response questionnaires were averaged and categorized into predefined validity and practicality criteria. For the effectiveness analysis, student learning outcomes were evaluated by calculating the Normalized Gain (N-Gain) score from the pre-test and post-test results. The resulting N-Gain score ranges from 0.00 to 1.00 and is interpreted according to Hake’s (1998) criteria to classify the application's effectiveness: $g > 0.70$: High effectiveness; $0.30 \leq g \leq 0.70$: Medium effectiveness; $g < 0.30$: Low effectiveness.

■ RESULT AND DISCUSSION

Analysis Stage

The analysis stage was conducted through teacher interviews and student observations to identify learning needs and challenges related to the human blood circulation system. Based on the results, the classroom teacher confirmed that Grade 5 students frequently struggled with this topic because of its abstract nature. Students could not directly observe blood flowing through their bodies, which made it difficult to understand concepts such as the direction of blood flow, the role of the four heart chambers, and the difference between pulmonary and systemic circulation. The available learning media in the classroom consisted mainly of printed textbooks with static diagrams, which were insufficient to represent the dynamic, three-dimensional nature of the circulatory system. These findings confirmed the need for a more interactive, visual learning medium that could help students build a concrete mental model of blood circulation processes.

Design Stage

Based on the results of the analysis, the design of BloodFlowAR was developed with the following key components: (1) a main menu with buttons for Start AR, Quiz, and About; (2) an AR view that activates the device camera and renders a 3D animated blood circulation model upon detecting the marker card; (3) interactive information popups that appear when the student taps on a specific organ, displaying the organ name and its function; and (4) a quiz feature with 10 multiple-choice questions related to blood circulation. The user interface was designed using a bright, child-friendly color scheme with clear Indonesian-language labels to ensure accessibility for Grade 5 students. The marker card featured a distinctive, high-contrast pattern to ensure reliable detection across various lighting conditions.

Table 1. Expert validation results

No.	Aspect	Score Obtained	Maximum Score	Percentage	Category
1	Cover Design (Marker Card)	16	16	92.5%	Very Valid
	Display & Visual Design	23	24		
	AR Programming & Functionality	19	20		
	Text & Content Presentation	16	20		
2	Content Appropriateness	38	40	95.0%	Very Valid
	Content Presentation	15	16		
	Language Appropriateness	4	4		

DevelopmentStage

The development of BloodFlowAR was completed using Unity version 2021.3 LTS with the Vuforia Engine SDK for augmented reality functionality (Nazri et al., 2024). The 3D heart model was imported and rigged with animation controllers to simulate rhythmic pumping motion. Blood flow was visualized using Unity's particle system, with directional flow paths configured to trace the pulmonary and systemic circulation routes. Red and blue particle colors were used to distinguish oxygenated and deoxygenated blood, respectively. Upon completing the initial build, the application was validated by two expert validators. The results of expert validation are presented in Table 1.

The qualitative evaluations from both validators provided detailed insights into the pedagogical and technical strengths of the BloodFlowAR application. Notably, the Language Appropriateness aspect achieved a perfect rating, as the material validator confirmed that the vocabulary and sentence structures were highly suitable for the cognitive level of Grade 5 elementary students. The terminology was communicated clearly and accessibly, without ambiguous biological jargon, helping young learners understand abstract circulatory concepts without cognitive overload. Additionally, while the media validator affirmed that the AR visual interface was engaging and marker detection functioned reliably, minor revisions were suggested regarding presentation. These included simplifying the vocabulary in the information pop-up cards and integrating explicit labels for blood vessel names directly onto the 3D models. All recommended adjustments were fully incorporated before the field implementation stage.

ImplementationStage

The implementation stage was carried out with 29 Grade 5 students at SDN 002 Loa Janan. Students were given a pretest prior to the learning session, followed by a 15-minute session using the BloodFlowAR application. After the session, students completed a posttest. The posttest consisted of the same 10 multiple-choice questions used in the pretest, covering key concepts of the blood circulation system. Figure 2 shows the blood circulation system diagram used as the AR marker target. Figure 3 shows the quiz screen with 10 multiple-choice questions that appear in sequence to evaluate student understanding.

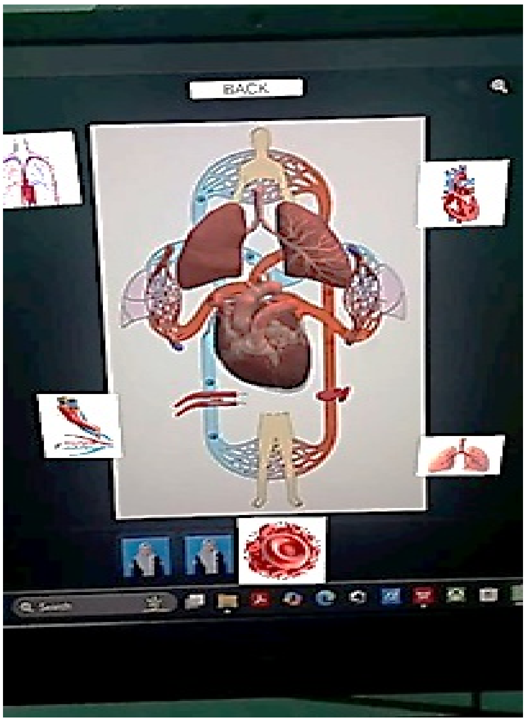

Figure 2. Home screen (main menu)

Figure 3. Quiz display

The implementation phase began with an orientation session and instruction on using the BloodFlowAR application in the classroom. As shown in the figure, the researcher directly guided the students in operating the devices and navigating the interactive learning workflow. The Grade 5 students showed high enthusiasm and closely observed the scanning process demonstration. The learning activity involved scanning the visual markers or target interfaces using a smartphone camera to render 3D models of the human blood circulation system. Through this visual interaction, students could intuitively observe the structure of the heart and the pathways of blood vessels directly at their desks. The following figures document the BloodFlowAR application testing session at SDN 002 Loa Janan, showing Grade 5 students and their teacher interacting with the application in Figure 4.

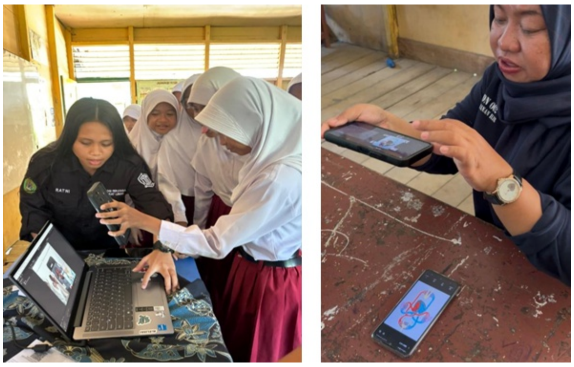

Figure 4. Documentation of Bloodflowar field testing at SDN 002 Loa Janan.

The practicality of the BloodFlowAR application was evaluated through questionnaires distributed to the classroom teacher and students. The results are presented in Tables 2 and 3. To verify the claim of improved cognitive understanding, an item-by-item analysis was conducted across all 10 test items for the 29 participating students, as summarized in Table 4. Prior to using BloodFlowAR, students exhibited low baseline performance on complex abstract concepts, such as tracing pulmonary circulation (Item 6: 20.7%) and differentiating oxygenated from deoxygenated blood (Item 4: 27.6%). Following the intervention, significant cognitive gains were observed across all items, with the class average percentage of correct answers rising from 36.5% (n = 10.6) in the pretest to 84.5% (n = 24.5) in the posttest. The greatest improvement occurred in Item 4 (+62.1%) and Item 5 (+55.2%), confirming that interactive 3D visualizations and color-coded particle flow animations successfully facilitated students' mental representation and conceptual mastery of dynamic biological processes.

Table 2. Teacher practicality response results

Aspect	Score Obtained	Max Score	Category
Content and Material	29	32	Very Practical
Display and Visual Design	31	32	Very Practical
Ease of Use	27	32	Very Practical
Total	87	96	90.6% (Very Practical)

Table 3. Student practicality response results

Respondents	Score Obtained	Maximum Score	Percentage	Category
29	1,595	1,740	91.7%	Very Practical

Table 4. Student correct answer distribution and percentage per test item (n = 29)

Item No.	Learning Indicator / Question Focus	Correct Answer in Pretest (n)	Pretest (%)	Correct Answer in Posttest (n)	Posttest (%)	Gain (%)
1	Identifying main organs of the circulatory system	17	58.60%	27	93.10%	+34.5%
2	Distinguishing heart chambers (atria vs. ventricles)	10	34.50%	25	86.20%	+51.7%
3	Identifying the function of the left ventricle	9	31.00%	24	82.80%	+51.8%
4	Differentiating oxygenated and deoxygenated blood	8	27.60%	26	89.70%	+62.1%
5	Tracing systemic blood circulation path	7	24.10%	23	79.30%	+55.2%
6	Tracing pulmonary blood circulation path	6	20.70%	22	75.90%	+55.2%
7	Identifying the function of blood vessels (arteries)	12	41.40%	25	86.20%	+44.8%
8	Identifying the function of blood vessels (veins)	11	37.90%	24	82.80%	+44.9%
9	Explaining the role of capillaries in gas exchange	7	24.10%	21	72.40%	+48.3%
10	Identifying healthy habits for the circulatory system	19	65.50%	28	96.60%	+31.1%
Mean	**Overall Cognitive Performance**	**10.6**	**36.50%**	**24.5**	**84.50%**	**+48.0%**

EvaluationStage

The evaluation stage analyzed the effectiveness of the BloodFlowAR application by comparing student pretest and posttest scores using the N-Gain formula. The results are presented in Table 5. Students achieved an average pretest score of 42.3, which increased to 63.8 after using the BloodFlowAR application. The resulting N-Gain value of 0.37 falls within the lower boundary of the moderate improvement category (0.30 ≤ N-Gain ≤ 0.70), as established by Rahman et al. (2024). While this indicates a meaningful overall increase in conceptual understanding, particularly for concepts like white blood cell functions (82.8% correct) and blood clotting (79.3% correct), the pulmonary circulation pathway remained exceptionally challenging, with only 41.4% of students answering correctly. From a pedagogical perspective, this modest N-Gain result can be attributed to extraneous cognitive load induced by the visual complexity of the 3D AR environment (Haryadi et al., 2026). Grade 5 elementary students often experience a

Table 5. N-gain learning outcome results

Description	Pretest	Posttest
Overall Average Score	42.3	63.8
Ideal Score	100	
Category	Moderate Improvement	

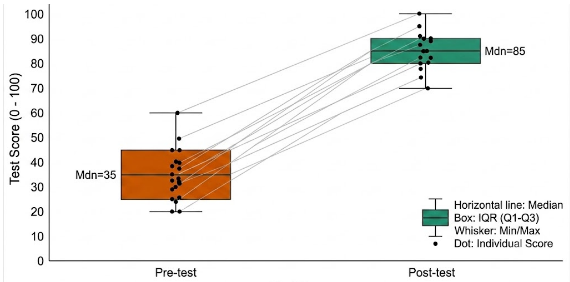

Figure 4. Paired boxplot comparing student pre-test and post-test score distributions (n = 29)

split-attention effect when simultaneously visualizing spatial blood flow dynamics, tracking moving target markers, and reading on-screen textual information. This working memory overload inhibits deep processing of complex circulatory trajectories. (2025), single-session AR deployments frequently yield moderate gains due to novel tech distraction and limited exposure time. To overcome these constraints, the recommended instructional scaffolding (Kim, 2024) must be operationalized through concrete teacher-led interventions: (1) Pre-training: A 5-minute pre-lesson orientation using simplified diagrams to build baseline mental models of core terms; (2) Prompted Signal Guidance: Distributing structured inquiry worksheets during the AR activity with step-by-step visual cues; (3) Fading and Peer Synthesis: Gradually removing software prompts to let students verbally explain the sequence in small peer groups.

■ CONCLUSION

This study successfully developed BloodFlowAR, an Android-based augmented reality application built using Unity, designed as a visual learning medium for the human blood circulation system topic for Grade 5 elementary school students. The development followed the ADDIE model and incorporated marker-based AR technology through the Vuforia SDK to display animated 3D models of the heart and blood circulation pathways. The validity test results showed that the media validator scored the application at 92.5% and the material validator at 95.0%, both categorized as very valid. Practicality test results showed teacher response scores of 90.6% and student response scores of 91.7%, both categorized as very practical. The effectiveness evaluation using the N-Gain formula produced a value of 0.37, indicating a moderate improvement in student learning outcomes after using the application.

BloodFlowAR has been demonstrated to be a valid, practical, and moderately effective visual learning medium that makes the abstract concept of blood circulation more accessible for elementary school students. Future development should focus on expanding the application to cover additional human body systems, improving the difficulty distribution of quiz questions, particularly regarding pulmonary circulation, and testing the application with larger and more diverse student populations to obtain more generalizable results.

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