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Implementation of Augmented Reality Technology for Human Anatomy Learning Media Using Mobile-Based Gamification Models

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Abstract *- SMP Negeri 38 Bekasi faces low student learning outcomes in Science, particularly in human body anatomy material, as reflected in students' failure to meet the Minimum Mastery Criteria (KKM). This issue stems from the abstract nature of anatomy topics, which demand strong visualization skills, while current instruction still relies on conventional, text-based, two-dimensional media that are less interactive. To address this gap, this study develops a mobile-based learning application that integrates Augmented Reality (AR) and a gamification approach to present three-dimensional models of human body organs, complemented by interactive quizzes, a scoring system, and a leaderboard. The application was built using the Multimedia Development Life Cycle (MDLC) method. Usability testing with the System Usability Scale (SUS) showed that the AR Human Body Anatomy application achieved a score of 84.05 (Excellent), while the Management Dashboard achieved 80.5 (Excellent), indicating that both applications are highly usable and well-received by users. These findings suggest that AR-based learning media with gamification can support students' understanding of human body anatomy through three-dimensional visualization, and has the potential to increase learning motivation and engagement. This study contributes a practical AR-gamification model for science education that can serve as an alternative to conventional visualization methods in anatomy instruction, particularly for the achievement of the KKM standard.*

Keywords: *Augmented Reality; Gamification; Human Body Anatomy; Learning Media; Multimedia Development Life Cycle.*

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Abstrak *– SMP Negeri 38 Bekasi mengalami rendahnya hasil belajar siswa pada mata pelajaran IPA, khususnya pada materi anatomi tubuh manusia, yang tercermin dari belum tercapainya Kriteria Ketuntasan Minimal (KKM). Permasalahan ini disebabkan oleh sifat materi anatomi yang abstrak dan menuntut kemampuan visualisasi yang kuat, sementara pembelajaran masih didominasi metode konvensional berbasis teks dan gambar dua dimensi yang kurang interaktif. Untuk mengatasi permasalahan tersebut, penelitian ini mengembangkan aplikasi pembelajaran berbasis mobile yang mengintegrasikan teknologi Augmented Reality (AR) dengan pendekatan gamifikasi untuk menampilkan model tiga dimensi organ tubuh manusia, dilengkapi fitur kuis interaktif, sistem skor, dan papan peringkat (leaderboard). Aplikasi dikembangkan menggunakan metode Multimedia Development Life Cycle (MDLC). Hasil pengujian usability menggunakan metode System Usability Scale (SUS) menunjukkan bahwa aplikasi AR Anatomi Tubuh Manusia memperoleh skor 84,05 (kategori Excellent), sedangkan aplikasi Management Dashboard memperoleh skor 80,5 (kategori Excellent), yang menunjukkan bahwa kedua aplikasi tersebut sangat mudah digunakan dan diterima baik oleh pengguna. Temuan ini menunjukkan bahwa media pembelajaran berbasis AR dengan pendekatan gamifikasi dapat membantu pemahaman siswa terhadap anatomi tubuh manusia melalui visualisasi tiga dimensi, serta berpotensi meningkatkan motivasi dan keterlibatan belajar siswa. Penelitian ini memberikan kontribusi berupa model AR-gamifikasi yang aplikatif untuk pembelajaran IPA, sebagai alternatif metode visualisasi konvensional dalam pembelajaran anatomi, khususnya untuk mendukung pencapaian KKM.*

Kata Kunci*: Anatomi Tubuh Manusia, Augmented Reality, Gamifikasi, Media Pembelajaran, Multimedia Development Life Cycle.*

I. INTRODUCTION

The development of information and communication technology has had a major impact on the world of education. One technology that is beginning to be widely used as a learning medium is Augmented Reality (AR). AR enables real-time integration between the real world and the digital world, providing a more interactive, engaging, and visual learning experience. This technology has great potential for application in science education, especially for topics that are difficult to visualize, such as human anatomy [1].

Anatomy lessons at the junior high school level often still use conventional methods such as textbooks and blackboards. These methods tend to be passive and non-interactive, making them less effective at capturing students' attention, especially for those with visual or kinesthetic learning styles. In this context, the use of AR can be a solution to present 3D models of human organs, allowing students to understand the structure and function of organs in a more concrete and enjoyable way [2].

State Junior High School 38 Bekasi, commonly known as SMP N 38 Bekasi, is located at Perum Villa Mas Indah, Jl. Kali Abang Tengah Blk. A, RT.001/RW.018, Perwira, North Bekasi District, Bekasi City, West Java. Based on observations and interviews conducted with teachers in the field of Science at SMP N 38 Bekasi, there are still many low student learning outcomes, as seen in the data on the grades of eighth-grade students in the odd semester of the 2025/2026 academic year. The score limit set by SMP N 38 Bekasi for Natural Sciences is 78, but the data shows that 16 (40%) students have not reached the minimum passing grade and 24 (60%) have reached the minimum passing grade, with a total of 40 students. This shows that the learning process cannot be considered successful because the number of students who have reached the minimum passing grade is still less than 85% of the total number of students.

TABLE 1
STUDENT DATA BELOW MINIMUM COMPETENCY STANDARDS

No.	Student	M/F	Exam Scores
1	S1	M	50
2	S2	F	45
3	S3	F	75
4	S4	M	60
5	S5	M	70
6	S6	M	50
7	S7	F	65
8	S8	M	55
9	S9	M	60
10	S10	M	75
11	S11	F	75
12	S12	M	65
13	S13	M	70
14	S14	F	55
15	S15	M	70
16	S16	M	70

Referring to Table 1, the low learning outcomes of students in science learning are caused by a lack of creativity and limited teaching tools. It was found that the teaching of human anatomy to 8th grade students is still done manually, using books as the main medium. Although the school has interactive whiteboards in the science laboratory, their use is still limited to showing videos from YouTube or presentations, rather than as interactive tools that allow students to interact directly with anatomical objects visually.

In addition, the school only has one torso or anatomical model that is used alternately, so it is unable to optimally support 3D visualization for all students. This has an impact on students' low understanding of anatomy material, as shown by suboptimal scores and some students who have not met the Minimum Completion Criteria (KKM). This was proven when the author conducted research at SMP N 38 Bekasi. To overcome this problem, technology can be utilized in education through gamification learning methods to teach natural sciences, especially human anatomy, where the learning method is designed in accordance with the junior high school curriculum. This learning application can be used by students in accordance with the material being studied, namely displaying 3D visualizations of human anatomy using a scanning system on mobile phones, quizzes, scores obtained, and leaderboards. That way, students will not feel bored, and it will be easier for them to understand the material by presenting interesting visualizations.

Augmented Reality (AR) technology is one of the rapidly growing innovations in the world of education, especially after the COVID-19 pandemic forced the education sector to adapt to online learning systems. In this context, AR presents itself as a solution that can combine virtual information with the real world in real time. This technology not only presents content visually, but also provides an interactive learning experience. One of its applications is in the introduction of human anatomy through AR-based mobile applications, which allow students to view and interact with 3D models of organs that resemble the real thing. This helps to increase understanding, interest in learning, and the overall effectiveness of the learning process [3]. The use of AR as an interactive learning medium has also been demonstrated in other subject areas, such as computer network hardware education, further confirming its broad applicability across disciplines [4].

The use of Augmented Reality (AR) technology in education offers various advantages, including helping students visualize abstract material in a more concrete way, creating an interactive and engaging learning environment, accelerating concept understanding through 3D visualization, increasing student motivation, and facilitating teachers in delivering material in innovative ways, especially in subjects such as human anatomy that require good spatial understanding [5]. Gamification is an approach that integrates game elements and mechanisms into non-game contexts, such as education, with the aim of increasing student engagement and motivation. Through this method, students are encouraged to actively participate in the learning process, which is packaged like a game, such as completing missions, earning points, leveling up, and viewing rankings. When applied to Pancasila education, gamification has been proven to help students understand the material more easily, increase their enthusiasm for learning, and have a positive impact on student learning outcomes and the achievement of Minimum Passing Criteria (KKM) [6]. Furthermore, the application of gamification elements such as points, leaderboards, and badges has also been shown to significantly increase student motivation and learning outcomes in science subjects at the junior high school level [7].

Application of the MDLC method to develop an Android application that introduces Lampung script through 3D objects, pronunciation sounds, interactive quizzes, and a marker tracking system. Based on blackbox testing results, this application achieved a 100% feasibility rating, and usability aspects such as Learnability 4.78; Efficiency 4.75; and Satisfaction 4.69, all of which fall into the excellent category as an alternative digital-based learning medium [8].

TABLE 2
SUMMARIZES RELATED STUDIES ON AR AND GAMIFICATION IN EDUCATION

Ref	Method	Object	Key Result	Limitation
[3]	AR-based mobile application	Human anatomy	Increased understanding, interest, and learning effectiveness	Only AR visualization; no gamification elements (quiz, score, leaderboard) or teacher monitoring tools
[4]	AR Android + MDLC	Human anatomy IPA (MTs)	Improved student understanding of human anatomy using AR-based 3D visualization on Android	No gamification, no teacher dashboard
[5]	AR in education (general review)	Various STEM subjects	AR helps visualize abstract material, increases motivation	Conceptual/general discussion, not implemented as a case-study application
[6]	Gamification approach	Pancasila education	Increased understanding, enthusiasm, learning outcomes (KKM)	Applied to non-science subject; not combined with AR/3D visualization
[8]	MDLC method + AR elements (marker tracking, 3D objects)	Lampung script learning	100% feasibility, high usability (Learnability 4.78; Efficiency 4.75; Satisfaction 4.69)	Applied to language/script learning; no scoring/leaderboard system or teacher dashboard

Based on the studies above, AR-based applications have generally been used only for visualization purposes without integrating gamification elements such as scoring and leaderboards, while gamification-based studies have mostly been applied to non-science subjects and have not utilized 3D AR visualization. In addition, none of the reviewed studies provide a web-based management dashboard that allows teachers to monitor student progress in real time. This indicates a gap in the development of an integrated learning system that combines AR-based 3D visualization, gamification elements (quiz, scoring, and leaderboard), and a teacher-side management dashboard specifically for human anatomy learning at the junior high school level.

The novelty of this study lies in three main aspects: (1) the integration of Augmented Reality and gamification within a single mobile-based learning application for human anatomy material, which has not been combined in previous studies; (2) the development of a web-based management dashboard that allows teachers to monitor student activity, scores, and learning progress; and (3) the implementation of interactive quiz, scoring, and leaderboard features directly linked to AR-based 3D visualization of human body organs.

This study offers three main contributions. From a technical perspective, it produces an integrated mobile-based AR and gamification application developed using the Multimedia Development Life Cycle (MDLC) method, complemented by a web-based management dashboard for monitoring student learning activities. From an educational perspective, it provides an alternative interactive learning medium that supports students' visualization and understanding of abstract anatomical concepts, expected to increase learning motivation and support the achievement of the Minimum Mastery Criteria (KKM). From an implementation perspective, this study offers a practical solution for schools with limited physical teaching tools, such as SMP N 38 Bekasi, which currently relies on a single anatomical model for all students and the resulting application can potentially be adopted by other schools facing similar resource constraints.

Based on the above description, a study will be conducted with the title “Implementation of Augmented Reality Technology for Human Body Anatomy Learning Media with Mobile-Based Gamification Model: A Case Study of SMP N 38 Bekasi”. The results of the study will make it easier for students to understand the material by visualizing it with AR technology, fostering enthusiasm for learning about human anatomy, and improving student learning outcomes (KKM).

II. METHOD

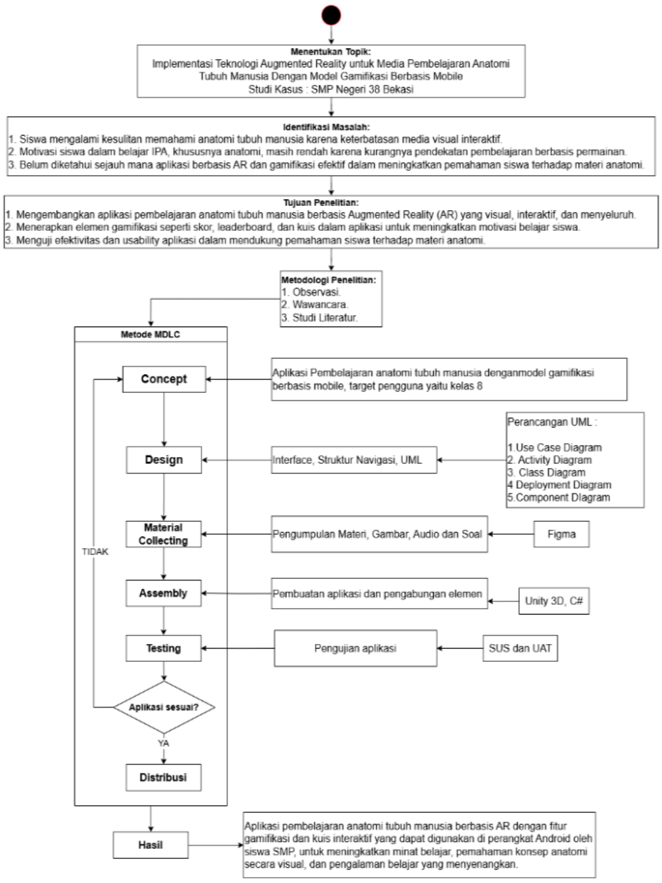


Figure 1. Research Method

Figure 1 shows the initial steps used. The first step is to determine the topic of the problem, find targets that match the problem, and then identify each problem. The core of the problem is that there are several students' scores below the minimum passing grade. The lack of learning variety to increase student motivation and the use of information technology in classroom learning has not been supportive.

The purpose of this study was to develop an Augmented Reality (AR)-based human anatomy learning application to improve student learning outcomes, particularly in understanding the structure and function of human organs. This application was designed to produce interactive and visual learning through the use of multimedia-based learning media, thereby helping students achieve the Minimum Passing Grade (KKM).

The research methodology used in this study consisted of three stages, namely direct observation at SMP Negeri 38 Bekasi with permission from the school, interviews with eighth-grade science teachers to obtain data related to the learning process, and a literature study reviewing various references from previous studies relevant to the research topic.

The development method used in this study was the Multimedia Development Life Cycle (MDLC) method, which consists of six stages, namely Concept (formulation of the concept of the application developed in accordance with the research topic), Design (design of the appearance and flow of the application), Material Collecting (collection of supporting materials and resources), Assembly (the process of creating and integrating all application components), Testing (testing the application), and Distribution (distributing the application to users).

A. Research Type and Design

This study is a Research and Development (R&D) study aimed at developing a mobile-based Augmented Reality learning application integrated with gamification for human body anatomy material at the junior high school level [9]. R&D research in education is defined as a systematic research method used to produce a specific product and to test the effectiveness of that product in real learning contexts [9]. The study was conducted from June 2025 to January 2026 at SMP Negeri 38 Bekasi. To evaluate the effectiveness of the application on student learning outcomes, a pre-experimental design with a One-Group Pretest-Posttest approach was employed, in which student scores were measured before and after using the application without a control group.

B. Data Collection

This research began with observation activities at SMP Negeri 38 Bekasi to observe the learning process and collect the necessary data. In addition, this research was also supplemented with a literature study through a search of relevant journal references and scientific literature as a basis for supporting the research. Data validity was ensured through triangulation of three sources: direct observation of the learning process, structured interviews with science teachers, and student learning outcome data from the school's academic records.

C. Research Sample

The sample for the pretest-posttest evaluation consisted of 16 eighth-grade students who had not met the Minimum Mastery Criteria (KKM ≥ 78) in the Science subject, selected using purposive sampling based on their academic scores in the odd semester of the 2025/2026 academic year. For usability testing using the System Usability Scale (SUS), the respondents consisted of 45 participants: 40 eighth-grade students (the entire class) and 5 teachers at SMP Negeri 38 Bekasi.

D. Development Method

The development method used in this study was the Multimedia Development Life Cycle (MDLC) method. MDLC is not only a technical reference in multimedia product development, but also a conceptual framework that supports the effectiveness of the planning and implementation processes [10]. This model provides guidelines so that all stages of development can run according to user needs, both in terms of design, content, and the resulting application functions. MDLC was selected over other development models such as Waterfall or Agile because it is specifically designed for multimedia product development, supports flexible and iterative stage execution based on project needs, and has been widely applied in AR-based educational application development in previous studies [5]. This makes MDLC particularly suitable for this study, which involves the development of a multimedia-rich application combining 3D AR visualization, interactive quizzes, and a scoring system. MDLC consists of six stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution, as illustrated in Figure 2.

Referring to Figure 2, the Concept stage involves determining target users and learning objectives. Design covers the specification of application architecture, interface, and user requirements. Material Collecting involves gathering all project assets including images, 3D models, animations, and audio. Assembly involves building the application from the collected materials. Testing is conducted to identify and resolve any errors or bugs. Finally, Distribution occurs once the application is verified to be error-free.

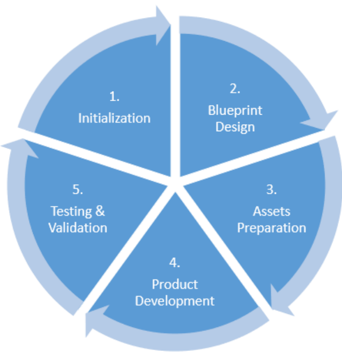


Figure 2. MDLC Development Method

Referring to Figure 2, the MDLC method consists of six stages, namely Concept, in which the author determines the target users and objectives before creating the game. Design is the specification of application development, such as architecture, appearance, and user requirements. Material Collecting is the collection of project materials, which consist of images, videos, animations, and audio. Assembly involves creating the project from the previously collected materials and converting them into code. Once the game is complete, Testing is conducted to check for any errors in the application. The final stage is Distribution, which occurs if the application is error-free.

E. Testing Using the System Usability Scale (SUS)

The System Usability Scale (SUS) has the advantage of a simple formula, consisting of 10 questions, with SUS scores ranging from 0 to 100. The interpretation of SUS makes it easier for respondents to understand the questions [11]. For questions (1, 3, 5, 7, 9), the user's answers are reduced by 1. For questions (2, 4, 6, 8, 10), the value of 5 is reduced by the user's answers [12]. Then, to obtain the final SUS score, multiply the total score by 2.5 [13]. For further calculations, find the average score by adding up all the respondent scores that have been multiplied by 2.5 and then dividing by the number of participants. The following is the formula for calculating the average SUS score [14].

$$\bar{x} = \frac{\Sigma x}{n}$$

Explanation:
$\bar{x}$ = Average score
ΣX = Total SUS score
n = Number of respondents

F. Learning Outcomes Evaluation

To evaluate the effectiveness of the application on student learning outcomes, a pretest-posttest design was applied to 16 students who had previously scored below the KKM. The pretest was administered before the students used the AR application, and the posttest was administered after a learning session using the application. The increase in student scores was analyzed using a Paired Sample T-Test to determine whether the improvement was statistically significant [15]. The Paired Sample T-Test is used to evaluate the effect of a specific treatment on the same sample group measured at two different time points, making it appropriate for a One-Group Pretest-Posttest research design [15]. The hypothesis tested was as follows: H_0 states that there is no significant difference between pretest and posttest scores, while H_1 states that there is a significant difference between pretest and posttest scores. The significance level (α) was set at 0.05.

III. RESULTS AND DISCUSSION

This chapter presents the results and discussion of the research, which includes the design of the proposed business process, the results of the development of an Augmented Reality (AR)-based human anatomy learning application, and the testing and distribution of the application to users.

A. Application Development Results

The AR Human Body Anatomy application and its accompanying Management Dashboard were developed using the Multimedia Development Life Cycle (MDLC) method, consisting of six sequential stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution [10].

At the Concept stage, the application was designed to target eighth-grade junior high school students at SMP Negeri 38 Bekasi, with the primary objective of addressing low learning outcomes in human anatomy material through AR-based 3D visualization and gamification elements including quizzes, a scoring system, and a leaderboard. At the Design stage, the system architecture was modeled using UML diagrams including Use Case, Class, Deployment, and Component diagrams to define actor interactions, class structures, physical deployment infrastructure, and inter-component dependencies across the mobile application and web-based dashboard. A Use Case Diagram is a visual representation of system functionality and interactions between one or more actors and the system [16], and helps model the behavior of information systems by describing what functions are available and who is authorized to access them [17]. The Class Diagram illustrates the application structure by displaying the classes, attributes, methods, and relationships between components, thereby facilitating the design of the system [18], and is also effective for describing workflows, menus, and business processes in software development [19]. The Deployment Diagram maps the physical system architecture, depicting nodes, artifacts, and network connections to clearly describe how software artifacts are deployed on relevant hardware [20] [21]. The Component Diagram illustrates the main components of the system and their dependencies on backend components and databases [22], supporting the visualization of system architecture in conveying technical information to stakeholders and development teams [23]. The overall application architecture describes the technology infrastructure that connects all components of the system [24].

During Material Collecting, anatomy learning content was compiled from the official eighth-grade science curriculum, covering organs such as the heart, lungs, kidneys, liver, and intestines, while 3D organ models were prepared for AR rendering using Unity and Vuforia, and quiz content was structured for management via the dashboard.

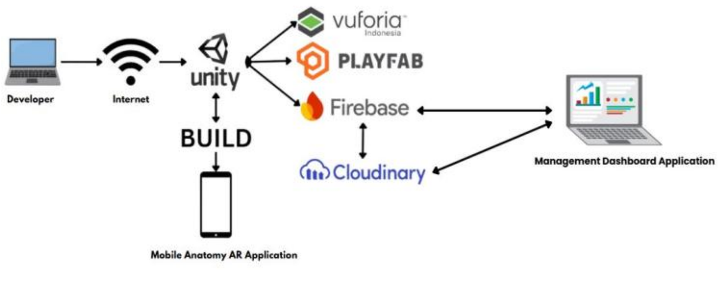
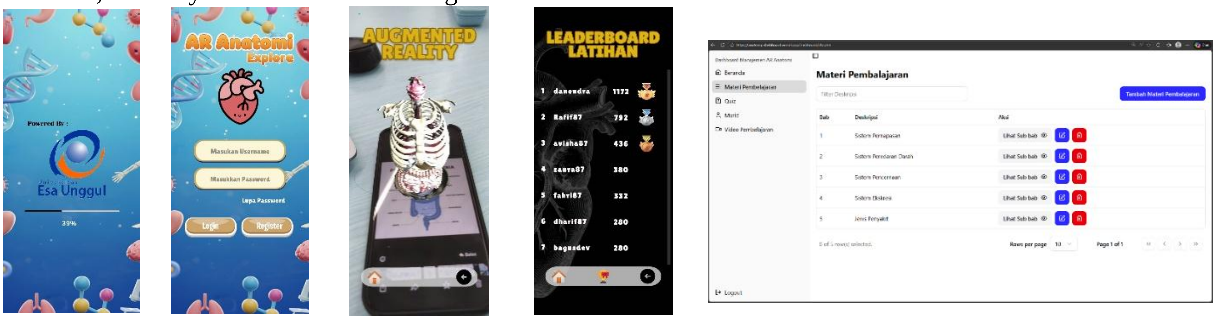


Figure 3. Application Architecture

The Assembly stage involved developing the mobile application using Unity Engine (C#), integrating PlayFab SDK for authentication and cloud storage, Vuforia Engine for AR marker-based 3D rendering, and Firebase for real-time leaderboard synchronization. The Management Dashboard was developed in parallel using Next.js with Firebase as the backend, enabling centralized management of learning materials, quizzes, videos, and student data. The Testing stage involved 45 respondents at SMP Negeri 38 Bekasi to evaluate usability and learning outcomes, with detailed results presented in Section B. Finally, the Distribution stage delivered the Android application and web-based dashboard, with key interfaces shown in Figures 4.



(a) (b) (c) (d) (e)

Figure 4. User interfaces of the developed application and Management Dashboard: (a) splash screen, (b) authentication page, (c) AR visualization module, (d) gamification leaderboard, and (e) teacher Management Dashboard.

B. System Testing Results

1) Respondent Demographic Data

Testing was conducted at SMP Negeri 38 Bekasi from June 2025 to January 2026, involving two groups of respondents. The first group consisted of 45 respondents for the AR Anatomy mobile application, comprising 40 eighth-grade students and 5 non-student respondents (4 science teachers and 1 Science Lab IT staff). Of the 45 respondents, 21 were male (47%) and 24 were female (53%), with student respondents aged 13-14 years and non-student respondents aged 30-50 years. The second group consisted of 5 respondents exclusively for the Management Dashboard evaluation, namely the same non-student respondents: 4 teachers (80%) and 1 Science Lab IT staff (20%), aged between 30–50 years.

The 40 student respondents represent the full eighth-grade class at SMP Negeri 38 Bekasi, selected using total sampling to ensure comprehensive coverage of the class population. The 5 non-student respondents were selected using purposive sampling based on their role as educators and system administrators who would directly interact with the Management Dashboard in actual classroom implementation. A separate sub-group of 16 students those who had previously scored below the KKM was additionally evaluated through a pretest-posttest assessment to measure the effect of the application on learning outcomes, as discussed in Section 4.

TABLE 3
RESPONDENT DEMOGRAPHIC DATA MOBILE APPLICATION

Characteristics	Category	Number of Respondents	Percentage
Gender	Male	21	47%
	Female	24	53%
Role	Students (Class VIII)	40	89%
	Science Teachers	4	9%
	Science Lab IT Staff	1	2%
Age	13 - 14 tahun	40	88%
	30 – 50 tahun	5	12%
Total		**45**	**100%**

TABLE 4
RESPONDENT DEMOGRAPHIC DATA MANAGEMENT DASHBOARD

Characteristics	Category	Number of Respondents	Percentage
Gender	Male	4	80%
	Female	1	20%
Role	Science Teachers	4	9%
	Science Lab IT Staff	1	2%
Age	30 – 50 tahun	5	12%
Total		**5**	**100%**

2) System Usability Scale (SUS) Results AR Anatomy Application

Usability testing of the AR Human Body Anatomy application was conducted using the System Usability Scale (SUS) method involving 45 respondents. Each respondent completed a 10-item questionnaire via Google Form, with responses scored on a scale of 1 to 5. The raw scores were processed using the standard SUS calculation formula, where scores for odd-numbered questions (Q1, Q3, Q5, Q7, Q9) were reduced by 1, scores for even-numbered questions (Q2, Q4, Q6, Q8, Q10) were subtracted from 5 [12], and the total per respondent was multiplied by 2.5 to produce a final SUS score ranging from 0 to 100. The complete score calculation results are presented in Table 5.

TABLE 5
SUS CALCULATION RESULTS AR ANATOMY APPLICATION

SUS Calculation Score										Total	Result
Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**		
4	3	4	2	4	1	4	4	2	3	31	77.5
4	4	3	3	4	3	4	3	4	4	36	90
4	4	4	4	4	4	4	4	4	4	40	100
4	4	3	3	4	2	4	3	4	4	35	87.5
3	1	3	2	2	2	2	1	2	2	20	50
3	4	3	4	4	3	4	4	4	4	37	92.5
2	3	3	2	3	3	3	3	3	2	27	67.5
2	2	2	2	2	2	2	2	2	2	20	50
3	3	4	1	4	4	4	4	2	1	30	75
3	2	3	3	3	3	3	3	3	2	28	70
4	4	4	4	4	4	4	4	4	4	40	100
4	4	3	2	3	4	4	3	4	2	33	82.5
3	4	3	2	3	4	4	4	3	3	33	82.5
4	4	4	4	4	4	4	4	4	4	40	100
4	3	4	2	4	2	3	4	4	2	32	80
4	4	3	3	4	3	4	3	4	4	36	90
4	4	4	2	4	3	4	3	4	3	35	87.5
4	4	4	4	4	4	4	4	4	4	40	100
3	4	3	2	4	3	4	3	3	4	33	82.5
4	3	3	3	3	2	4	3	3	1	29	72.5
4	4	3	2	4	4	3	4	4	2	34	85
4	3	3	4	3	4	3	4	2	3	33	82.5
3	4	3	2	3	2	4	3	3	2	29	72.5
4	4	3	3	3	4	3	3	4	3	34	85
3	3	4	3	3	4	3	3	3	1	30	75
4	4	4	4	4	4	4	4	4	4	40	100
3	2	4	2	1	2	3	2	3	2	24	60
3	3	3	3	4	3	4	4	4	1	32	80
4	3	4	3	4	3	3	4	4	3	35	87.5
4	4	4	2	3	4	4	3	3	4	35	87.5
4	4	4	3	4	4	4	4	3	2	36	90
4	4	4	2	3	4	4	3	3	2	33	82.5
3	3	3	3	2	3	4	3	3	3	30	75
4	4	4	4	4	4	4	4	4	4	40	100
4	4	3	3	3	4	3	2	0	2	28	70
4	4	4	4	4	4	4	4	4	4	40	100
4	3	4	2	4	3	3	4	3	3	33	82.5
1	4	4	4	4	3	4	4	4	0	32	80
4	2	3	4	3	4	3	3	3	2	31	77.5
4	2	3	4	2	3	4	3	2	4	31	77.5
4	4	4	4	4	4	4	4	4	4	40	100
4	4	4	4	4	4	4	4	4	4	40	100
4	4	4	4	4	4	4	4	4	3	39	97.5
4	4	4	3	4	4	4	4	4	4	39	97.5
4	4	4	4	4	4	4	4	4	4	40	100
Total Calculated Value											**3782.5**

Based on Table [X], the total SUS score obtained from 45 respondents was 3,782.5. Dividing this total by the number of respondents yields an average SUS score of 84.05, which is positioned in the Excellent (Grade A) category on the SUS benchmarking scale [25], as illustrated in Figure 5.

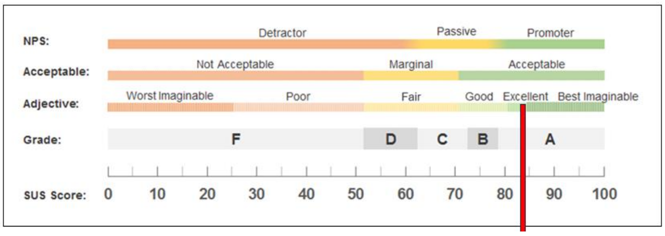


Figure 5. SUS Score Interpretation Chart of Mobile Application

The high SUS score of 84.05 can be attributed to several key design factors. First, the marker-based AR scanning mechanism was implemented with a straightforward scanning flow, minimizing the learning curve for first-time users and directly contributing to high learnability scores among student respondents [11]. Second, the gamification elements particularly the real-time leaderboard and immediate quiz score feedback created a clear, goal-oriented user flow that kept students engaged throughout the session, which is reflected in the high satisfaction scores [7]. Third, the application interface was intentionally designed for the junior high school age group, using large visual elements, simple navigation menus, and minimal text input requirements, making it accessible even for students with limited prior experience with mobile learning applications [4].

(a) (b) (c)

Figure 6. Field testing session: (a) student completing tasks on the AR Anatomy app, (b) students performing the SUS evaluation, (c) student interacting with the application interface.

3) System Usability Scale SUS Results Management Dashboard

Usability testing of the Management Dashboard application was conducted separately involving 5 non-student respondents, consisting of 4 science teachers and 1 Science Lab IT staff. The same SUS calculation method was applied, where each respondent completed a 10-item questionnaire and scores were processed using the standard SUS formula. The complete score calculation results are presented in Table 6.

TABLE 6
SUS CALCULATION RESULTS MANAGEMENT DASHBOARD

SUS Calculation Score										Total	Result
(Q1)	(Q2)	(Q3)	(Q4)	(Q5)	(Q6)	(Q7)	(Q8)	(Q9)	(Q10)		
3	4	4	4	4	2	1	4	3	4	33	82.5
4	3	4	2	4	4	2	3	4	2	32	80
4	4	4	2	4	2	3	3	4	3	33	82.5
3	2	4	2	4	2	4	4	4	1	30	75
3	3	4	3	4	4	2	3	4	3	33	82.5
Total Calculated Value											**402.5**

Based on Table [X], the total SUS score obtained from 5 respondents was 402.5. Dividing this total by the number of respondents yields an average SUS score of 80.5, which is positioned in the Excellent (Grade A) category on the SUS benchmarking scale, as illustrated in Figure 7.

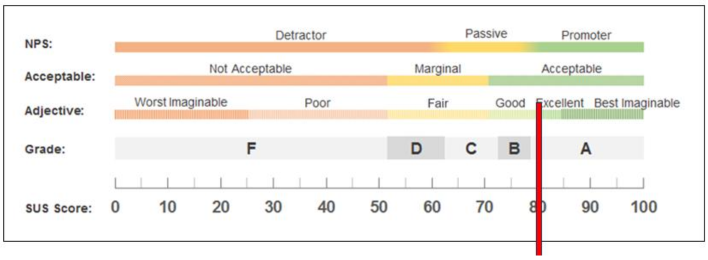
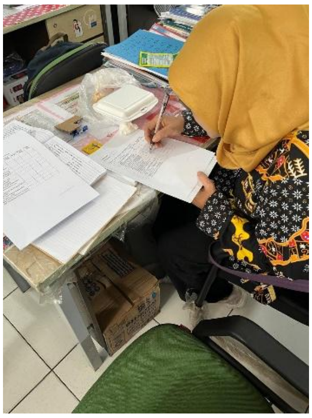


Figure 7. SUS Score Interpretation Chart of Management Dashboard

The Excellent rating achieved by the Management Dashboard reflects several design strengths specific to the teacher-facing system. First, the web-based interface was built using a clean and familiar layout structure, allowing teachers to navigate between content management menus such as learning materials, quiz management, and student data without requiring technical training or prior experience with similar systems. This contributed to high learnability scores among teacher respondents [12]. Second, the real-time Firebase synchronization ensured that any content added or updated through the dashboard was immediately reflected on the student mobile application, providing teachers with a reliable and efficient content management experience that directly supported high efficiency scores. Third, the role-based access design ensured that teachers only interacted with features relevant to their responsibilities, reducing cognitive load and preventing user errors, which positively influenced overall satisfaction scores [11]. The slightly lower score of 80.5 compared to the mobile application score of 84.05 is consistent with the general expectation that web-based administrative systems tend to receive marginally lower usability ratings than consumer-facing mobile applications, given the broader range of functions and data management responsibilities involved.

(a)



(b)

Figure 8. Usability testing of the Management Dashboard: (a) the researcher introducing and demonstrating the web-based system to a teacher, and (b) a teacher completing the System Usability Scale (SUS) questionnaire for the dashboard evaluation.

4) Learning Outcomes Evaluation Pretest-Posttest

To evaluate the effectiveness of the AR Human Body Anatomy application on student learning outcomes, a pretest-posttest assessment was conducted using a One-Group Pretest-Posttest design [9]. The evaluation involved 16 eighth-grade students at SMP Negeri 38 Bekasi who had previously scored below the Minimum Mastery Criteria (KKM = 78) in the Science subject, selected using purposive sampling based on their academic scores in the odd semester of the 2025/2026 academic year. The pretest was administered before students used the application, and the posttest was administered after a structured learning session using the AR Anatomy application. The complete pretest and posttest scores are presented in Table 7.

TABLE 7
PRETEST AND POSTTEST SCORE COMPARISON

No	Student	Pretest	Posttest	Difference
1	S1	50	76	+26
2	S2	45	72	+27
3	S3	75	92	+17
4	S4	60	84	+24
5	S5	70	88	+18
6	S6	50	80	+30
7	S7	65	88	+23
8	S8	55	72	+17
9	S9	60	84	+24
10	S10	75	84	+9
11	S11	75	88	+13
12	S12	65	82	+17
13	S13	70	96	+26
14	S14	55	80	+25
15	S15	70	92	+22
16	S16	70	84	+14
Mean		**63.12**	**83.88**	**20.75**

Based on Table 7, all 16 students (100%) scored below the KKM prior to using the application, with a mean pretest score of 63.12. Following the learning session using the AR Anatomy application, the mean posttest score increased to 83.88, representing an average improvement of 20.75 points. Of the 16 students, 13 (81.25%) successfully reached or exceeded the KKM threshold after using the application, with only 3 students (18.75%) remaining below the KKM. These results indicate a substantial improvement in student learning outcomes following the use of the application.

To verify whether this improvement was statistically significant, a Paired Sample T-Test was conducted at a significance level of α = 0.05 [15]. The hypothesis tested was as follows: H_0 states that there is no significant difference between pretest and posttest scores, while H_1 states that there is a significant difference between pretest and posttest scores. The results of the statistical test are summarized in Table 8.

TABLE 8
PAIRED SAMPLE T-TEST RESULTS

Parameter	Value
N (sample size)	16 students
Mean Pretest	63.12
Mean Posttest	83.88
Mean Difference	20.75
Standard Deviation of Difference	5.88
t-value (t-count)	14.11
t-table (α = 0.05, df = 15)	2.131
Significance Level (α)	0.05
Decision	H_0 Rejected
Conclusion	Significant improvement

Based on Table 8, the Paired Sample T-Test yielded a t-value of 14.11, which substantially exceeds the t-table value of 2.131 (df = 15, α = 0.05). Since t-value > t-table, H_0 is rejected and H_1 is accepted, confirming that there is a statistically significant difference between pretest and posttest scores [15]. These findings demonstrate that the use of the AR Human Body Anatomy application with gamification had a measurable and statistically proven positive effect on the learning outcomes of students who previously failed to meet the KKM standard. The significant improvement from a mean score of 63.12 to 83.88, combined with 81.25% of students achieving the KKM after using the application, provides empirical evidence that the application effectively supports anatomy learning at the junior high school level.

C. Discussion

1) Comparative Analysis with Previous Studies

The findings of this study are compared against four related studies reviewed in the literature to assess the extent to which this study advances the existing body of knowledge in AR-based and gamification-based educational application development. The comparison is summarized in Table 9.

TABLE 9
COMPARISON WITH PREVIOUS STUDIES

Aspect	Study [3]	Study [4]	Study [5]	Study [6]	Study [8]	This Study
Technology	AR-based mobile application (Marker-Based AR)	AR Android + MDLC	AR in education + MDLC	Gamification approach	MDLC + AR	AR + Gamification + MDLC
Subject	Human anatomy (general)	Human anatomy IPA (MTs)	Human anatomy (MTs students)	Pancasila education	Lampung script learning	Human anatomy (SMP)
Gamification	None	Yes (missions, points, levels)	None	Yes (missions, points, levels)	Partial (quiz only)	Yes (quiz, scoring, leaderboard)
Teacher Dashboard	None	None	None	None	None	Yes (web-based)
Usability Testing	Not reported	Not reported	Black-box testing	Black-box testing	Learnability 4.78; Efficiency 4.75; Satisfaction 4.69	SUS = 84.05 (Excellent)
Learning Outcome Evaluation	Not reported	Not reported	Not reported	KKM improvement reported	Black-box feasibility / expert validation	Paired T-Test: t = 14.11 (significant)
Development Method	Marker-Based Tracking Method	MDLC	MDLC	Multimedia Development / Gamification Design	MDLC	MDLC

Based on Table 9, several important distinctions can be drawn between this study and prior works. With respect to AR implementation, Study [3] demonstrated that AR-based mobile applications can improve student understanding and learning interest in anatomy through 3D visualization. However, that study did not integrate any gamification elements such as scoring or leaderboards, nor did it provide a mechanism for teachers to monitor student progress. The present study extends this work by combining AR visualization with a full gamification system, resulting in both high usability (SUS = 84.05) and statistically proven learning outcome improvement (81.25% of below-KKM students reaching KKM after using the application).

With respect to gamification, Study [5] demonstrated its effectiveness in increasing student motivation, enthusiasm, and KKM achievement in Pancasila education. However, that study was applied to a non-science subject and did not utilize AR or 3D visualization as part of the learning experience. The present study replicates and extends these positive gamification effects within a science context specifically human anatomy by combining gamification with AR-based 3D organ visualization, suggesting that the AR-gamification integration is effective and transferable across different subject areas.

With respect to the development methodology, Study [6] applied the MDLC method to develop an AR-based Android application for Lampung script learning, achieving high usability scores (Learnability 4.78; Efficiency 4.75; Satisfaction 4.69) and 100% blackbox feasibility. The present study corroborates these findings, with an even higher overall usability score of 84.05 on the SUS scale, further validating MDLC as a reliable and appropriate methodology for AR-based educational application development across different subject domains.

Unlike all four reviewed studies, this study uniquely incorporates a web-based Management Dashboard for real-time teacher monitoring of student scores and learning progress a feature absent from all prior works and is the only study to employ a formal Paired Sample T-Test to statistically verify learning outcome improvement, providing a higher level of empirical rigor.

2) Limitations

Despite the positive results demonstrated in this study, several limitations must be acknowledged to provide a balanced and critical assessment of the application's current state and the scope of the research findings.

First, the AR marker-based scanning system requires adequate lighting conditions and a minimum print quality for the barcode markers to be recognized accurately by the application. In classroom settings where lighting is inconsistent or printed markers are of low quality, the AR scanning process may fail or produce unstable 3D rendering, which could disrupt the learning experience for some students.

Second, the application requires Android devices with sufficient processing power, RAM, and camera specifications to render 3D organ models smoothly through the Vuforia AR engine [4]. Students using older or low-specification Android devices may experience performance degradation, including slow rendering, application lag, or crashes, which could negatively affect their engagement and learning experience. This is reflected in the small number of respondents who gave lower SUS scores, likely attributable to device compatibility issues during the testing session [11].

Third, features such as real-time leaderboard synchronization, score updates, and content delivery between the Management Dashboard and the mobile application depend on a stable internet connection. In schools or classrooms with limited or unstable network infrastructure, these features may not function optimally, reducing the overall effectiveness of the gamification system [6].

Fourth, the current version of the application covers only five selected human body organs the heart, lungs, kidneys, liver, and intestines which represents a partial coverage of the full eighth-grade science anatomy curriculum [5]. Students and teachers who require a more comprehensive set of organ systems, such as the skeletal, muscular, or nervous systems, would find the current application insufficient as a standalone learning medium.

Fifth, the pretest-posttest evaluation was conducted on a relatively small sample of 16 students from a single school, SMP Negeri 38 Bekasi. While the Paired Sample T-Test confirmed statistically significant improvement within this sample [15], the generalizability of these learning outcome findings to larger student populations, different schools, or different geographic and socioeconomic contexts remains limited and requires further investigation through broader multi-school studies [9].

3) Implications

The findings of this study carry several practical and theoretical implications across three dimensions: educational impact, implementation potential, and contribution to the broader field of digital learning media development.

The findings of this study have educational, implementation, and research implications. From an educational perspective, the results demonstrate that AR-based gamification is an effective alternative to conventional anatomy learning for junior high school students [2]. Learning outcomes improved significantly, with mean scores increasing from 63.12 to 83.88 and 81.25% of previously below-KKM students achieving the minimum competency standard. This indicates that interactive 3D visualization combined with gamification features effectively supports understanding of abstract anatomical concepts[5]. High SUS scores from students (84.05) and teachers (80.5) further indicate that the application is engaging and suitable for classroom use, particularly in schools facing similar learning challenges [2].

From an implementation perspective, the relatively high usability scores from both student and teacher respondents indicate that the application can be adopted in school settings without requiring extensive technical training or prior experience with AR technology. The intuitive interface design and straightforward marker-based scanning mechanism lower the barrier to entry for students, while the web-based Management Dashboard enables teachers to manage and update learning content independently without programming knowledge [24]. This makes the system practically deployable in schools with limited technology support staff. Additionally, the dashboard's real-time Firebase synchronization means that content updates such as new quiz questions or additional learning materials can be pushed to all student devices simultaneously, reducing the administrative burden on teachers and ensuring consistency of learning content across the classroom. Schools with similar resource constraints to SMP Negeri 38 Bekasi, which currently relies on a single physical anatomical model shared among all students, could adopt this application as a scalable and cost-effective alternative that provides every student with individual access to interactive 3D organ visualization [4].

From a research and development perspective, this study provides an empirically validated model for integrating AR technology, gamification mechanics, and a teacher-side management dashboard within a single unified educational system, developed using the MDLC methodology [10]. This integrated model addresses gaps identified in the existing literature, where AR and gamification have largely been studied and applied in isolation rather than in combination [4], and where teacher monitoring tools have been absent from AR-based learning applications. The use of a formal Paired Sample T-Test to verify learning outcome improvement rather than relying solely on usability metrics such as SUS establishes a stronger empirical basis for evaluating the effectiveness of AR learning media [15], and sets a methodological precedent that future studies in this domain can build upon. The application and its development framework can serve as a replicable reference model for researchers and developers seeking to create integrated AR-gamification learning systems for other science subjects or educational levels beyond the junior high school context examined in this study [7].

IV. CONCLUSION

This study successfully developed a mobile-based Augmented Reality learning application integrated with gamification for human body anatomy material at the junior high school level, using the Multimedia Development Life Cycle (MDLC) method. The application consists of two interconnected systems: an AR Anatomy mobile application for students, featuring 3D organ visualization, interactive quizzes, a scoring system, and a leaderboard; and a web-based Management Dashboard for teachers, enabling real-time monitoring and management of learning content, quiz questions, and student progress. Usability testing using the System Usability Scale (SUS) method demonstrated that both systems were well-received by users. The AR Anatomy mobile application achieved a SUS score of 84.05 (Excellent, Grade A) from 45 respondents consisting of 40 students and 5 non-student respondents, while the Management Dashboard achieved a SUS score of 80.5 (Excellent, Grade A) from 5 teacher and staff respondents. These results confirm that both applications meet high standards of usability, learnability, and user satisfaction. The learning outcomes evaluation conducted through a One-Group Pretest-Posttest design on 16 students who had previously scored below the KKM demonstrated a statistically significant improvement in student scores. The mean score increased from 63.12 (pretest) to 83.88 (posttest), representing an average improvement of 20.75 points. Furthermore, 13 out of 16 students (81.25%) successfully reached or exceeded the KKM threshold of 78 after using the application. A Paired Sample T-Test confirmed the statistical significance of this improvement, yielding a t-value of 14.11, which exceeds the t-table value of 2.131 (df = 15, $\alpha = 0.05$), resulting in the rejection of H_0 and acceptance of H_1. These findings demonstrate that the integration of Augmented Reality and gamification within a single mobile-based learning system can effectively support students' understanding of abstract anatomical concepts, increase learning motivation, and improve learning outcomes particularly for students who struggle to meet the minimum mastery standard through conventional instruction alone. The addition of a web-based Management Dashboard further distinguishes this study from prior works by providing teachers with a practical tool for centralized content management and real-time student monitoring. For future research, it is recommended that the application be expanded to include additional organ systems such as the skeletal, muscular, and nervous systems to achieve full coverage of the eighth-grade science anatomy curriculum. The learning outcomes evaluation should also be replicated using a larger sample of at least 60-100 students across multiple schools in the Bekasi region to strengthen the external validity and generalizability of the findings. Furthermore, future studies could explore the development of an offline mode to eliminate dependency on internet connectivity, and conduct longitudinal assessments to measure the long-term retention effects of AR-gamification learning on students' understanding of human anatomy material.

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