Innovating Digestive System Education through Augmented Reality Technology: Enhancing Student Engagement, Understanding, and Motivation

Inovasi Pembelajaran Sistem Pencernaan melalui Teknologi Augmented Reality: Meningkatkan Keterlibatan, Pemahaman, dan Motivasi Siswa

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Abstract – Augmented reality (AR) has emerged as a transformative tool in education, offering immersive and interactive learning experiences. Anatomy education, particularly the gastrointestinal system, often relies on traditional 2D materials that fail to engage students or provide sufficient visualization of its complex structure and functions. To address these challenges, this study developed a mobile AR application featuring 3D visualizations of the gastrointestinal system, designed to enhance student engagement and learning outcomes. The application, created using Unity 3D and Vuforia with the Prototyping method, incorporates interactive features such as animated organ models, quizzes, and multimedia content. Black box testing validated its functionality, while usability testing highlighted improvements in user satisfaction and learning. Quantitative analysis revealed a 30% reduction in quiz completion time and a 25.3% improvement in post-test scores, indicating enhanced comprehension and retention. These results demonstrate the application's effectiveness in engaging students and simplifying complex concepts. The interactive and immersive AR features significantly boosted understanding and motivation. This research highlights AR's potential to revolutionize educational tools, with future studies focusing on its long-term effects on learning outcomes and broader applications in education.
Keywords: augmented reality, gastrointestinal system, 3D visualization, interactive learning, educational tools

***Abstrak** – Augmented reality (AR) telah muncul sebagai alat transformatif dalam pendidikan, menawarkan pengalaman belajar yang imersif dan interaktif. Pendidikan anatomi, khususnya sistem gastrointestinal, sering kali mengandalkan materi 2D tradisional yang kurang mampu menarik minat siswa atau memberikan visualisasi yang memadai terhadap struktur dan fungsi kompleksnya. Untuk mengatasi tantangan ini, penelitian ini mengembangkan aplikasi AR berbasis mobile dengan visualisasi 3D dari sistem gastrointestinal, yang dirancang untuk meningkatkan keterlibatan siswa dan hasil belajar. Aplikasi ini dibuat menggunakan Unity 3D dan Vuforia dengan metode Prototyping, serta dilengkapi fitur interaktif seperti model animasi organ, kuis, dan konten multimedia. Pengujian black box memvalidasi fungsionalitasnya, sementara pengujian kegunaan menunjukkan peningkatan signifikan dalam kepuasan pengguna dan hasil belajar. Analisis kuantitatif mengungkapkan pengurangan waktu penyelesaian kuis sebesar 30% dan peningkatan skor post-test sebesar 25,3%, yang menunjukkan peningkatan pemahaman dan retensi. Hasil ini menunjukkan efektivitas aplikasi dalam melibatkan siswa dan menyederhanakan konsep yang kompleks. Fitur AR yang interaktif dan imersif secara signifikan meningkatkan pemahaman dan motivasi. Penelitian ini menyoroti potensi AR untuk merevolusi alat pendidikan, dengan studi masa depan yang berfokus pada dampak jangka panjangnya terhadap hasil belajar dan penerapan yang lebih luas dalam pendidikan.*
***Kata Kunci:** augmented reality, sistem pencernaan, visualisasi 3D, pembelajaran interaktif, perangkat pendidikan*

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INTRODUCTION

The rapid evolution of technology plays a pivotal role in daily life, becoming an indispensable aspect of human existence (Nizetic et al., 2020). Technological progress has impacted various spheres including business, socio-culture, economy, health, and education, necessitating individuals to adapt to these transformations. A notable advantage of technological advancement lies in the discovery of sophisticated technologies facilitating daily tasks, among which is augmented reality (AR) technology (Sharma et al., 2021).

Augmented reality, or AR, represents a technology that merges real-time virtual objects with tangible objects in the physical world (Balakrishnan et al., 2021). Its widespread adoption and extensive development have positioned it as a valuable tool in assisting people with everyday activities. In education, AR presents novel opportunities for tailoring unique learning approaches that cater to diverse student needs (Yiannis Koumpouros, 2024). Specifically, AR has shown promise in aiding the study of human anatomy, with a focus on complex systems like the digestive system. The limitations of conventional 2D materials in depicting the complexity of anatomical systems highlight the need for AR-based educational tools to enhance visualization, engagement, and understanding. AR-based learning methodologies are being actively developed, aiming to revolutionize education by providing engaging, interactive, and immersive learning experiences (Hajirasouli & Banihashemi, 2022).

Human anatomy, a branch of biology, delves into the structure of the human body, dissecting it into smaller components to elucidate the function of each part (Hernanda & Aji, 2024). The human body's anatomy comprises several systems, including the skeletal, muscular, circulatory, digestive, nervous, respiratory, immune, lymphatic, excretory, urinary, reproductive, and sensory systems (Srivastava et al., 2020). However, this research exclusively focuses on the human digestive system, as depicted in Figure 1, encompassing the gastrointestinal (GI) tract and biliary system (Ghazanfar et al., 2022).

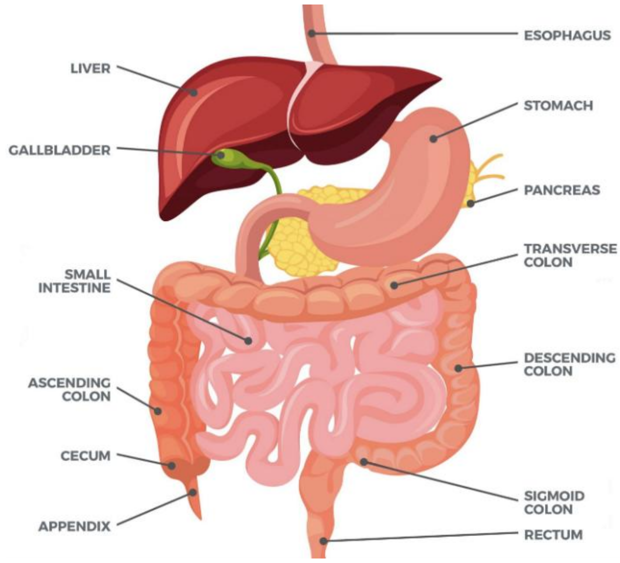

Figure 1 Human Digestive System Anatomy (Capsule Endoscopy | Gastro MD, 2020)

The digestive system coordinates the processing of food by the digestive organs to facilitate the absorption of nutrients and their conversion into energy for human use (Mackie et al., 2020). As outlined by Zubaidah et al. (2017), the human digestive system comprises primary organs that form the digestive tract, along with auxiliary organs. The digestive tract serves as the conduit through which food traverses, commencing from the mouth, esophagus, stomach, small intestine, large intestine, rectum, and concluding at the anus (Elgazzar et al., 2022). Auxiliary organs encompass the tongue, teeth, salivary glands, liver, gallbladder, and pancreas. These auxiliary organs work in coordination with the primary digestive organs to ensure efficient digestion and nutrient absorption (Malik et al., 2023).

The development of mobile-based learning methodologies in biology remains ongoing in Indonesia (Ernawati et al., 2021; Rahmasuci & Ngabekti, 2023; Saputra et al., 2022; Tamam & Corebima, 2023). Mobile learning using AR constitutes one of six categories of mobile-based learning (Khan & Gupta, 2021). Additionally, various studies have confirmed the widespread adoption of mobile edu-games (Johnson-Glenberg, 2018; Ridwan et al., 2021; Lazo-Amado & Andrade-Arenas, 2023). The inception of AR development in biology initially served as a simulation tool for educational content delivery. However, traditional educational media for learning about the human digestive system often rely on animations or 2D images to depict digestive organ structures (Hamizi et al., 2023). This approach presents significant limitations as students lack a tangible representation of the human body's organs, leading to gaps in understanding. Given the importance of a comprehensive understanding of the digestive system for biological studies and its relevance to human health, addressing these educational gaps is critical.

In response to this challenge, the application was developed by (Pattiasina et al., 2024). Using augmented reality technology, the app optimally visualizes human digestive organs for 8th-grade students and biology teachers. Two significant features were integrated into the app's development: an animated video feature for comprehensive organ explanations and an interactive quiz to assess student understanding. By enhancing students' cognitive abilities, particularly memory and information processing, this educational tool is expected to lead to a deeper comprehension of the human digestive system and improved understanding of the subject matter (Adipat et al., 2021; de Campos et al., 2020; Situmorang, 2023). Augmented reality offers theoretical advantages in improving learning experiences and practical benefits in real-world applications, preparing students for future pursuits and ensuring global access to educational materials (Iqbal et al., 2022). This initiative aims to bridge the gaps in traditional learning methods, advancing teaching and learning approaches, particularly in studying the gastrointestinal system.

RESEARCH METHOD

Further development of the mobile application as an educational medium is being conducted using the throwaway prototyping method. This method was also employed in the initial stages of application creation. The earlier iteration of the application featured augmented reality (AR) technology that showcased three-dimensional depictions of the digestive organs. These representations were supplemented with textual and audio explanations, triggered when the image target was detected. Additionally, users could interact with the digestive organs by zooming in or rotating them. Building on the findings of previous research, the next phase of development involved incorporating two features: animated learning videos and interactive quizzes for each organ of the human digestive system.

In throwaway prototyping, prototypes are created and discarded if they fail to meet the objectives or demonstrate inadequate performance, rendering them unsuitable for further development (Zaina et al., 2022). The throwaway prototyping method is illustrated as a flow for application development in Figure 2. This method involves creating prototype versions of the application, which are then tested and evaluated (Bellino et al., 2023). If the prototypes fail to meet the desired objectives or demonstrate inadequate performance, they are discarded, and the development process starts again. This iterative approach allows for rapid refinement and improvement of the application until the desired functionality and performance are achieved (Mackay & Beaudouin-Lafon, 2023).

To ensure successful implementation, the development team must adopt a structured approach to prototyping, emphasizing clear documentation of requirements and results for each iteration. Regular user feedback, particularly from educators and students, is essential to validate the effectiveness of features and identify necessary adjustments. Additionally, performance metrics, such as system responsiveness and user interaction quality, should be consistently monitored and evaluated to guide the refinement process (Marvel et al., 2020). This approach ensures that the final application not only meets technical standards but also aligns with educational objectives and user expectations.

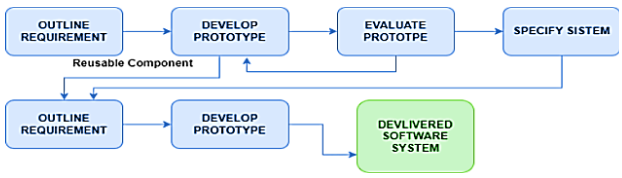

Figure 2 Throwaway Prototyping Phase (Chalik et al., 2022)

Following the steps of throwaway prototyping, three primary phases were employed to achieve the design of the desired application, which include gathering system requirements, designing prototypes, and evaluating prototypes. The following outlines the procedure for developing this educational application:

1. Gathering System Requirements
   In the phase of gathering system requirements, an interview was conducted with a natural science teacher at a local middle school. This step is crucial for gathering pertinent information needed to design and develop the application. According to the teacher, incorporating animated video features for each organ of the digestive system would enhance the application. This addition would provide students with a more detailed explanation of

the digestive organs through animated videos. Additionally, the interactive quiz feature serves to assess students' abilities and comprehension of the human digestive system material. Developing this interactive quiz menu is the primary focus of this research, aiming to complement the features of the human digestive system learning tool. Meanwhile, further development of the application, such as creating learning materials and dynamically adding quiz questions that can be carried out by teachers themselves, is still under consideration in the development of this quiz menu.

The design and analysis of these two features will establish the foundation for identifying the necessary functionalities of each. The design process for developing animation videos and interactive quizzes will utilize Unified Modeling Language (UML) as an object-oriented modeling technique (Alamsyah & Fauziyah, 2021). The UML diagrams to be generated include the use case diagram, activity diagram, sequence diagram, communication diagram, class diagram, and state machine diagram. Below are several UML diagrams as depicted in Figure 3, and 4.

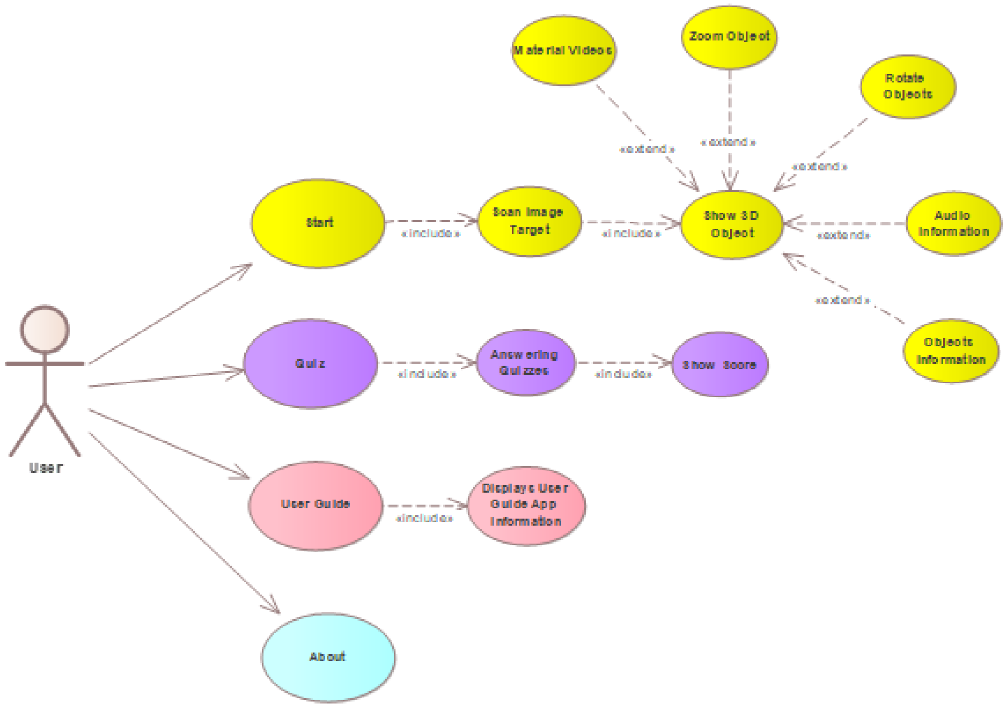

Figure 3 Human Digestive System AR Use Case Diagram

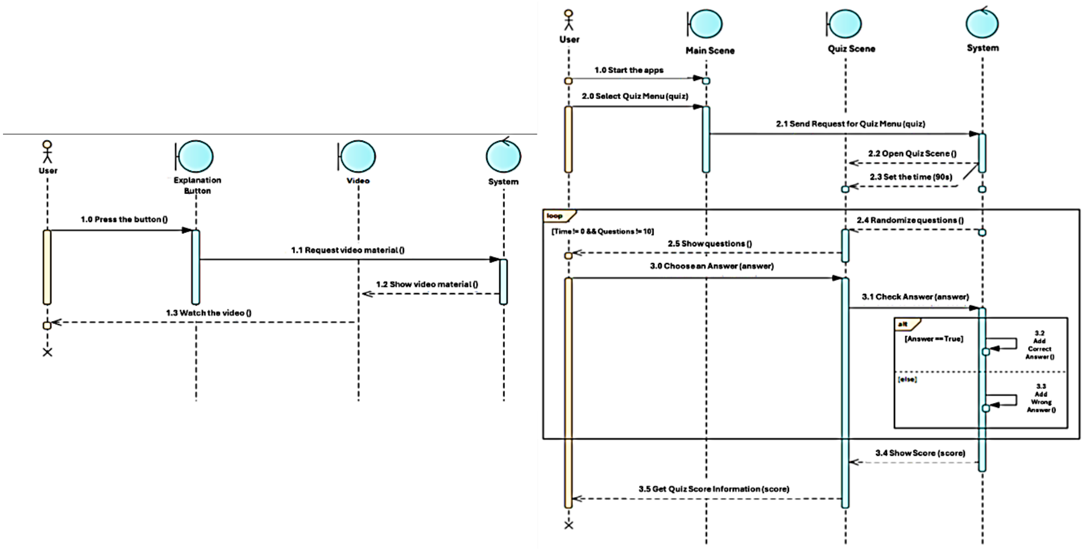

Figure 4 Sequence Diagram for Displaying an Explanation Video and Taking a Quiz

For the interactive quiz feature, the application incorporates a timed element. As the user progresses through the quiz, the application actively tracks the remaining time. If the timer reaches zero, the quiz session automatically ends, closing the quiz scene and opening the score scene to display the results.

During the quiz, the system continuously monitors the user's progress to ensure that all 10 questions have been answered before completing the quiz. After presenting each question, the system checks whether the user has selected an answer. If any question remains unanswered, the system will keep presenting the current question until the user provides an answer. Once the user has answered all 10 questions, the system proceeds to end the quiz. At this point, it automatically calculates the final score based on the number of correct answers and presents the results to the user, providing immediate feedback on their performance. Each question in the quiz is carefully crafted to align with the learning material, ensuring that it reflects the key concepts covered in the educational content. The design of the questions focuses on assessing the user’s understanding of the most critical and relevant aspects of the human digestive system, enabling a more targeted evaluation of their comprehension. The table below outlines the scoring system, showing how each question is weighted in the final score calculation, and highlights the results for each individual question answered correctly or incorrectly.

Table 1 Quiz Score Calculation

Answer Result	Time (s)	Score
True	< 90 s	+10
False	< 90 s	+0

Figure 5 displays a state machine diagram that illustrates the flow of actions when the user selects the quiz menu within the application. Upon the user's selection, the system transitions to a 'quiz scene' where the quiz interface is presented. The system initiates a timer, setting a strict 90-second time limit for the quiz, which is displayed prominently to the user. The timer countdown begins immediately after the quiz scene is loaded. Additionally, the system dynamically selects 10 questions from a pool of 90 available questions. These questions are chosen at random to ensure variety and unpredictability in each quiz session. The pool of 90 questions includes a range of topics related to the human digestive system, ensuring that each quiz offers a comprehensive assessment of the user's understanding.

Once the questions are selected, the system presents them one by one in a randomized order, with the user required to answer each question before moving to the next. After the time limit expires or all questions are answered, the quiz is automatically submitted, and the system displays the final score, providing feedback based on the user's performance.

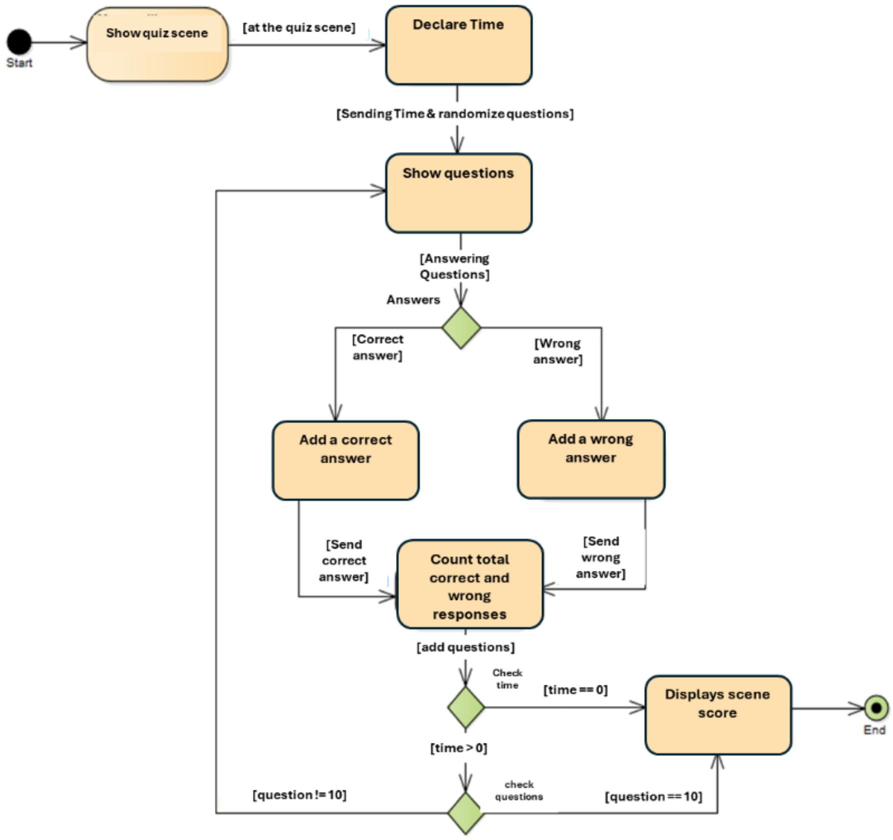

Figure 5 State Machine Diagram Select Quiz Menu

2. Designing Prototypes
During the prototyping phase, we developed several prototypes for menu options, including the Main Menu Prototype Design, AR View Menu with Animated Explanatory Video, and Quiz Menu. Multiple prototype options were created for each menu and then presented to application users, including teachers and students from a local middle school. This iterative design process aimed to identify a final design that meets users' needs and can be implemented in the application. To collect data, we used a closed-ended questionnaire format, allowing respondents to select a design from the various options provided (Baburajan et al., 2021). This method helped respondents choose the design that best suited their preferences and facilitated a quick analysis of the data, as it aligned with the provided options. Figures 6 and 7 present an overview of the design options for each menu in the application.

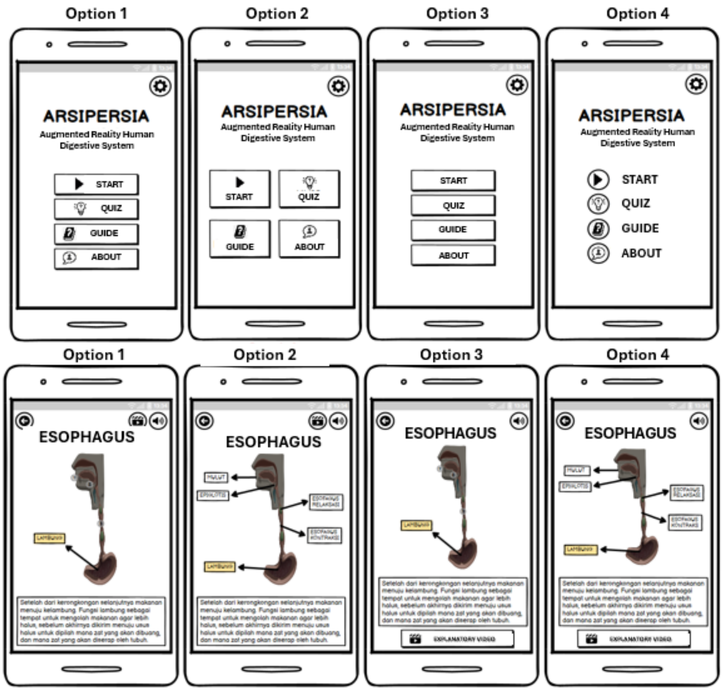

Figure 6 Main Menu & AR Video Options

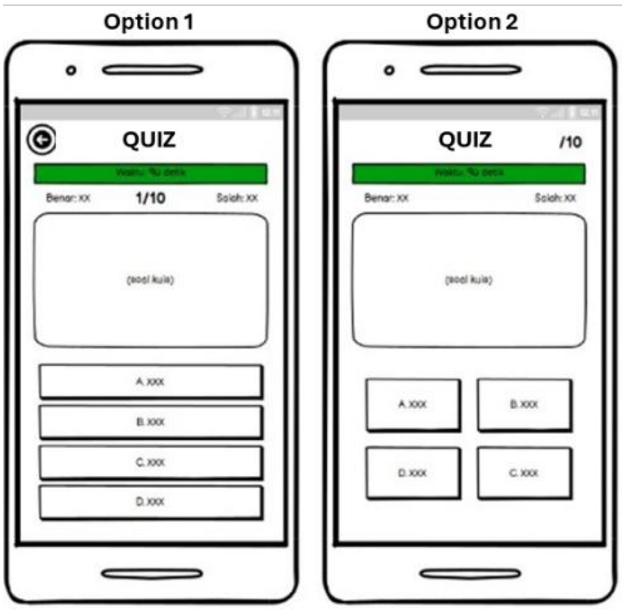

Figure 7 Quiz Scene Options

3. Evaluating Prototypes

   During the prototype evaluation phase, feedback from respondents, including both teachers and students from a local middle school, was gathered. These evaluations guided the further development of the learning application. The evaluation of the prototype design involved 36 participants, consisting of 35 eighth-grade students and one science teacher. In this process, the science teacher played a crucial role as a mentor, actively contributing to the organization and development of the learning materials. As an experienced educator, the teacher provided valuable insights into the educational content's alignment with the curriculum, ensuring the materials were both relevant and effective for the students. Additionally, the teacher offered guidance on how the learning experience could be enhanced to foster better understanding and engagement. By evaluating the prototype from a pedagogical perspective, the teacher helped refine the design, ensuring that the educational goals were met while also considering the practical needs of both students and the classroom environment. Their feedback was instrumental in improving the usability and educational value of the mobile application prototype.

Based on the data presented in Table 2, the design selected for the interface display of the application was determined by choosing the option with the highest percentage of respondents who completed the prototyping design questionnaire. The interface display implemented in the mobile application was selected based on the results presented in Table 2, which indicated the design that had the highest percentage of respondents completing the prototyping design questionnaire.

Table 2 Prototype Design Questionnaire Evaluation Results

Prototype Design	Opt 1	Opt 2	Opt 3	Opt 4
Main Menu	25%	47.2%	8.3%	19.4%
AR View + Video	2.8%	27.8%	5.6%	63.9%
Quiz Scene	55.6%	44.4%	-	-

RESULTS AND DISCUSSION

This research successfully developed a learning application for the human digestive system utilizing augmented reality (AR) technology. The application is designed to enhance educational experience by providing an interactive and immersive way for students to explore and understand the human digestive system. Through AR, students can visualize and interact with 3D models of the digestive organs, enriching their learning process and making complex anatomical structures more accessible and engaging.

Enhanced Features for Interactive Learning

In the second phase of development, two significant features were added to the mobile application to further enhance its functionality and educational value:

1. Animated Video Feature: This feature provides detailed explanations of each part of the digestive system. It combines visual and auditory elements to offer students a more engaging and comprehensive understanding of the digestive organs. By watching these animated videos, students can deepen their knowledge and retain complex information more effectively.
2. Interactive Quiz Feature: The second feature is an interactive quiz that tests students' knowledge of the digestive system. The quiz serves both as a reinforcement tool for the material presented in the animated videos and as an assessment tool for evaluating students' comprehension. Through interaction with these quizzes, students can assess their understanding in a fun and educational manner.

These new features significantly contribute to making mobile applications a more interactive and engaging educational tool. The combination of augmented reality, videos, and quizzes allows for a multi-modal learning experience, catering to different learning styles and improving knowledge retention.

Development Tools and Implementation

To bring the mobile application to life, several software tools were employed during its development. Unity 3D was used for overall application development, creating an environment that supports interactive 3D experiences. Blender was utilized for designing the 3D models of the digestive organs, ensuring accuracy and visual appeal. The Vuforia SDK was implemented as a marker database, enabling augmented reality functionality by recognizing and tracking real-world images to trigger the corresponding digital content (Ali et al., 2022).

Figure 8 Augmented Reality Application Interfaces for the Human Digestive System

Figure 8 illustrates the final implementation of the mobile application, showcasing its augmented reality-based learning approach to the human digestive system. The image highlights the integration of the new animated video and quiz features, demonstrating how these enhancements contribute to a more interactive and engaging educational tool.

The second phase of this research focused on evaluating two new features added to the interactive video presentations and student quizzes. These features were tested for both functionality and user engagement through black box and usability testing. Black box testing ensured that all system components, including the new features, functioned correctly, while usability testing measured how well they enhanced the learning experience. The results showed that these features significantly improved communication and comprehension, making the application a more effective educational tool.

Time and Score Analysis and Improvement

To measure the impact of the transition from 2D to 3D learning on the speed of students understanding of the digestive system, a time and score analysis was conducted. The method involved tracking the time it took students to complete tasks or quizzes related to the digestive system both before and after using the 3D learning tool. The time students spent answering questions was recorded, comparing the duration of completing the quiz using traditional 2D methods with the time taken using the new 3D augmented reality-based learning application.

The Time-Based analysis involved two key stages: a pre-test and a post-test, with a total of 35 eighth-grade students participating. The pre-test and post-test provided two-time measurements for each student. In the pre-test, these students were given a quiz featuring 2D representations of the digestive system. The time it took for each student to complete the quiz was recorded. After interacting with the 3D tool, the students then took a similar quiz in the post-test, where the same process of recording time was applied. This allowed for a direct comparison of the time spent on both quizzes.

The analysis focused on evaluating whether there was a reduction in the time spent answering the questions in the post-test, as this could indicate that the 3D tool helped improve students' understanding of the digestive system, enabling them to process the information more quickly and accurately. A significant decrease in completion time would suggest that the 3D learning tool facilitated a faster comprehension of the material. The table below summarizes the time analysis for both the pre-test and post-test.

Table 3 Time Reduction in Quiz Completion

Pre-test (Minutes)	Post-test (Minutes)	Time Reduction (%)
15.5	10.9	29.6%
14.8	10.2	31.1%

From the table, it shows a significant reduction in the time taken to complete the quiz after using the 3D tool. The average reduction across all groups was approximately 30%, highlighting an improvement in students' ability to understand and process information about the digestive system more efficiently. This time-based improvement suggests that the 3D learning tool helped students grasp the concepts faster and with greater ease, potentially due to the interactive and immersive nature of the augmented reality environment, which enhanced their understanding of complex anatomical structures.

In addition to time, scores were analyzed to assess knowledge retention and understanding. Table 4 summarizes the average pre-test and post-test scores:

Table 4 Pre-test and Post-test Scores

Stage	Average Score (out of 100)
Pre-test	68.2
Post-test	85.4

The results show an average score improvement of 25.3%, further supporting the claim that the 3D tool enhanced students' understanding of the material.

The observed reduction in quiz completion time and the improvement in quiz scores underscore the role of the augmented reality (AR) environment in facilitating a better understanding of complex anatomical structures. While these results demonstrate the potential of 3D learning tools to enhance engagement, retention, and learning efficiency, they also raise important considerations about the broader application of such technologies. Implementing AR-based tools on a larger scale may face challenges such as the high cost of development and deployment, the need for robust technical infrastructure, and the requirement for teacher training to effectively integrate these tools into the curriculum.

Furthermore, variations in students' access to compatible devices and differing levels of familiarity with AR technology could limit its accessibility and effectiveness. Addressing these limitations is essential for ensuring the equitable and sustainable adoption of AR tools in educational settings.

Testing and Evaluation of AR Features

The research outcomes were followed by a rigorous testing phase using the black box testing method. Black box testing is a user-centric approach that focuses on evaluating the functional aspects of a system without needing to understand its internal code structure. This method allows end users to thoroughly examine all the application functions from their perspective (Kenny et al., 2021).

By employing black box testing, the researchers were able to assess the system's functionality in a holistic manner. The goal was to determine whether the application's features and capabilities were aligned with the expected outcomes, ensuring that the system met the desired performance and usability standards.

The results of this testing process are summarized in the following tables (Table 3 and Table 4), which document the outcomes of black box testing conducted on the video explanatory menu and the interactive quiz menu. These tables provide a detailed view of how each feature performed under user evaluation, confirming the effectiveness of the application in delivering its intended educational content.

Table 5 Test Scenario Results for Video Scene Explanatory Material

Testing Scenario	Expected Outcome	Results
Press the video section	Shows video button	Succeed
Pressing the back button	Display the AR view scene	Succeed
Pressing the pause button	Pause the video	Succeed
Pressing the play button	Play video	Succeed
Pressing the replay button	Looping videos	Succeed
Move the slide bar	Display videos according to slide bar settings	Succeed

Table 6 Test Scenario Results for Interactive Quiz Menu

Testing Scenario	Expected Outcome	Results
Pressing the cross button on the pop-up quiz guide	Closes quiz, opens main menu.	Succeed
Press the start quiz button	Show countdown for quiz start	Succeed
The countdown starts and the quiz ends	Show questions, answers, calculates quiz time	Succeed
Pressing the back button	Show pop-up to pause/stop quiz	Succeed
Press the correct answer option	Show correct answers, pauses timer	Succeed
Pressing the wrong quiz answer option	Show correct answer, pauses timer for incorrect choices	Succeed
Processing time > 45 seconds	Display the time bar in green	Succeed
Processing time ≤ 45 seconds and > 22 seconds	Display the time bar in yellow	Succeed
Processing time ≤ 22 seconds	Display the time bar in red	Succeed

Processing time ≤ 10 seconds	Plays a sound effect when activated	Succeed
Pressing the "yes" button	Closes the quiz scene and returns to the main menu scene	Succeed
Pressing the "no" button	Resets the quiz timer	Succeed

Figure 9 Video Explanatory Scene Interface

Figure 10 Multiple Quiz Menu Display

Usability testing evaluates user-friendliness (Derby & Chaparro, 2021) by gathering data via questionnaires from 17 participants, including 16 eighth-grade students and one science teacher. Calculations from the questionnaire data assessed the successful implementation of usability aspects. Phase two of the usability testing focused on learnability (Tuli & Mantri, 2020), using three statements to evaluate the effectiveness of explanatory videos and interactive quizzes; the results are presented in Table 5.

Table 7 Usability testing result*

Statement	Aspect	Percentage	
		Agree	Strongly Agree
The explanatory video material helped me understand the digestive system better.	Learnability	17.6%	82.4%
The quality of the questions on the quiz is in accordance with the learning	Learnability	41.2%	58.8%

Statement	Aspect	Percentage	
		Agree	Strongly Agree
material received.			
Quiz questions can help me evaluate my abilities regarding the human digestive system that I have studied.	Learnability	23.5%	76.5%

Based on 5 Point Likert Scale Analysis: strongly disagree (1) – strongly agree (5)

From the above results, respondents evaluated the video material in the application as clear and beneficial, with 17.6% agreeing and 82.4% strongly agreeing. Moving on to the interactive quiz menu, 41.2% of respondents agreed and 58.8% strongly agreed that the quality of the quiz questions matched the learning material. Finally, 23.5% of respondents agreed, while the remaining 76.5% strongly agreed that the list of questions in each quiz helped them evaluate their ability to understand the human digestive system organs.

The favorable response indicates that the application effectively conveys understandable information, thereby improving the overall learning experience (De Paolis et al., 2022). These outcomes emphasize its attractiveness, ease of use, educational impact, and motivational aspects, laying a solid groundwork for enhancements to cater to user requirements in interactive learning about the human digestive system.

CONCLUSIONS

Ultimately, this learning application for Android employs Unity 3D and Augmented Reality (AR) technology to present detailed 3D models of digestive organs, accompanied by text and audio explanations upon image target detection. The application offers users interactive features such as zooming and rotation. In the second development phase, a quiz menu was integrated with questions and organ videos, which were validated through testing.

Usability testing highlighted the effectiveness of animated videos in aiding student understanding and the clarity of organ explanations. Additionally, learnability testing for the interactive quiz menu showed alignment with learning material and efficient assessment of students' comprehension. Future updates will focus on empowering teachers to create learning materials and add quiz questions, further enhancing the educational experience of the application.

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