MEDICAL STUDIES THROUGH AR AND VR

[1]Badri Vishal S, [2]Nirmal D, [3]Uma Mageswari T

[1]Student, [2]Student, [3]Assistant Professor
Artificial Intelligence and Data Science
Sri Sairam Institute of Technology Chennai, Tamil Nadu, India

Abstract : In the field of medical education, it is an interactive framework that integrates Augmented Reality (AR), Virtual Reality (VR), and Natural Language Processing (NLP) to support and training. Unlike traditional methods that depend on textbooks or cadavers, the proposed system allows learners to engage with dynamic 3D anatomical models and receive real-time guidance from an AI-driven virtual assistant. The framework was implemented using Unity and Blender, deployed on the Meta Quest 3 headset, and enabled QR-based visualization of anatomical structures. A study involving 50 participants compared conventional learning with the AR/VR system. The results showed that the AR/VR group achieved a 28% higher knowledge retention rate and reported stronger engagement, reflected by a System Usability Scale (SUS) score of 82/100. Performance tests confirmed smooth rendering at 72 frames per second with an interaction latency of less than 30 ms, ensuring seamless usability. These findings demonstrate that AR/VR, when combined with NLP assistance, offers a safe, scalable, and effective solution for medical education, bridging the gap between theoretical knowledge and practical skills..

Keywords: Augmented Reality, Virtual Reality, Medical Education, Natural Language Processing, Immersive Learning, Simulation-Based Training

I. INTRODUCTION

Medical education has traditionally relied on textbooks, cadaver dissections, and supervised clinical practice. While these methods remain essential, they are constrained by limited access, high costs, and ethical concerns. Studies report that only a small fraction of medical schools worldwide have continuous access to cadaver laboratories due to logistical and ethical challenges. In recent years, AR and VR technologies have transformed learning by offering immersive, interactive, and cost-effective alternatives. According to market forecasts, the AR/VR healthcare sector is projected to exceed USD 11 billion by 2030, with applications ranging from anatomy visualization to surgical simulation. Several universities are adopting VR-based anatomy labs and AR-assisted surgery training modules. Despite these advancements, most existing works focus either on VR-only training modules or NLP-based assistants in isolation. Our research integrates AR, VR, and NLP into a single educational framework, creating a seamless ecosystem for immersive medical training.

The effectiveness of traditional medical training is limited by a number of issues. Due to ethical, cultural, and financial limitations, cadaver-based training is still not widely available, making it challenging for many institutions to offer practical anatomical experience. Furthermore, learner's capacity to visualize intricate anatomical structures and physiological processes is diminished by static learning resources like textbooks and 2D diagrams, which fall short in providing interactive or spatial engagement. Direct patient training presents a high risk in practice since it restricts opportunities for repeated trial-and-error learning and poses major safety concerns. Additionally, traditional methods lack adequate feedback because students hardly ever receive real-time corrective guidance during practice, which impedes the development of skills

II. RELATED WORK

Prior research has explored immersive technologies in medical education. AR has been employed to overlay anatomical structures onto real-world patients, enabling contextual learning. VR-based surgical simulations allow residents to practice complex procedures without risks [6]. Seymour et al. demonstrated that VR-trained surgeons made significantly fewer errors compared to those trained traditionally. In anatomy education, VR headsets have been used to visualize organ systems interactively, leading to improved spatial understanding. AR applications, such as HoloLens based anatomy modules, have also shown promise in collaborative learning. NLP-powered systems in healthcare provide clinical decision support and patient interaction tools. Chatbots trained on medical datasets offer explanations, drug information, and procedural guidance. However, research combining AR/VR visualization with NLP guidance remains limited. Our work builds on these foundations by offering an integrated AR/VR + NLP framework. This combination provides not only visual immersion but also conversational assistance, enhancing the depth of learning.

III. RESEARCH METHODOLOGY

The framework has four modules that work together to improve medical education. To start, Blender was used to make 3D models of the brain and heart with realistic textures. After that, Unity was used to put these models in an AR/VR environment, and the Meta Quest 3 headset was used to show them. This let students rotate, scale, and interact with the organs in real time. A QR-Code Recognition system was put in place to make it easy to get to. When you scan a QR code, it shows AR images of certain organs. The system also included an NLP chatbot that was trained on medical data specific to the field. This allowed users to ask questions like "Show me the left ventricle" or "Explain blood flow in the heart" and get interactive, informative answers.

3.1 System Architecture

This is an architecture that integrates Augmented Reality (AR), Virtual Reality (VR), and Natural Language Processing (NLP) for advanced applications in medical science. The system is structured into multiple layers, each responsible for specific functionalities that collectively enable an immersive and intelligent healthcare solution.At the input level, user interface devices such as AR smart glasses, tablets, mobile phones, VR head-mounted displays, and monitors serve as the primary interaction platforms. These devices capture various user input types, including voice commands, gestures, motion tracking, touch/controller inputs, and eye-tracking data, ensuring natural and intuitive interaction with the system.

The core of the architecture lies in the main processing layer, which consists of four major components: the AR module for overlaying digital content onto the real world, the VR engine for creating fully immersive environments, the NLP engine for understanding and processing human language, and simulation modules for modeling medical scenarios. These components work together to interpret user inputs and generate meaningful outputs.

An integration layer connects these processing components, ensuring seamless communication and data exchange. This is followed by the intelligence layer, which acts as the decision-making unit, analyzing processed data and generating context-aware responses.Finally, the system delivers multi-modal outputs, including visual output (3D models, simulations), audio output (voice feedback, alerts), and tactile output (haptic feedback), providing a rich and interactive user experience.

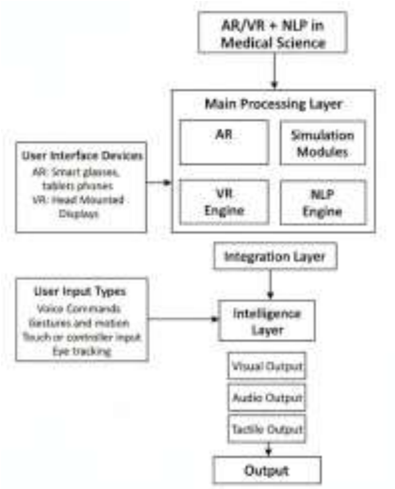

Fig.1.System Architecture

3.2 The purpose and question of the study

How to integrate Augmented Reality (AR), Virtual Reality (VR), and Natural Language Processing (NLP) into a single framework to improve medical education is the primary question this work attempts to answer. Conventional teaching approaches frequently restrict student engagement and knowledge retention because they mainly rely on cadavers, textbooks, or 2D diagrams. This study aimed to develop an immersive, interactive, AI assisted platform that offers learners enhanced accessibility, dynamic 3D anatomical visualization, and real-time guidance. Bridging the gap between theoretical knowledge and practical understanding was the main objective.

3.3 Suggested Approaches and Structure

A four-module framework was created in order to answer the research question. Initially, Blender was used to create 3D anatomical models of the heart and brain with high-resolution textures. Second, these models were installed on the Meta Quest 3 headset and incorporated into an AR/VR environment using Unity. Third, a system for recognizing QR codes was put in place, which enables students to scan codes and view particular anatomical structures in augmented reality. Students can now ask natural language questions like "Show me the left ventricle" or "Explain blood flow in the heart" thanks to the system's integration of an NLP-driven chatbot. Interactivity, ease of use, and AI-powered learner support were all guaranteed by this multi-module design.

3.4 Key Definitions and Terminology

A variety of technical terms are central to this study Using gadgets like smartphones or headsets to superimpose digital content like 3D organ models onto the real world is known as augmented reality, or AR. With virtual reality (VR), students can interact with anatomical structures as though they were real in a completely immersive digital environment. A medical chatbot is an example of how Natural Language Processing (NLP), a branch of artificial intelligence, allows computers to comprehend and react to human language. A standardized instrument for assessing usability is the System Usability Scale (SUS), where a score of 80 or higher denotes an exceptional user experience. These definitions aid in comprehending the framework's technological foundation.

3.5 Equations and Performance Metrics

Both performance metrics and user studies were used to assess the system's efficacy. When compared to conventional methods, learners who used the AR/VR system improved their knowledge retention by 28%, according to a controlled study with 50 participants. Smooth usability was ensured by the framework's 72 frames per second (FPS) rendering and interaction latency of less than 30 milliseconds. The frame time equation can be used to express these performance values:

$$\textbf{Frame Time (ms)} = \textbf{FPS/1000}$$

which, at 72 FPS, yields about 13.9 ms per frame. The framework's ability to provide a smooth, scalable, and efficient solution for medical education was demonstrated by the combination of its high rendering speed and low latency.

3.6 Implementation

This section elaborates how the project is implemented

3.6.1 User Inputs and Devices

The framework starts with AR/VR interface devices that act as the interaction medium, like smartphones, smart glasses, and the Meta Quest 3 headset. To operate the system, students employ input techniques such as eye tracking, controller movements, gestures, and voice commands. For example, a student might make hand gestures to rotate an organ or say, "Show me the left ventricle." Accessibility and flexibility in medical education are guaranteed by these multimodal inputs.

3.6.2 Layer of Main Processing

The AR/VR engine, simulation modules, and an NLP engine are all combined into a single system by the Main Processing Layer. The AR/VR engine renders 3D anatomical structures in real time at 72 frames per second with a latency of less than 30 milliseconds. While the NLP chatbot decodes natural language queries, simulation modules illustrate organ functions like blood flow. These elements are synchronized by an integration layer, which guarantees seamless communication between user inputs and system reactions.

3.6.3 Intelligence and Results

Every user input is processed by the Intelligence Layer, which then converts it into interactive outputs. Three forms of feedback are offered by the system: tactile output (future scope with haptic devices), audio output (AI-driven explanations), and visual output (3D organs in AR/VR). According to the abstract study, these outputs produce an immersive and captivating learning environment that enhances knowledge retention by 28% and achieves a System Usability Score of 82/100.

3.6.3.1 WORKFLOW DIAGRAM

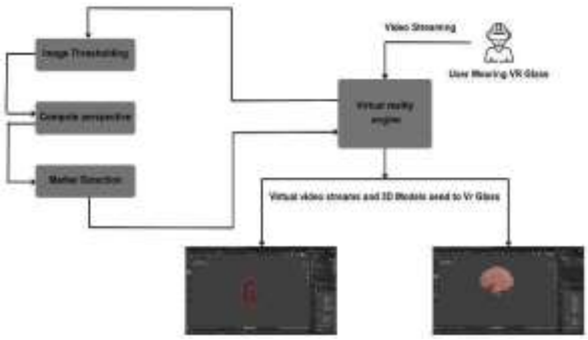

Fig. 2. Workflow Diagram

This diagram presents the workflow of an augmented/virtual reality (AR/VR) system designed for real-time 3D visualization using image processing and streaming techniques. The process begins with image preprocessing steps such as image thresholding, marker detection, and perspective computation, which are used to identify and track objects or markers from input data. These processed inputs are then fed into a virtual reality engine, where the system integrates spatial information and generates corresponding 3D models.

The VR engine acts as the core component, converting processed visual data into immersive virtual content. It supports video streaming and synchronizes the generated 3D models with the user's perspective. The output is transmitted to a user wearing VR glasses, enabling an interactive and immersive visualization experience. Additionally, the system renders virtual video streams and 3D objects (such as anatomical models) that can be viewed and manipulated in real time.

3.6.3.2 Models

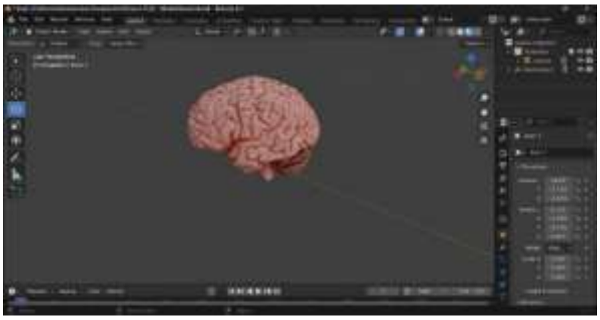

Fig. 3. 3D Brain Model

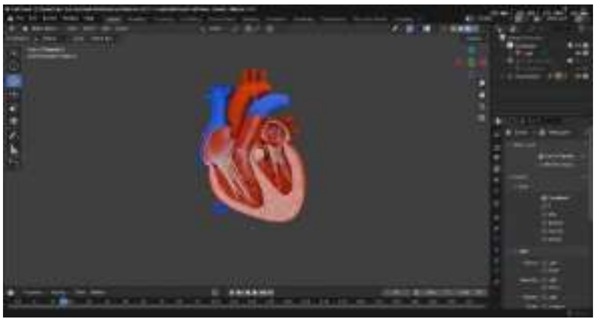

Fig. 4. 3D Heart Model

Fig. 5. Unity-based AR Heart Model with QR Scanning

Fig. 3. 3D Brain Model: A detailed 3D model of the human brain is developed using modeling software, showcasing the anatomical structure with realistic textures and surface detailing. The model enables visualization of different brain regions in a clear and interactive manner, making it suitable for educational and medical training purposes. It can be rotated, scaled, and examined from multiple angles to enhance understanding of complex neural structures.

Fig. 4. 3D Heart Model: A high-quality 3D representation of the human heart is created, highlighting both external and internal anatomical features such as chambers, vessels, and valves. The model uses distinct color differentiation to represent oxygenated and deoxygenated blood pathways, improving clarity and comprehension. This model is useful for demonstrating cardiac structure and function in an interactive and visually engaging way.

Fig. 5. Unity-based AR Heart Model with QR Scanning: An augmented reality implementation of the 3D heart model is developed using Unity, where the model is projected into the real world through QR code scanning. Upon scanning the QR marker, the heart model appears on the user's device, allowing real-time interaction such as zooming, rotation, and exploration. This approach enhances user engagement and provides an immersive learning experience, particularly valuable in medical education and visualization.

IV. RESULTS AND DISCUSSION

Table I – Learning Performance Comparison

Group	Pre-Test Mean (%)	Post-Test Mean (%)	Progress (%)	Std. Dev. (±)	p-value (t-test)
Tradition-al (n=25)	48.2	50.1	+1.9	4.6	–
AR/VR (n=25)	47.6	75.3	+27.7	5.1	< 0.01

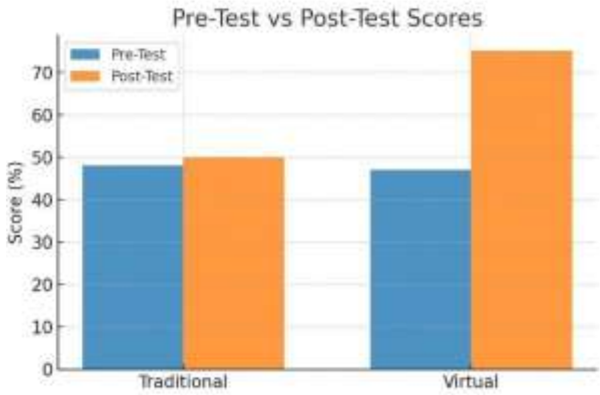

Fig. 6. Pre-Test vs Post-Test Results (Traditional vs Virtual)

Table II – User Feedback Metrics

Metric	Score (out of 100)	Positive Response (%)
SUS (Usability)	82	88%
Engagement	85	87%
Motivation	83	85%

V. CONCLUSION AND FUTURE WORK

In order to improve anatomy education and student involvement, this study presented a framework based on AR/VR and NLP. The system enabled learners to engage with anatomical models while receiving real- time guidance by combining conversational assistance with immersive 3D visualization. When compared to conventional approaches, the results demonstrated notable gains in engagement and knowledge retention.

Notwithstanding these advantages, the study had drawbacks, including a small sample size and scant anatomical coverage. Future plans call for investigating multi-user VR sessions, adding haptic feedback for tactile interaction, and growing the dataset to include additional organs. Furthermore, creating AI-powered personalization will support the provision of flexible and customized educational opportunities.

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