# ÇANKAYA UNIVERSITY
# FACULTY OF ENGINEERING
# COMPUTER ENGINEERING DEPARTMENT

## Project Report

# CENG 407

Innovative System Design and Development I

## VR Anatomy - VR Based Educational Interactive Human Anatomy Training Platform

Kutay Ayoğlu | Çağla Pelin Doğan | Elifnaz Talas | Öykü Çoban | Sena Akbaba

{c2111019, c2111026, c2111069, c2111021, c2111066, c228003}@student.cankaya.edu.tr

Advisors:

Assoc. Prof. Dr. Gül TOKDEMİR

&

Dr. Instr. Talha KARADENİZ

# Table of Contents

# Abstract

VR Anatomy is a virtual reality learning project designed to support human anatomy education at the health vocational high school level. The application enables students to examine three-dimensional anatomy models in an immersive VR environment and learn through interactive exploration. In addition, an AI-supported assistant is integrated to help students ask questions and receive explanations during learning. Overall, VR Anatomy aims to improve visualization, understanding, and motivation in anatomy education.

# 1.Introduction

Human anatomy is a fundamental subject in health education. At the health vocational high school level, learning is often based on text-heavy resources and two-dimensional visuals, which can make it difficult for students to form a clear three-dimensional understanding of anatomical structures and their spatial relationships. As a result, students may learn terminology but still struggle with questions such as where a structure is located, how it is oriented, and how it relates to surrounding parts.

Virtual reality offers a practical way to address this challenge by enabling students to examine anatomical structures in three dimensions through active exploration rather than only reading. Learners can observe models from different angles, build a clearer sense of spatial relationships, and engage with the content in a more concrete way. In addition, receiving quick and understandable explanations when questions naturally arise during exploration can strengthen learning flow and support students without interrupting the experience.

The VR Anatomy project presented in this report is a VR learning application developed to support anatomy education at the health vocational high school level. The application enables students to explore three-dimensional anatomy models in VR and access essential information by selecting structures within a guided learning flow. Alongside this experience, an AI-supported assistant is integrated to help students ask questions and receive short explanations during learning. In this way, VR strengthens visualization and engagement, while AI support complements learning as a supportive layer that provides guidance without breaking focus.

The rest of the report is organized as follows. First, the related literature and technology background are summarized. Then, the product vision and scope boundaries are presented. Next, the overall design and main components of the application are described, followed by a discussion of key decisions made during development and the resulting outcomes.
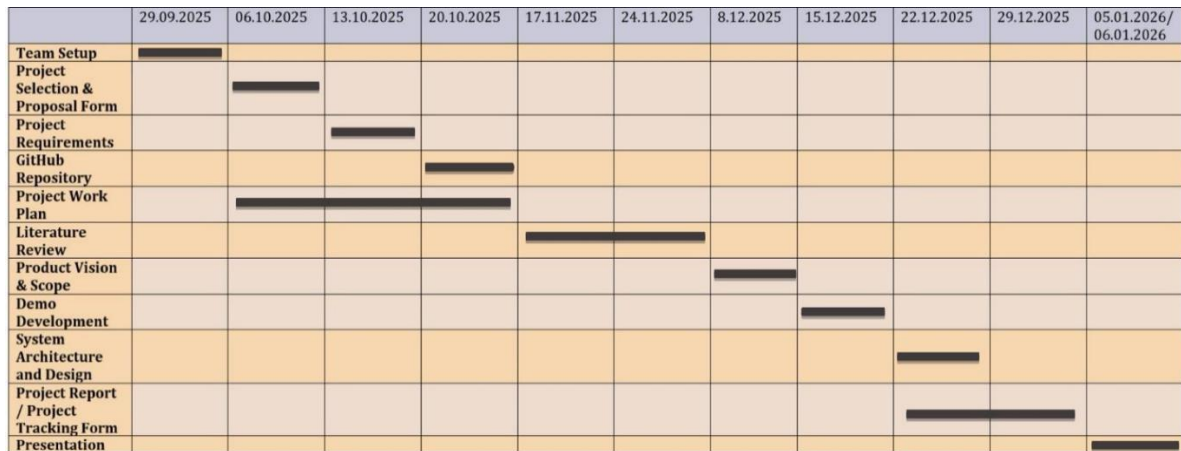
# 2.Project Work Plan

| | 29.09.2025 | 06.10.2025 | 13.10.2025 | 20.10.2025 | 17.11.2025 | 24.11.2025 | 8.12.2025 | 15.12.2025 | 22.12.2025 | 29.12.2025 | 05.01.2026/ 06.01.2026 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Team Setup** | ▬▬▬ | | | | | | | | | | |
| **Project Selection & Proposal Form** | | ▬▬▬ | | | | | | | | | |
| **Project Requirements** | | | ▬▬▬ | | | | | | | | |
| **GitHub Repository** | | | | ▬▬▬ | | | | | | | |
| **Project Work Plan** | | ▬▬▬▬▬▬▬▬ | | | | | | | | | |
| **Literature Review** | | | | | ▬▬▬▬ | | | | | | |
| **Product Vision & Scope** | | | | | | | ▬▬▬ | | | | |
| **Demo Development** | | | | | | | | ▬▬▬ | | | |
| **System Architecture and Design** | | | | | | | | | | ▬▬▬ | |
| **Project Report / Project Tracking Form** | | | | | | | | | ▬▬▬▬▬ | | |
| **Presentation** | | | | | | | | | | | ▬▬▬ |

*Figure 1. Project Work Plan for "VR Anatomy - VR Based Educational Interactive Human Anatomy Training Platform"*

Figure 1. shows the 14-week program and main work packages of the VR Anatomy project. The process is planned to include the initial preparation phase (team formation, project selection, and requirements definition), infrastructure setup (GitHub repository), research and scope definition (literature review and product vision), development and demo application, followed by architectural/design documentation and final reporting phases. In the final stage, the project outputs are planned to be presented.

# 3. Literature & Technology Review

## 3.1. Abstract

This report presents a literature review conducted for the design of a virtual reality-based learning environment focused on human anatomy and body systems. The main objective of the project is to support introductory anatomy education by providing an accessible, immersive, and interactive 3D experience that complements traditional teaching methods such as plastic models and 2D atlases, helping students recognize and understand basic human anatomy and body systems. To position the proposed system within existing work, we reviewed studies at the intersection of VR, anatomy, and medical education, as well as selected commercial applications that offer 3D anatomical content. The literature includes academic studies that compare VR or 3D systems with traditional teaching methods, generally evaluating learning outcomes, user satisfaction, and perceived usefulness. Overall, the findings suggest that VR can improve motivation, interest, and spatial understanding of anatomical structures. Based on observations, our project aims to develop a VR-based human anatomy and body systems learning application that combines interactive exploration with detailed 3D models and integrated testing.

2

## 3.2. Introduction

Human anatomy is a fundamental topic in health-related education and an essential for understanding how the human body functions. However, for many introductory-level learners, such as vocational high school students in health or related programs, anatomy is often perceived as abstract and difficult to visualize. Traditional teaching materials, including 2D atlases, posters and simple plastic models, can be sufficient for memorizing the names of structures but may not fully support the development of three-dimensional spatial understanding. Differences in learning styles, limited prior knowledge and restricted access to high-quality physical models can make it even harder for some students to build a solid conceptual understanding of basic anatomical structures and body systems. As a result, students may struggle to connect what they see in books with how organs and systems are actually organized in the human body. Recent advances in educational technology, and particularly in virtual reality, offer new opportunities to address these challenges.

VR can provide an immersive, interactive 3D environment in which learners can explore anatomical structures from multiple angles, zoom in on specific regions and engage with content in a more active and engaging way. Many existing VR anatomy platforms, however, are designed primarily for university-level medical students, and can be too complex, dense or language-heavy for younger learners. In addition, they may lack guided activities and explanations tailored to the needs and curriculum of vocational high school students, making them difficult to integrate directly into basic anatomy courses. This situation creates a need for a VR-based learning tool that is specifically designed for introductory anatomy education, with clear, accessible content and structured learning activities aligned with basic curriculum goals.

The project presented in this report aims to design a VR-based learning environment that supports introductory human anatomy and body systems education. The focus is on helping students recognize and understand basic anatomical structures through an accessible, immersive and interactive 3D experience that complements traditional teaching methods like plastic models and 2D atlases. Within the VR environment, learners will be able to explore 3D models of key anatomical structures, observe their relative positions and relationships and interact with them through actions such as rotating, zooming, highlighting and viewing basic descriptions. Integrated quizzes are planned to reinforce learning, turning the application into an active learning tool rather than a purely visual reference. In this way, the system is intended to make introductory anatomy more concrete, engaging and memorable for vocational high school students.

## 3.3. Background and Core Topics Related to the Project

### 3.3.1. Anatomy Education and Challenges in Introductory Learning

Anatomy is one of the core components of health-related education and provides the structural basis for understanding how the human body functions. In introductory courses, students are typically introduced to the major body systems rather than very

detailed regional anatomy. Each system is presented as a set of organs and structures that work together to perform specific functions, such as movement, breathing, circulation or digestion. For learners at the vocational high school level, the goal is practical understanding of how the body is organized, so that they can interpret basic health information, understand simple clinical situations and communicate effectively in health-related environments.

Traditional anatomy education in this context often relies on textbooks, 2D atlases, posters and, when available, simple plastic models. These materials usually present each body system separately, outlining its main organs, basic structure and key functions. While this approach can be effective for listing and memorizing anatomical terms, it can make it difficult for students to develop an integrated mental picture of how the different systems are arranged in three-dimensional space and how they relate to one another. For example, a student might know the names of the major bones or organs, but still struggle to visualize where they are located relative to each other in the body, what their approximate size is or how they fit within the overall structure of the torso, head or limbs.

In addition to these representational limitations, introductory anatomy learning is also affected by factors such as limited lesson time and varying levels of motivation among vocational high school students. Some learners may quickly memorize names without fully understanding what they represent, while others may feel overwhelmed by the volume of unfamiliar terms and diagrams. When anatomical structures are taught largely as lists to be remembered rather than as meaningful parts of a coherent whole, students can have difficulty retaining what they learn or applying it in new situations. Altogether, these challenges make it harder for beginners to develop an intuitive, three-dimensional understanding of the body, even when they appear to know individual anatomical terms [1].

### 3.3.2. Virtual Reality in Education and VR-Based Anatomy Learning

Virtual reality has emerged as a promising technology in education because it can create immersive, three-dimensional environments that go beyond the limitations of traditional classroom materials. In a VR setting, learners are visually and sometimes physically "placed" inside a virtual world, where they can look around freely, interact with objects and experience situations that would be difficult, expensive or impossible to reproduce in real life. This sense of immersion can increase attention and curiosity, especially for students who are used to digital media and games. Instead of only reading about a topic or viewing static pictures, learners can actively explore content, which can make abstract or complex concepts more concrete and memorable [2].

From a pedagogical perspective, VR supports active and experiential learning approaches. When students are able to manipulate virtual objects, perform simple tasks and see the immediate consequences of their actions, they are not just receiving information but also constructing their own understanding. This can be particularly valuable in subjects that involve spatial relationships or procedural steps, such as navigating a virtual environment, assembling components or visualizing 3D structures. VR also allows educators to design safe and controlled scenarios. In addition, VR

experiences can be repeated and paused as needed, giving students the opportunity to revisit challenging concepts at their own pace [3].

In the context of health and anatomy education, VR offers specific advantages that align well with the needs of introductory learners. Three-dimensional models of the human body and its systems can be explored from different perspectives, enlarged for closer inspection and selectively highlighted to focus attention on particular structures. For vocational high school students, this can bridge the gap between abstract textbook images and the actual organization of the body by providing a more intuitive sense of depth, position and scale. However, to be effective at this level, VR applications must balance immersion with simplicity: interfaces need to be clear and easy to use, content must be aligned with basic learning objectives and the overall experience should support rather than overwhelm beginners. When designed with these considerations in mind, VR can become a powerful complementary tool that enhances motivation, supports visual understanding and enriches the learning experience in introductory anatomy courses.

### 3.3.3. User Experience and Feedback in VR Anatomy Applications

In VR anatomy learning environments, interaction design and user experience play a central role in determining whether students can focus on the content or become distracted by the interface. For vocational high school learners, who may have limited experience with VR, controls need to be intuitive and consistent. Core actions such as rotating 3D models, zooming in and out, selecting structures and revealing labels or short descriptions should be easy to discover and perform without reading long instructions. Overly complex menus, dense interfaces or advanced options designed for experts can increase cognitive load and frustration. Clear visual cues, such as highlighting selected structures, using readable labels and providing straightforward icons or tooltips, help learners understand what they can do and what is currently happening in the virtual environment. A well-designed interaction model therefore supports students in engaging with anatomical content rather than struggling with technology [4].

Comfort and accessibility are equally important aspects of user experience in VR-based anatomy learning. Poorly designed camera motion, navigation or visual layouts can cause motion sickness, eye strain or fatigue, which is especially problematic for younger learners. To avoid these issues, navigation is often kept simple, for example by using teleportation or fixed viewpoints instead of continuous free movement, and by ensuring that camera transitions are smooth and predictable [5]. Text and anatomical labels should be sufficiently large and high-contrast to be easily readable, and interactive elements such as buttons or hotspots on the model must be sized and positioned so they can be reached comfortably with standard VR controllers. In addition, providing light guidance can keep learners oriented and help them progress through the activity step by step, instead of feeling lost in a complex virtual space [6].

Assessment and feedback mechanisms within the VR application complete this picture by turning exploration into a structured learning process. Rather than serving only as a visual reference tool, a VR anatomy system can integrate simple quizzes and

tasks that ask learners to identify structures, match names to locations or recall basic functions of organs and systems. When students receive immediate feedback, they can monitor their own understanding and correct misconceptions in real time. Combining intuitive interaction, comfortable and accessible design, and built-in assessment and feedback therefore creates a cohesive VR learning experience that supports both engagement and meaningful understanding of anatomy [7].

### 3.3.4. Unity as a Game Engine for VR-Based Anatomy Applications

Unity is a widely used game engine and development environment that supports the creation of interactive 2D and 3D applications for multiple platforms, including virtual reality. It provides a scene-based workflow in which developers can place and configure 3D models, lights, cameras and user interface elements, and then attach scripts written in C# to define interactive behaviours. Unity's component-based architecture allows functionality to be built by combining reusable components on game objects rather than writing all logic from scratch [8]. This combination of visual editing tools, scripting capabilities and built-in VR support makes Unity a practical choice for educational VR applications, where developers often need to focus on designing meaningful content and interactions rather than on implementing low-level rendering or tracking systems.

For a VR anatomy learning application, Unity can be used to manage and present 3D anatomical models in a clear and controllable way. Different body systems or regions can be organized into separate scenes, while lighting and camera settings can be adjusted to highlight relevant structures. Typical interactions, such as rotating a model, zooming in and out, selecting a structure, highlighting it and displaying its name or a short description, can be implemented by attaching scripts to anatomical objects and using Unity's event system to respond to VR controller input. Unity's UI tools also make it possible to create simple, readable menus, buttons and information panels, which is particularly important for introductory learners who may be using VR for the first time [9]. In addition, the engine supports an iterative workflow in which developers can quickly test changes in play mode, reuse existing assets and benefit from extensive documentation, tutorials and community resources [10].

Unity can also serve as a bridge between the VR application and external AI-based services that support feedback and assessment. Through its C# scripting and networking capabilities, Unity can communicate with machine learning models or educational back-end systems that analyse quiz results, track common mistakes or generate simple hints for learners. Unity's ability to integrate third-party libraries and web APIs allows developers to experiment with features such as adaptive question selection, simple conversational guidance or automated progress summaries without embedding complex AI logic directly into the game engine. In this way, AI-enhanced functionality can be layered on top of the core Unity-based interaction and visualization, gradually enriching the learning experience while keeping the underlying architecture manageable [11].

### 3.3.5. AI-Supported Learning in VR Anatomy Applications

Artificial intelligence has increasingly been used in educational systems to provide more personalized and data-driven support for learners, without replacing the teacher. Rather than always relying on fully dynamic or self-learning systems, AI in educational applications can also be built on carefully designed, static data sets that are structured for teaching. This approach allows developers and educators to control the accuracy, scope and difficulty of the material while still benefiting from AI techniques to deliver, organize and present the content in a flexible way. At the same time, it makes it possible to monitor learning progress in more detail and to provide timely, targeted support to learners [12].

Feedback is a central area where AI can contribute to educational applications, both through automated responses and conversational support. In many traditional settings, students receive feedback only after an exam or assignment has been graded, which can delay the correction of misconceptions, whereas AI-supported systems can provide immediate feedback during or right after a learning activity. When a learner answers a quiz question, selects an option or interacts with a digital object, the system can automatically classify the response as correct or incorrect, highlight the relevant part of the material and display a short explanation or hint [12]. In addition to this automated feedback, AI can also support learning through interactive question–answer mechanisms and conversational assistance: a chatbot-style component, connected to the underlying anatomy content, can allow students to ask questions in natural language and receive concise, targeted answers. This conversational layer can be integrated into the VR experience or provided alongside it, and, depending on available resources, may be extended with speech technologies so that students can listen to explanations or even ask questions by speaking instead of typing. Such features are particularly helpful for introductory learners, as they reduce the barrier to seeking help and make the interaction feel more similar to asking a teacher for clarification [13].

In a VR-based anatomy learning environment, AI-supported feedback and assessment can complement the system's visual and interactive features by using a static educational knowledge base, a structured set of test questions and a chatbot-style interface. Even if the goal at the introductory level is not to build highly complex adaptive systems, integrating AI-driven feedback and simple forms of adaptation can make the learning experience more responsive to individual needs: fixed data ensure that explanations and questions remain aligned with the curriculum and at an appropriate level for vocational high school students, while AI components help deliver this content in a more interactive way. By combining VR-based visualization with AI-supported assessment, such applications can offer both engaging exploration and structured guidance. In this setting, AI does not replace traditional teaching but reinforces it through instant answers, basic feedback and additional practice opportunities that are closely linked to the anatomical concepts presented in the virtual environment [14].

*Figure 2. Conceptual illustration of VR-based anatomy learning, where students explore 3D anatomical models and receive AI-supported explanations and feedback.*

## 3.4. Related Work and Existing Applications

In this section, we focus more concretely on existing systems and studies that have applied our project's topic in practice. Our aim is to understand how VR-based anatomy applications have been designed, what kinds of learners they target, which interaction and feedback mechanisms they use and what kinds of learning outcomes have been reported. This overview helps us position our own project within the current landscape of VR anatomy tools rather than designing it in isolation.

The literature on VR in anatomy and health education is quite diverse. Some systems are designed as immersive 3D atlases that allow students to explore anatomical structures in detail, while others focus on specific regions such as the heart, skull or brain, or even on advanced surgical training scenarios. Many studies compare VR-based learning with traditional methods typically measuring knowledge gains, spatial understanding, motivation and user satisfaction. More recent work also explores how AI components, such as virtual assistants or adaptive assessment, can be integrated into VR environments to provide more personalized support.

For our purposes, we concentrate on a subset of studies and applications that are most relevant to an introductory-level, system-focused anatomy course. The following paragraphs summarize five representative examples in more detail and highlight how their design choices and findings inform the design of our own VR-based anatomy and body systems learning environment.

- In the study "An Alternative Method for Anatomy Training: Immersive Virtual Reality", examined whether an immersive 3D VR application could be used as an alternative to traditional anatomy education for undergraduate physical therapy students. In their randomized controlled study, 72 students were divided

8

into a control group, which used traditional materials, and a VR group, which used an interactive 3D anatomy application. Both groups completed anatomy tests before and after the learning sessions. The results indicated that students in the VR group showed a greater improvement in test scores and reported positive impressions of the immersive environment, suggesting that VR can support understanding of anatomical structures rather than serving only as an eye-catching technology [15]. Although the study was conducted with university-level students, it provides useful evidence that interactive 3D visualization in VR can enhance anatomy learning. For our project, which targets introductory-level vocational high school students, this work supports the idea that a VR-based system with 3D anatomical models and structured quizzes can improve learners' motivation and help them build a more robust understanding of body structures compared to relying solely on traditional 2D materials.

- In the article "Immersive Anatomy Atlas: Learning Factual Medical Knowledge in a Virtual Reality Environment", the authors present an immersive VR-based anatomy atlas designed to help students learn factual anatomical information through three-dimensional exploration. Instead of studying only from textbooks or 2D images, learners use a VR headset to inspect anatomical structures from different angles, zoom in on specific regions and access basic labels and descriptions inside the virtual environment. In their evaluation, the immersive atlas was tested with high school students and compared with more traditional learning resources, and the authors examined outcomes such as factual test scores, learning time and students' perceptions of the VR tool. The results suggest that the immersive atlas can support the acquisition of factual anatomical knowledge at least as effectively as conventional methods, while also increasing engagement and interest in the subject [16]. Because this study was conducted with learners at the high school level rather than only with university students, it is particularly relevant for our project. It shows that a relatively simple VR atlas with clear 3D models and basic information can function as a structured learning tool for younger learners, which supports our decision to design a VR-based application in which vocational high school students explore key body systems in three dimensions and reinforce their learning through integrated quizzes and short descriptions aligned with their introductory curriculum.

- In the article "Using Virtual Reality to Complement and Enhance Anatomy Education", describe the development of a pilot VR anatomy resource that presents a set of 3D anatomical models in an immersive environment for university students. Instead of replacing existing teaching methods, the system is explicitly designed to complement traditional resources such as atlases and models by allowing learners to inspect structures in three dimensions and experience a stronger sense of being inside the anatomy. The authors report that students who used the VR resource generally found it engaging and helpful for

understanding spatial relationships, and they viewed the technology as a valuable addition to their anatomy teaching rather than a novelty. At the same time, the study is a small-scale pilot conducted in a single institution, so the results mainly provide qualitative evidence about perceived usefulness and acceptance rather than large-scale learning gains [17]. For our project, this work is important because it supports the idea of positioning our VR application as a complementary tool alongside existing materials used in vocational high schools, helping students visualize body systems in 3D while still staying aligned with the more familiar 2D diagrams and models used in their regular lessons.

- In the conference paper "Towards Anatomy Education with Generative AI-based Virtual Assistants in Immersive Virtual Reality Environments", the authors explore how a generative AI assistant can be embedded inside a VR anatomy environment to support learners during complex question-answer tasks. They design a virtual reality system in which students interact with an embodied AI tutor that can respond to different levels of anatomy questions through natural language dialogue, and they compare different assistant configurations, such as avatar-based versus screen-based presentation. In a small pilot study with medical students, they report that the AI-supported VR environment was generally usable, that students perceived a good sense of presence and that the assistant could help them handle cognitively demanding anatomy questions without overloading them [18]. Although this work targets a more advanced medical education context and uses state-of-the-art generative AI, it is conceptually relevant to our project. It illustrates how conversational AI can be integrated into a VR anatomy application to provide on-demand explanations and guidance. Our system aims to apply the same idea at an introductory level, using a simpler, curriculum-aligned knowledge base and basic chatbot interface to allow vocational high school students to ask questions about body systems and receive concise, supportive feedback while exploring the VR environment.

- In the article "Cognitive Load Measurement of Using Virtual Reality Headset (Oculus Rift CV1) to Enrich the Anatomy Course and Increase Motivation Among Medical Students", Alfarani and Alharbi examine how adding a VR headset–based anatomy application to a university anatomy course influences students' mental effort and motivation. Third-year medical students used an headset to complete several anatomy-related tasks and then rated how demanding and useful they found the experience, which was compared with their impressions of traditional teaching methods. The authors report that, although VR is a new medium, students did not experience an unacceptable increase in cognitive load and generally viewed the VR activities as engaging and motivating, suggesting that well-designed VR sessions can support learning without overwhelming learners. The study is limited to medical students and a

specific institutional context, but it underlines the importance of designing VR tasks that are short, focused and clearly structured [19]. For our project, this work reinforces the idea that an introductory VR application for vocational high school students should use simple interactions, clear instructions and modest amounts of content per session, so that the motivational benefits of immersion are preserved while cognitive load remains manageable.

In addition to these core studies, several other works provide useful background on VR-based anatomy tools and delivery options. "Virtual Reality in Anatomy: A Pilot Study Evaluating Different Delivery Modalities" compares different ways of presenting VR content such as desktop, stereoscopic display and head-mounted display and shows that the choice of modality can influence students' comfort, engagement and perceived usefulness, which is relevant for deciding how immersive our own system should be [20]. Earlier systems such as the "Virtual Reality Educational Tool for Human Anatomy" and the "Virtual Reality Medical Training System for Anatomy Education" demonstrate how 3D anatomical models and basic interactions like rotation, zooming and selection can be implemented in VR for specific regions such as the cranium or the heart, indicating that even relatively simple applications can support anatomy learning [21] [22]. Finally, the book chapter "Learning Anatomy Using Virtual Dissections: Previous Experience and Future Directions Integrating Artificial Intelligence and Multiple Approaches" reviews the use of virtual dissection tools alongside textbooks and physical models, and discusses how AI could help adapt these tools to different learner needs [23]. Together, these studies illustrate a progression from early VR anatomy prototypes to more structured and AI-aware systems, and they support our decision to design a focused, system-level VR application that combines clear 3D visualization with simple interaction and curriculum-aligned assessment for vocational high school students.
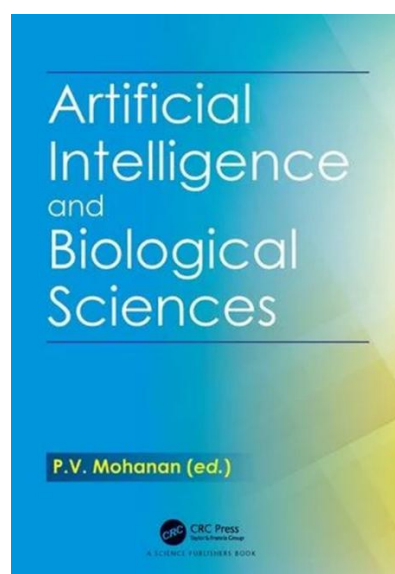


*Figure 3. Cover of the book Artificial Intelligence and Biological Sciences (P. V. Mohanan, ed.), used as a reference source in the study.*

## 3.5. Discussion and Identified Gaps

The studies and applications reviewed in the previous section suggest that virtual reality has clear potential to support anatomy education with the positive findings such as visualization, spatial understanding and learner motivation. Although, despite these positive findings, several gaps emerge when the existing literature is considered from the perspective of our target context. First, most VR anatomy systems are designed for medical or university-level students and assume a relatively high degree of prior knowledge and familiarity with scientific terminology. There is much less work focusing on introductory-level learners, such as vocational high school students, who need simplified, system-level content rather than detailed regional or surgical anatomy. Second, many applications either present highly detailed whole-body models or focus on advanced, specialized topics, which makes them difficult to adapt to a basic curriculum that aims primarily to introduce major body systems and key structures. Third, although some studies integrate quizzes or evaluation components, a considerable number of VR tools are used mainly for free exploration and do not include simple, curriculum-aligned assessment and feedback mechanisms that could help beginners check their understanding while they explore.

A further set of gaps concerns user experience and the integration of AI-based support. Several works acknowledge issues such as motion sickness, interface complexity and the need to manage cognitive load, but relatively few explicitly address the design of VR interactions for learners who may be encountering both the content and the technology for the first time. Simple controls, clear labels and short, focused activities are particularly important at this level, yet many existing systems are not tailored with these constraints in mind. In parallel, only a small number of recent studies investigate how conversational AI or virtual assistants can support anatomy learning inside VR environments, and these are typically aimed at advanced medical students and complex question types. There is still limited evidence on AI-supported VR tools that rely on a static, curriculum-aligned knowledge base, provide basic question–answer interactions and offer immediate but simple feedback suitable for beginners. Overall, these observations indicate a need for a VR-based anatomy application that is explicitly designed for introductory, system-level content, combines guided 3D exploration with integrated quizzes and lightweight AI support, and is optimized for the usability and cognitive demands of vocational high school learners.

## 3.6. Proposed System and Expected Contributions

Our proposed system is a VR-based learning application that aims to support introductory human anatomy and body systems education for vocational high school students. The main idea is to provide an accessible 3D environment where learners will be able to explore key anatomical structures in an immersive but controlled way, instead of relying only on 2D textbook images and static posters. Using a Unity-based implementation, the system is planned to present simplified 3D models of selected body systems with a level of detail appropriate for an entry-level curriculum. Students will be able to inspect these models from different viewpoints, zoom in on specific regions and

highlight individual structures, while seeing short, curriculum-aligned labels and descriptions that focus on names, locations and basic functions rather than on advanced clinical detail.

The interaction design is intended to remain simple to match the needs of learners who may have little or no prior experience with VR. Core actions such as rotating a model, zooming, selecting a structure and toggling labels will be mapped to a small, consistent set of controller inputs and visually reinforced through clear on-screen hints. Navigation is planned to be organized around a limited number of scenes or "modules", each corresponding to a specific body system or region, so that students do not get lost in a large, complex virtual space. Text elements will be high-contrast and readable, and the duration of individual VR activities will be kept short and focused to help manage cognitive load. In this way, the system is designed to complement, rather than replace, existing teaching materials. Students are expected to encounter a topic in class or in a textbook and then use the VR environment as an additional step to build a three-dimensional mental model of what they have learned.

To move beyond pure visualization, the application is also planned to integrate basic assessment and AI-supported assistance. Within each module, learners will be able to complete simple quiz activities that ask them to identify structures on the 3D model, match names to locations or recall basic functions. The questions and correct answers will be stored in a static, curated question bank aligned with the vocational high school curriculum, which will allow the system to provide immediate feedback, such as indicating the correct region on the model and displaying a short explanation. In addition, a chatbot-style interface is envisioned to give students an opportunity to ask questions in natural language about the structures they are viewing and to receive short, targeted answers based on the same underlying knowledge base. This conversational component may initially be text-based, with the option of adding speech output at a later stage so that explanations can also be listened to rather than only read.

The expected contributions of this project are therefore prospective. Practically, the planned system aims to provide a VR anatomy tool that is explicitly tailored to vocational high school learners, combining simplified 3D models, guided exploration and integrated quizzes in a single environment. Conceptually, the project seeks to bring together ideas from the literature on VR anatomy education, cognitive load and AI-supported feedback by applying them to an introductory, system-level setting that is underrepresented in existing work. The design choices we outline such as limiting complexity, structuring content around body systems and embedding a lightweight, curriculum-aligned chatbot are intended to serve as a small set of design guidelines for similar applications targeting beginner-level learners. Overall, the proposed system is expected to demonstrate that a carefully scoped VR and AI-supported application can make basic anatomy more concrete, engaging and understandable for vocational high school students without overwhelming them with unnecessary detail or technological complexity.

## 3.7. Conclusion

In this report, we explored how virtual reality and AI-supported tools could be used to support introductory anatomy and body systems education for vocational high school students. We first discussed the difficulties of learning anatomy at this level, where students need a basic understanding of major body systems but often struggle to visualize structures using only 2D resources. We then reviewed core concepts related to VR, user experience and AI-based feedback, and examined existing VR anatomy systems and studies. The literature suggests that immersive 3D environments can enhance motivation and spatial understanding, but also reveals gaps. Most systems target university or medical students, many focus on advanced or highly detailed content and relatively few combine simplified models, curriculum-aligned assessment and lightweight AI support for beginners.

In response to these gaps, we proposed a VR-based learning application tailored to vocational high school learners, built around simplified 3D models of selected body systems, guided exploration, integrated quizzes and a chatbot-style assistant backed by a static, curriculum-aligned knowledge base. The project is currently at a design stage, and the next steps will involve implementing the planned system, refining the interaction design and evaluating it with actual students in terms of usability, motivation and learning outcomes. Our overall goal is to show that a carefully scoped combination of VR visualization and AI-supported feedback can complement existing teaching methods and help introductory-level learners build a more concrete and intuitive understanding of basic human anatomy.

# 4. Product Vision & Scope

## 4.1. Overview

### 4.1.1. Purpose

This report has been prepared to present the product vision and scope of the VR Anatomy project in a clear, measurable, and verifiable manner. The document explains the educational need the project addresses, the characteristics of the target user group, and the requirements under which the application will be used, thereby outlining the project's objectives. Within this framework, the report defines the system's main features and demonstrates how these features are linked to user needs.

In addition, the report captures the key actions users are expected to carry out in the application through a set of user stories. Each user story is supported with clear acceptance criteria that define what conditions must be met for the related functionality to be considered complete. This helps the team translate the vision into concrete development goals and provides a consistent reference point during implementation, testing, and evaluation.

Furthermore, the document specifies the project's scope boundaries by explicitly stating both the topics the team will focus on and those that are excluded from the scope. This clarifies expectations and provides guidance for potential future extensions.

### 4.1.2. Product Summary

VR Anatomy is an interactive educational application designed to help students who are health vocational high school students learn human anatomy more clearly and retain it more effectively in a virtual reality environment. The application aims to enable students to learn by experiencing, within VR, the three-dimensional form and basic relationships of anatomical structures that are difficult to grasp through two-dimensional textbook/atlas images. Rather than replacing existing resources, the system is positioned as a complementary tool and provides an immersive learning experience focused on selected anatomical systems.

VR Anatomy uses a modular content structure. Upon launch, the student selects the anatomical system to study from a main menu in VR, after which the relevant scene, 3D models, and learning content are loaded. To keep the initial release feasible, the project focuses on a limited set of anatomical areas, enabling a manageable initial version while still offering a clear learning path. Inside the VR environment, students explore a central 3D anatomical model using basic XR interactions. When a structure is selected, it is highlighted and an information card appears within the user's view, presenting the structure's name and a brief description. Students can manipulate the model to strengthen spatial understanding, and they can reinforce learning through short quizzes that provide immediate feedback.

Educational content including structure descriptions and quiz questions is delivered through JSON-based content files packaged with the application, supporting organized content management and easier future expansion. The system also includes an optional RAG-based AI Tutor that answers student questions using the provided learning materials.

## 4.2. Product Vision

### 4.2.1. Vision Statement

VR Anatomy enhances anatomy learning in VR through interactive 3D exploration, clear structure-based explanations, and optional tutoring support to help students learn faster and retain knowledge longer.

### 4.2.2. Problem and Opportunity

Anatomy education still relies heavily on two-dimensional materials such as textbooks, slides, and diagrams. Because of that, students may find it difficult to build an accurate mental model of anatomical structures especially when trying to understand

the true shape of bones and organs, their depth, and how different structures relate to one another in space. When students' questions are not answered promptly and reliably during the learning process, the learning flow can be interrupted. In addition, limited access to physical models or laboratory materials can reduce opportunities for detailed, hands-on exploration.

This creates an opportunity for a VR-based learning approach. Virtual reality enables students to view anatomical structures directly in 3D, inspect them closely, and explore spatial relationships more intuitively than with 2D resources. In VR Anatomy, selecting a structure provides clear visual feedback and opens a concise information card within the user's field of view. Combined with basic XR interactions such as selecting, grabbing, rotating, and examining from different angles learning becomes more active and structured, supporting both recognition of structures and understanding of their spatial context.

When available, the AI Tutor further supports this process by letting students ask short questions and receive immediate explanations without leaving the VR environment. Since responses are grounded in the project's prepared learning content, the system aims to keep explanations consistent with the scope and terminology of the course materials.

## 4.2.3. Value Proposition

### 4.2.3.1. For Students

VR Anatomy supports students in understanding and retaining anatomy by enabling interactive 3D exploration in a VR environment. Instead of relying only on 2D materials, students can examine structures from multiple angles, build stronger spatial understanding, and follow a more organized study flow through clear, structure-focused information shown at the moment of interaction. Learning is further reinforced through short self-assessment activities that provide immediate feedback. When available, the optional AI Tutor offers quick, content-based explanations without requiring students to leave the learning context.

### 4.2.3.2. For Instructors

For instructors, VR Anatomy can function as an interactive demonstration and support tool during lessons or guided practice sessions. The modular structure allows instructors to focus on specific systems aligned with lesson objectives, while the 3D environment helps communicate spatial relationships that can be difficult to convey with static visuals. In this way, the application complements existing teaching materials and can help students stay engaged and oriented while reviewing key structures.

## 4.3. Target Users and Context

### 4.3.1. Users

#### 4.3.1.1. Primary Users

The primary target users of VR Anatomy are health vocational high school students who study anatomy at an introductory level. This group typically needs support in forming an accurate 3D understanding of anatomical structures, including their shape, spatial relationships, and basic structure areas that can be challenging to grasp through 2D materials alone. Students also benefit from a guided learning flow that helps them stay oriented while exploring unfamiliar content and reinforces key concepts through short, clear explanations and practice activities. In addition, an optional AI Tutor that provides content-based question-and-answer support can further assist students during self-study by offering quick clarification without interrupting the learning process.

#### 4.3.1.2. Secondary Users

Instructors are identified as the secondary user group of VR Anatomy. Their main contribution is to support students during classroom or laboratory sessions by guiding the learning flow and helping the group stay focused on the intended topic. Instructors guide the session externally and are not required to interact with the VR interface directly.

### 4.3.2. Usage Environment

The application is designed as a virtual reality learning experience intended for short and controlled sessions in educational settings. A typical usage scenario takes place in a school VR or simulation laboratory, a computer lab, or any other area suitable for safe VR use. In the current setup, the application is intended for single user sessions and does not support simultaneous use by multiple students on the same device. In addition to individual study sessions, the application can also be used in a classroom demonstration setting led by an instructor. VR Anatomy is delivered as a Unity based VR application that runs on supported VR hardware. Students interact with the environment through standard VR controller inputs to select modules and explore anatomical content. Key interface elements such as information cards, quizzes, and the optional AI support panel are displayed within the VR view in a clear and readable format to guide the learning flow.

### 4.3.3. Assumptions and Constraints

The project assumes that students can learn basic VR controller operations with brief guidance and that the user interface can be kept simple and clear enough to support learning rather than distract from it. The application is intended for educational use and

is not designed for clinical or diagnostic purposes. If the AI Tutor feature is enabled, another assumption is that responses will be based on the learning content provided within the project scope so that explanations remain aligned with the intended curriculum focus. It is also assumed that content will be developed incrementally, meaning the first release will include a limited and modular set of topics that can be expanded in later releases.

The main constraints of the project are budget, time, and content production capacity. Producing anatomy content requires preparing and validating 3D models, optimizing them for VR performance, and linking them with educational descriptions and assessment items, which directly impacts the development timeline. In addition, VR comfort and performance requirements limit scene complexity and asset size, so the system is designed to load content per module rather than keeping all assets active at the same time. Finally, the AI Tutor depends on prepared data, retrieval components, and external service availability. Therefore, AI functionality and response quality may be affected by connectivity and resource limitations.

## 4.4. Main Features

### 4.4.1. Module Selection and Navigation

VR Anatomy uses a module based structure to divide anatomy content into manageable learning units. When the application starts, the student selects the module to study from a main menu in the VR environment. After a module is selected, the corresponding scene, 3D models, and module specific learning content are loaded.

Within a module, the student can use basic navigation controls to maintain a smooth learning flow, including returning to the main menu, switching to another module, and ending the session when needed. During loading and transitions, the application provides clear on screen feedback so users understand that content is being loaded and do not lose context.

### 4.4.2. 3D Exploration

The application enables comfortable 3D exploration in VR so that students can better understand the shape of anatomical structures and their spatial relationships. Students can adjust their viewpoint within the scene in a safe and controlled way to observe the model from different angles. They can also inspect details by moving closer to the structure or stepping back to view it as a whole. To support VR comfort and safe use, movement is designed to be controlled and limited, educing the risk of discomfort and helping users stay oriented during exploration.

### 4.4.3. Interaction

VR Anatomy's learning experience is centered on direct interaction with anatomical structures. Using VR controllers, the student can point to a structure and select it, after which the system highlights the selection to make it clearly identifiable. When supported by the module, the student can then manipulate the structure through actions such as grabbing, releasing, and rotating it to inspect it from multiple angles.

These interactions encourage active exploration and make it easier to understand a structure's form and key visual features, supporting stronger spatial understanding compared to relying on two-dimensional materials alone.

### 4.4.4. Labels and Info Cards

To support quick and clear learning of anatomical structures, VR Anatomy presents structure based labels and information cards. When a student selects a structure, the system displays its name and a short description in an information card that is easy to read within the VR environment. The text is kept brief and level appropriate so it can be understood without interrupting the exploration flow.

The information card is positioned to remain visible while minimizing obstruction of the main 3D view. Content shown on the card is retrieved through the mapping between each structure and its associated learning content, which is loaded together with the selected module.

### 4.4.5. AI Tutor

The application includes an AI Tutor feature to help students quickly clarify questions without leaving the learning flow. Students can submit questions through an in VR panel, and the system generates short educational explanations based on the learning content provided within the scope of the project. This helps keep answers aligned with the module content and terminology.

### 4.4.6. Quiz Mode

To reinforce learning, VR Anatomy provides a dedicated Quiz Mode that can be accessed directly from the main menu at any time. This mode is independent from the module exploration experience, meaning students may choose to solve questions without entering a module, or explore modules without completing quizzes.

In Quiz Mode, multiple choice questions are displayed on a VR panel. The student selects an answer using the controller and submits the response through a simple confirmation interaction. After submission, the system immediately provides correct or incorrect feedback to support quick self evaluation. Quiz content is drawn from module specific question pools.

### 4.4.7. Review Mode

In this mode, only the assets of the selected anatomical model are displayed, allowing the user to manipulate the model freely through standard VR interactions such as moving, rotating, and inspecting from different angles. Unlike the standard learning flow, Review Mode does not display information cards or automatic explanatory text. This enables instructors, as secondary users, to deliver their own explanations and guide students through the content in a way that matches their teaching plan.

## 4.5. User Stories

The following user stories define the core goals that the VR Anatomy application will provide for high school students and teachers. For each story, the acceptance criteria specify the observable conditions required for the feature to be considered "done."

### 4.5.1. Student User Stories

**US-S01 Module Selection**

- **Role:** Student
- **Goal:** Select an anatomy module to study.
- **Benefit:** Focus on a specific topic.
- **Priority:** Must-have
- **Acceptance Criteria:**
    - **AC1:** When the application launches, a main menu is displayed in VR and available modules are listed.
    - **AC2:** When the student selects a module, the corresponding scene and module content are loaded and ready for interaction.

**US-S02 In-Module Navigation**

- **Role:** Student
- **Goal:** Return to the main menu and switch modules without closing the application.
- **Benefit:** Maintain a continuous learning flow.
- **Priority:** Must-have
- **Acceptance Criteria:**
    - **AC1:** While inside a module, the student can access an option to return to the main menu.
    - **AC2:** After returning to the main menu, the student can select another module and load it successfully.

### US-S03 - Anatomical Structure Selection

- **Role:** Student
- **Goal:** Select an anatomical structure in VR.
- **Benefit:** Clearly identify the structure the student is examining.
- **Priority:** Must-have
- **Acceptance Criteria:**
  - **AC1:** The student can select a structure using VR interaction input available in the application.
  - **AC2:** When a structure is selected, the system provides a clear visual indication of the selection.

### US-S04- Grab & Inspect (Holding and Examining a Structure)

- **Role:** Student
- **Goal:** Examine a structure from different angles.
- **Benefit:** Better understand the structure's 3D form and spatial details.
- **Priority:** Must-have
- **Acceptance Criteria:**
  - **AC1:** Supported structures can be grabbed and released using VR controller input.
  - **AC2:** While grabbed, the structure can be rotated and inspected from multiple viewpoints.

### US-S05- Labels & Info Card

- **Role:** Student
- **Goal:** View the name and a short description for a selected structure.
- **Benefit:** Quickly learn basic information without breaking the study flow.
- **Priority:** Must-have
- **Acceptance Criteria:**
  - **AC1:** When a structure is selected, its name is displayed clearly in the VR environment.
  - **AC2:** An information card displays a short, level appropriate description for the selected structure.
  - **AC3:** The information card can be closed by the student.

### US-S06- Asking a Question to the AI Tutor Chat

- **Role:** Student
- **Goal:** Open the AI Tutor Chat for the selected module and ask questions.
- **Benefit:** Get quick explanations while studying the module content.
- **Priority:** Must-have

- **Acceptance Criteria:**
  - **AC1:** The student can open the AI Tutor panel within the application.
  - **AC2:** The student can submit a question using an available VR input method.
  - **AC3:** The system displays the AI Tutor response in a readable format within VR.
  - **AC4:** Responses are based on the project provided learning content and remain aligned with the module scope and terminology.
  - **AC5:** If no relevant content is found, the system returns a clear message indicating that information is not available in the current dataset.
  - **AC6:** The AI Tutor provides educational explanations only and does not provide diagnosis, treatment, or medical advice.

## US-S07- Quiz Mode Access

- **Role:** Student
- **Goal:** Access Quiz Mode to reinforce knowledge
- **Benefit:** Enable quick self-assessment on specific topics.
- **Priority:** Must-have
- **Acceptance Criteria:**
  - **AC1:** Students can access Quiz Mode directly from the main menu.

## US-S08- Answer and Feedback in Quiz Mode

- **Role:** Student
- **Goal:** Solve multiple choice questions and receive immediate feedback
- **Benefit:** Identify what students know and need to review
- **Priority:** Must-have
- **Acceptance Criteria:**
  - **AC1:** The student can select an answer and submit it within the quiz interface.
  - **AC2:** After submission, the system provides correct or incorrect feedback immediately.

## US-S09- Review Mode

- **Role:** Student
- **Goal:** Examine the selected anatomical model without automatic explanations
- **Benefit:** Enable focused review and instructor led explanation when needed
- **Priority:** Must-have
- **Acceptance Criteria:**

- o **AC1:** Review Mode can be accessed from the main menu or from within the module flow as defined by the application design.
- o **AC2:** In Review Mode, only the selected anatomical model assets are displayed for manipulation.
- o **AC3:** In Review Mode, the system does not display information cards or automatic explanatory text.

### US-S10- Basic Comfort and Audio Settings

- **Role:** Student
- **Goal:** Adjust basic settings to use the application comfortably
- **Benefit:** Better usability and comfort during VR sessions
- **Priority:** Should-have
- **Acceptance Criteria:**
  - o **AC1:** A settings menu is accessible from the main menu.
  - o **AC2:** Changes made in the settings take effect within the same session.

## 4.5.2. Instructor User Stories

### US-I01- Running a Demo Flow in Class

- **Role:** Instructor
- **Goal:** Guide students during VR Anatomy sessions without interacting with the VR application directly
- **Benefit:** Ensure a safe, structured, and curriculum aligned learning flow in classroom or laboratory use
- **Priority:** Should-have
- **Acceptance Criteria:**
  - o **AC1:** The application supports individual single headset sessions, allowing a student to use VR while the instructor guides the activity externally.
  - o **AC2:** The application provides a clear and predictable flow that can be followed without instructor interaction, including a visible main menu and a straightforward way for the student to start the learning experience.

# 4.6. Scope Boundaries

## 4.6.1. In Scope

Within the scope of this project, an initial version of a VR supported anatomy learning application will be developed. The goal of this initial version is to provide students with a clearer learning experience by enabling interactive, three dimensional exploration of anatomical content in a VR environment. The initial version includes the following capabilities:

- **Module based structure and flow:** When the application starts, the student selects an anatomy module from the main menu in VR. The content of the selected module is loaded and becomes available. In the initial release, the module set may be limited based on content production capacity.
- **3D visualization and exploration:** Anatomical models are displayed in VR and can be examined from different viewpoints through standard exploration controls.
- **Basic VR interactions:** Students can interact with the content using VR controllers, including selecting structures and examining supported parts through grabbing, rotating, and releasing.
- **Highlighting and information delivery:** When a structure is selected, the system visually highlights the selection and displays the structure name and a short, level appropriate information card. The information card can be closed by the student.
- **Review Mode:** A Review Mode is provided where only the assets of the selected anatomical model are displayed for free examine. In this mode, the system does not show information cards or automatic explanatory text, allowing instructor guided explanation when needed.
- **Quiz Mode:** Quiz Mode can be accessed directly from the main menu and can be used independently from module exploration. Multiple choice questions are presented on a VR panel, and the system provides immediate correct or incorrect feedback after an answer is submitted.
- **AI Tutor Chat:** The system provides question and answer support through an AI Tutor Chat interface that opens when the module is selected. Answers are generated based on the project provided learning content and are displayed within VR in a readable format. If relevant content is not available, the system returns a clear fallback message rather than guessing.
- **Basic UI and settings:** Core navigation and interface actions are included, such as returning to the main menu, switching modules, opening and closing panels, and basic comfort or audio settings.
- **Offline-capable core experience:** The core learning experience runs using locally packaged content. If the AI Tutor service is unavailable, the AI chat feature is disabled or unavailable while the rest of the application remains usable.

## 4.6.2. Out Of Scope

The following items are out of scope for the initial version of the project:

- **Broad anatomy coverage**: Full coverage of the entire human body and advanced level detail across all systems is not targeted. Content will remain limited and manageable based on production capacity.
- **Clinical and diagnostic use**: The application is not designed for diagnosis, treatment guidance, clinical decision support, or processing patient related data.
- **Advanced medical simulation and procedure training**: Features such as surgical simulation, medical procedure training, pathology and disease scenarios, and advanced haptic feedback are not included.

- **Multi user VR experience**: Multiplayer sessions, shared virtual classrooms, avatar based collaboration, and real time multiuser interaction are not supported.
- **Accounts and long term analytics:** User accounts, authentication, role based access control, persistent progress tracking across sessions, detailed assessment reports, and long term learning analytics are not included.
- **Instructor specific interface and in app content authoring**: A separate instructor interface and tools that allow adding or editing content during runtime are not included in the initial version.
- **Guaranteed AI accuracy and availability**: The AI Tutor feature does not provide guarantees of correctness under all conditions and may be affected by connectivity or external service availability. When the AI service is unavailable, the core application features remain usable.

## 4.6.3. Future Work

After the initial version, the product may be expanded depending on time, resources, and feedback gathered during use. Possible future improvements may include:

- **Content expansion:** Additional anatomical systems and a wider set of structures may be added in a modular manner to increase curriculum coverage.
- **Enriching the learning experience:** The quiz section may be expanded with more varied questions, optional mini activities, and a more structured progression to support step by step learning.
- **AI Tutor improvements:** If infrastructure allows, retrieval quality may be improved through better indexing and content organization. The system may also provide references to the learning material used to form answers, support multiple explanation levels, and optionally enable voice based question and answer.
- **Visual quality and performance:** 3D assets may be further optimized, performance tuning and level of detail improvements may be applied, optional lightweight animations may be added, and additional comfort settings could be included.
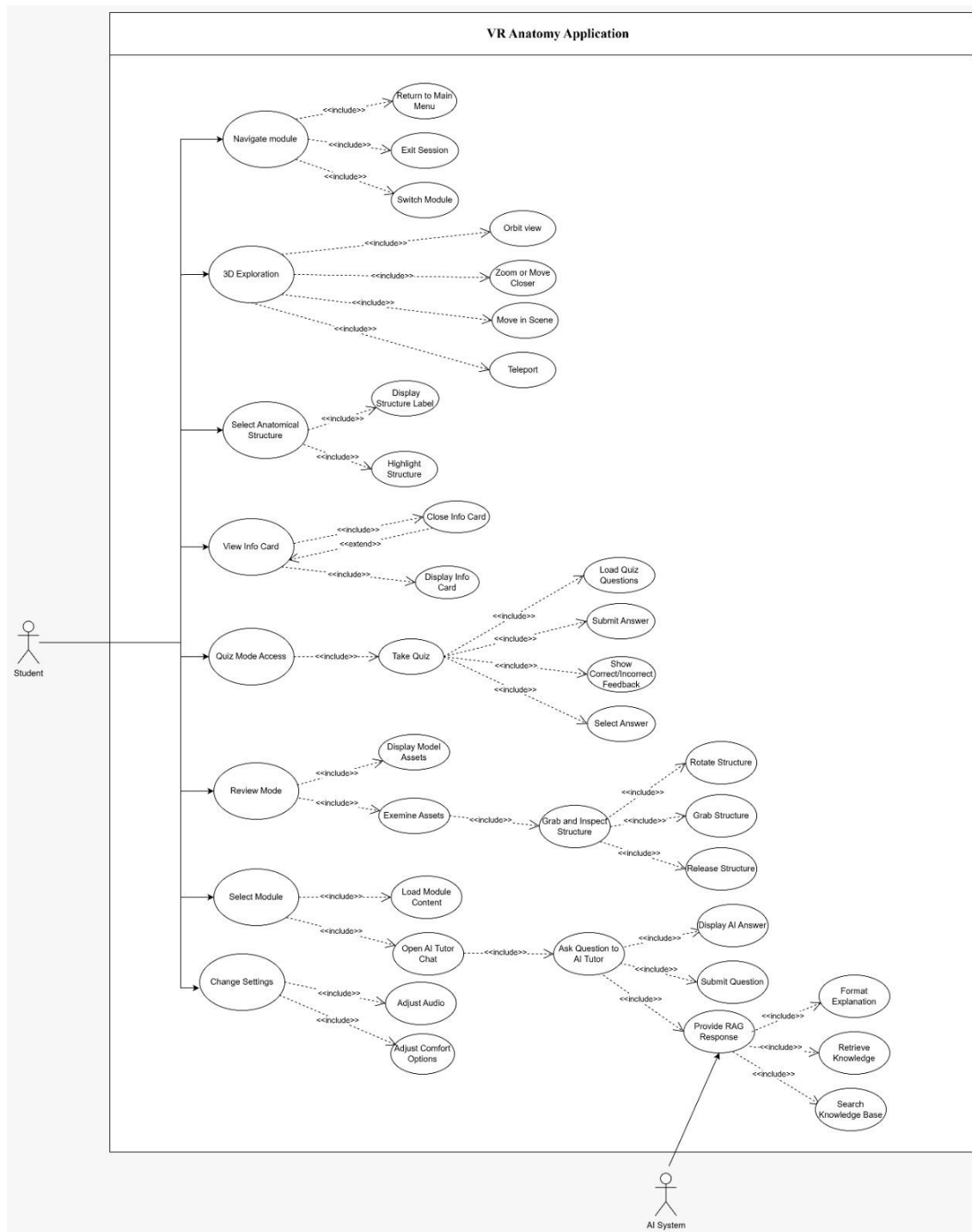
## 4.7. Use Case Model



*Figure 4. Use Case Model for "VR Anatomy - VR Based Educational Interactive Human Anatomy Training Platform"*

## 4.8. Conclusion

The VR Anatomy project presents a focused and deliverable initial version designed to support introductory anatomy learning through an immersive and interactive 3D VR experience. The application provides a clear navigation flow, basic VR interactions for exploring anatomical models, and structure focused learning support

through highlighting, labels, and short information cards. Learning is also reinforced through a dedicated Quiz Mode that enables quick self assessment with immediate feedback.

The report defines clear scope boundaries to keep the project feasible under constraints such as budget, time, content production capacity, and VR performance requirements. Broad anatomy coverage, clinical or diagnostic use, advanced medical simulations, multi user VR scenarios, persistent accounts and long term analytics, and in application content authoring tools are excluded from scope. The AI Tutor Chat, when available, provides educational explanations based on the project provided learning content without offering medical advice. Finally, the user stories and acceptance criteria provide measurable targets to guide implementation, testing, and evaluation in classroom or laboratory contexts.

# 5. System Architecture & Design Decisions

## 5.1. Overview

### 5.1.1. Purpose

The purpose of this report is to document the system architecture and the key design decisions of VR Anatomy. It explains how the Unity VR client, the packaged learning content, and the AI Tutor backend work together. It also states the reasons behind major choices such as scene organization, content storage format, and the separation between learning modes.

### 5.1.2. System Summary

VR Anatomy is a single user VR application designed for classroom guided use with one headset. The student is the primary user who interacts inside VR. The instructor is a secondary user who guides verbally and does not interact with the application directly.

Core features focus on module based anatomy exploration and a quiz mode that can be started from the main menu.

Main user capabilities are listed below.
• Select a module from the VR main menu
• Explore a 3D anatomy model in VR
• Select an anatomical structure and see it highlighted
• Perform basic interactions such as grab, rotate, and release
• View labels and short info cards for selected structures
• Start Quiz Mode from the main menu independent from modules
• Start Review Mode where only selected model assets are shown and info cards are not shown

• The AI Tutor provides a dedicated chat and voice interface that is opened from the main menu via the "AI Tutor" button.
• The student can ask questions either by typing or by using push-to-talk (speech-to-text).
• The backend returns a short text answer grounded in the project's learning content using a Retrieval-Augmented Generation (RAG) approach.
• The answer can optionally be read aloud via a speaker button (text-to-speech).
• In this version, the AI Tutor is not structure-aware and does not automatically use the currently selected anatomical structure as context.
• If the AI service is unavailable, the AI Tutor feature is disabled while core VR exploration and quiz features continue.

### 5.1.3. Architecture Goals

The architecture was designed to support an educational VR experience that is stable in classroom use and easy to expand with new modules and content. The system includes an AI Tutor feature that may become unavailable due to network or service issues. For this reason, the architecture separates the VR learning functions from the AI Tutor integration.

The main goals are listed below.
• Keep interactive exploration, Quiz Mode, and Review Mode clearly separated so that each mode remains simple and consistent
• Keep core VR functions usable when the AI Tutor service is unavailable, such as module selection, 3D exploration, structure highlighting, and basic interactions
• Allow content updates by changing JSON files and Unity model assets without changing the application logic
• Keep runtime behavior predictable for a single headset and a single student session
• Make the flow of information clear between user interface, content loading, interaction handling, and AI Tutor requests to simplify testing and troubleshooting
• Reduce reliance on online services so that non AI functions can still run in offline classroom conditions

## 5.2. High Level Architecture

This section describes the main building blocks of VR Anatomy and how data moves between them during key user actions. The system is centered on a Unity based VR client that loads local content for learning and calls an Azure based AI backend for the AI Tutor feature when available.

## 5.2.1. Architecture Diagram and Explanation

The diagram below shows the high-level components and their connections. The VR client runs on the headset, loads JSON and 3D assets locally, and communicates with the AI backend only for AI Tutor chat requests.
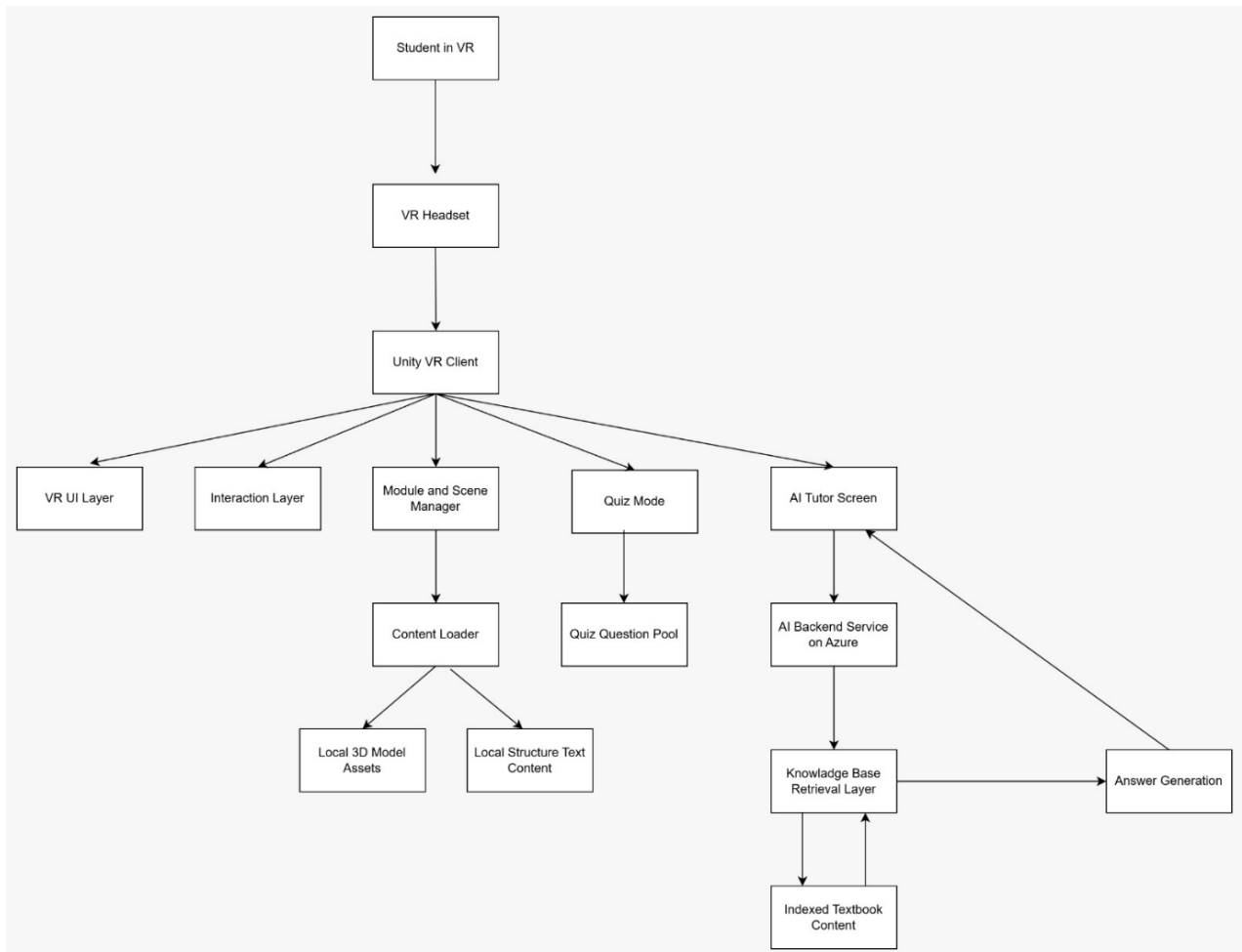


*Figure 5. High-level system architecture of the VR Anatomy.*

The architecture follows a simple rule. The VR learning functions rely on local assets so they can work without network access. The AI Tutor feature relies on the backend and may become unavailable while the VR client continues.

## 5.2.2. Main Components

**Unity VR Client:**
The VR client is the primary runtime environment. It renders the 3D anatomy scenes, handles XR input (controllers/hands), and displays all in-app UI. The client provides

the main user modes: Start Learning, Free Review, Quiz, Settings/About, and a dedicated AI Tutor screen. The VR client is designed to function offline for core exploration and quiz features.

**Main Menu and Global Screens:**
The main menu is the entry point for navigation across the application. From this screen, the student can select modules for learning/review, start the quiz mode, open settings and the about page, or access the AI Tutor. The AI Tutor is launched from the main menu via the "AI Tutor" button.

**Scene and Mode Management:**
A scene/mode management layer is responsible for launching the appropriate Unity scene and configuring the active mode. When the student starts a module, the system loads the required 3D assets and prepares the UI for the selected mode (learning vs. review). This separation prevents quiz and AI features from coupling tightly with the main exploration flow.

**Interaction and Selection Handling:**
The interaction subsystem manages core VR interactions such as grabbing, rotating, releasing, and selecting anatomical structures. It also triggers visual feedback (e.g., highlight) when a structure is selected. The selection output is used by the UI to show labels and short info cards, and by content lookup logic to fetch the correct text entry.

**Local Content Layer (Assets + JSON):**
The application ships with a local content package that includes 3D model assets and JSON files. These JSON files contain structure labels/descriptions and the quiz question pool. The exported JSON is the runtime source of truth for learning text and quizzes, enabling offline use and keeping content changes independent from Unity scripts.

**Content Loader:**
A content loader reads the packaged JSON data and serves the appropriate label and short description for a selected structure. The loader uses stable identifiers/tags (e.g., module_tag for scope and structure_id for individual objects) to perform a simple lookup and return the correct UI text.

**Quiz Manager:**
The quiz manager loads questions from the local JSON pool, displays them in VR, processes student answers, and shows immediate feedback and results. Quiz mode is intentionally independent from module exploration, allowing it to be launched directly from the main menu without requiring a module to be active.

**AI Tutor Client:**
The AI Tutor client is a dedicated UI screen that allows the student to ask questions via typing or push-to-talk (speech-to-text). It sends the question to the backend and displays a short text answer. Optionally, the student can play the answer aloud using text-to-speech. In the current scope, the AI Tutor is not structure-aware and does not automatically incorporate the currently selected structure as context.

**Azure AI Backend (RAG Service):**
The backend receives AI Tutor questions and generates grounded answers using a Retrieval-Augmented Generation (RAG) approach. It retrieves relevant content snippets from an indexed knowledge store and then produces a concise response. If the backend is unavailable, the AI Tutor feature is disabled while the core VR exploration and quiz features remain functional.

**Retrieval Index / Knowledge Store:**
The retrieval layer stores the learning content (e.g., curated notes or course material) in a form suitable for search. It provides the most relevant text chunks to the RAG pipeline so that generated answers remain aligned with the project's educational content.

### 5.2.3. Key Data Flows

This subsection summarizes the main runtime flows of VR Anatomy. Each flow is explained from the initial user action to the visible outcome inside the headset. For each flow, an activity diagram is provided to show the control steps and the decision points.

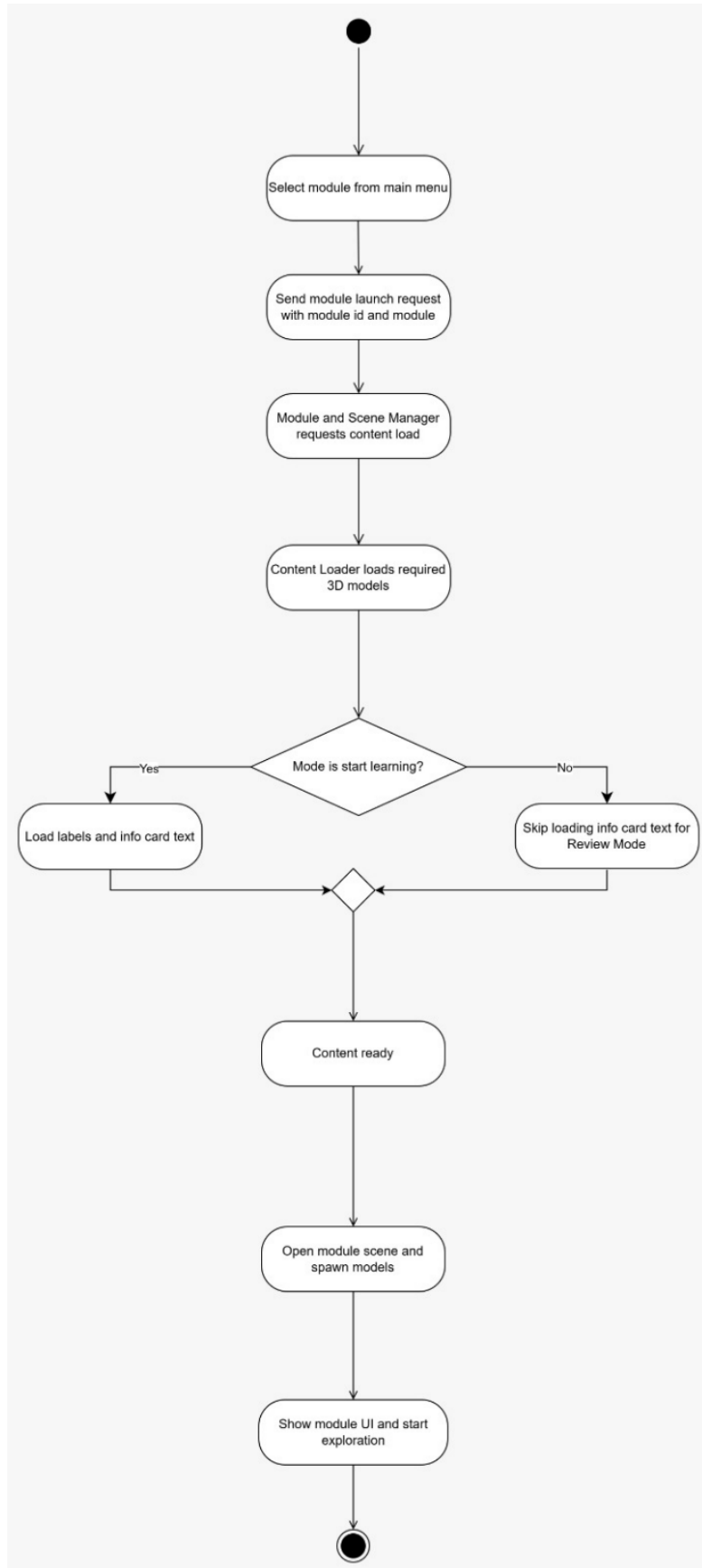## 5.2.3.1. Module Launch Flow



*Figure 6. Activity diagram of the "Module Launch Flow".*

## 5.2.3.2. Structure Selection and Info Card Flow



*Figure 7. Activity diagram of the "Structure Selection and Info Card Flow".*

### 5.2.3.3. Quiz Mode Flow
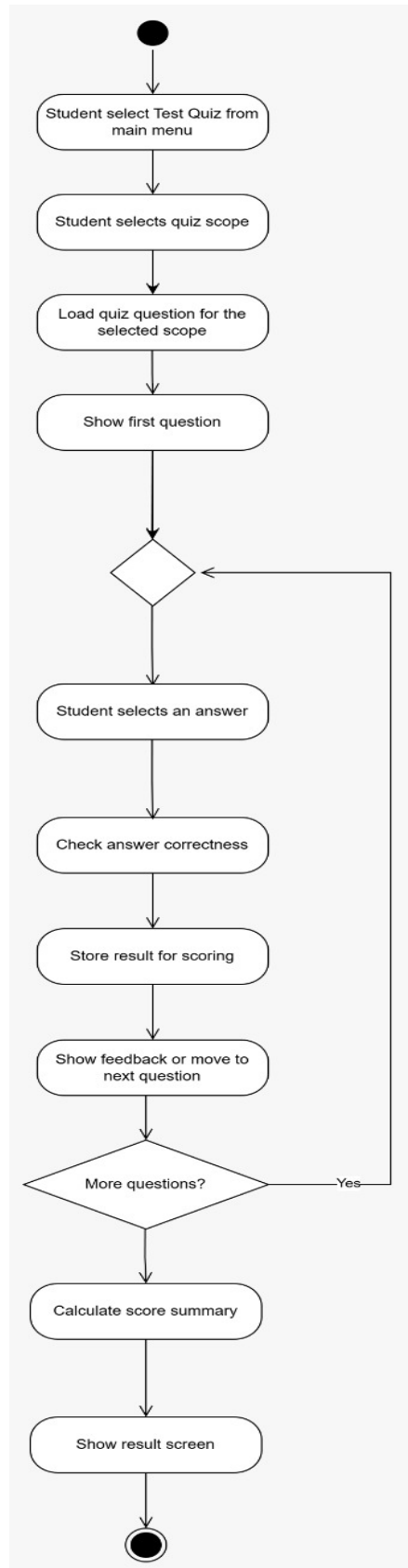


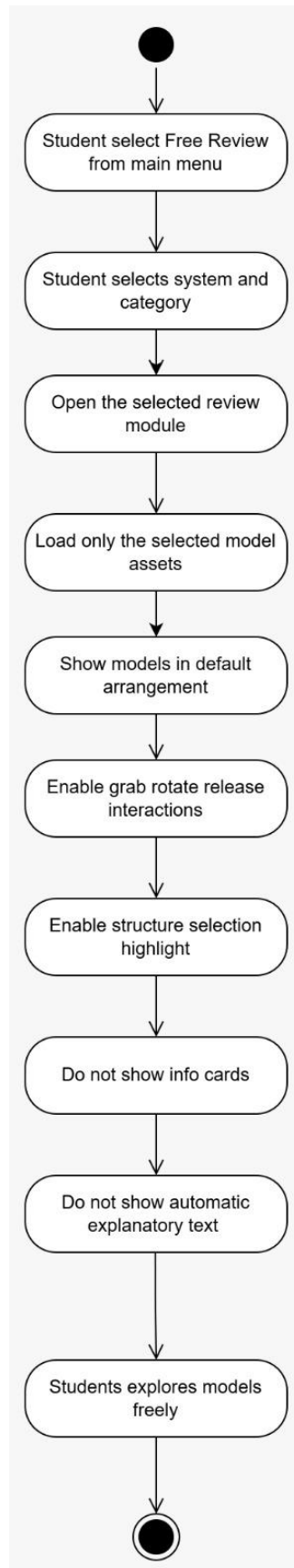*Figure 8. Activity diagram of the "Quiz Mode Flow".*

## 5.2.3.4. Review Mode Flow



*Figure 9. Activity diagram of the "Review Mode Flow".*
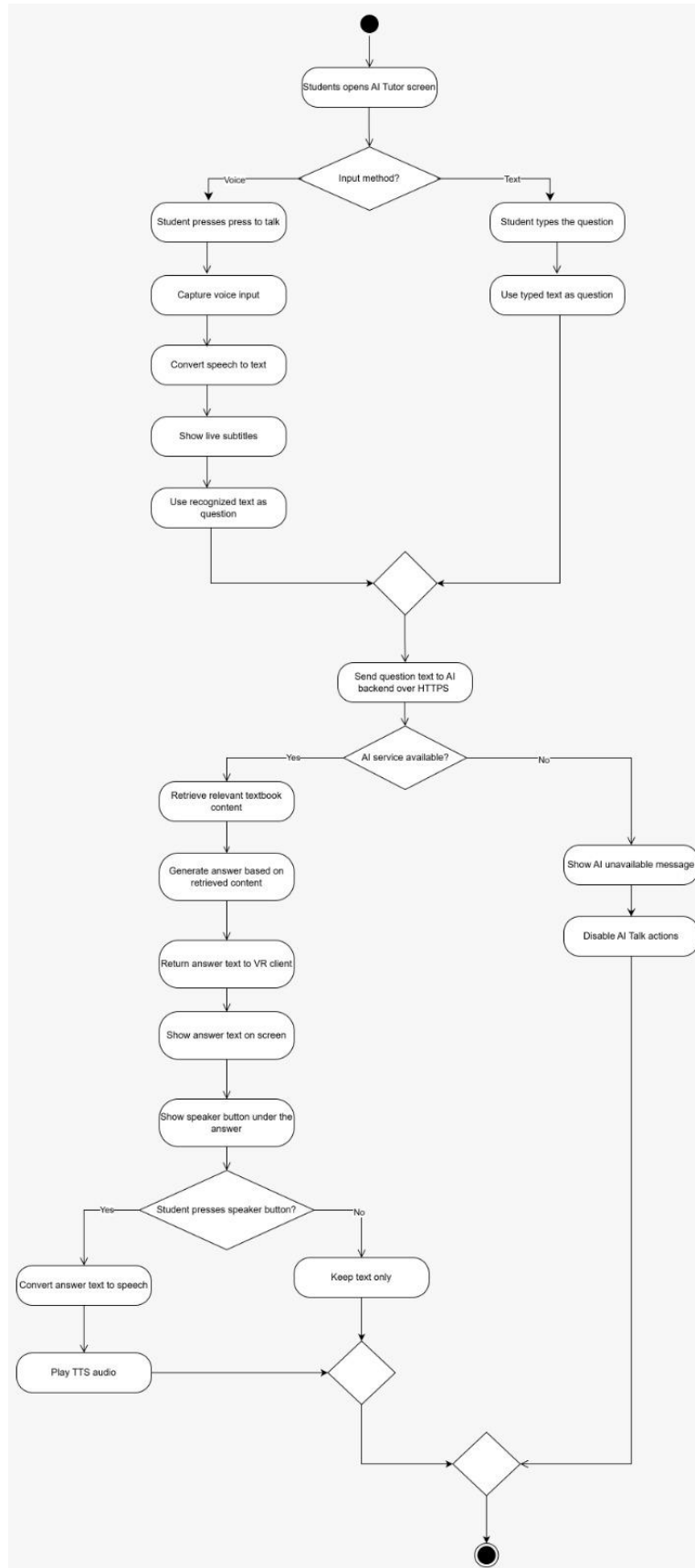
## 5.2.3.5. AI Tutor Chat Flow



*Figure 10. Activity diagram of the "AI Tutor Chat Flow".*

## 5.3. Module Design in Unity.

This section explains how VR Anatomy is organized inside Unity with the current main menu structure. It describes scene and mode organization, interaction handling, user interface design, content mapping, and fallback behaviors that keep the experience usable.

### 5.3.1. Scene and Module Structure

The Unity project is organized around a main menu entry scene and a small set of mode scenes or mode states. The main menu provides access to learning, free review, quiz, settings, AI tutor, and about screens.

A practical scene and mode structure is listed below:
• Main Menu scene as the entry point
• Learning mode scenes for module based exploration
• Free Review mode scenes that load selected model assets without info cards
• Quiz mode scene or UI flow that is independent from learning and review
• AI Tutor scene that opens as a full screen chat and voice interface
• Settings scene or panel that is reachable from the main menu
• About scene that shows project summary and credits

The main menu includes a hierarchical navigation structure for learning and free review. This navigation determines which content and model assets are loaded.

Start Learning supports guided exploration using hierarchical category selection. The student first selects an anatomy system and then selects a category within that system. In the current scope, both the Musculoskeletal System and the Circulatory System follow the same menu structure. The content coverage may be expanded in later iterations as new model assets and JSON entries are added.

Free Review uses the same category hierarchy as Start Learning. The difference is the mode behavior. Free Review loads only the selected model assets and does not show info cards or automatic explanatory text.

Test Quiz is accessed from the main menu and is independent from the category navigation used in learning and review. It provides three entry options for question pools. Musculoskeletal System, Circulatory System, and All Questions.

Settings, AI Tutor, and About are standalone screens that are reached directly from the main menu. They do not use the anatomy category hierarchy.

### 5.3.2. Interaction Layer

Key responsibilities are listed below:
• Detect structure selection using ray targeting or direct hand targeting
• Apply visual highlight to the selected structure
• Trigger label display and info card display in learning mode

• Support grab, rotate, and release interactions
• Provide a reset action on the controller that clears the current selection and restores the module to its initial state

The reset action supports classroom use. After the student moves or inspects parts, a single button press returns the model arrangement to the default state seen when the module first opened. This reduces confusion and helps the instructor quickly continue the lesson.

## 5.3.3. UI Layer

The UI layer supports navigation and learning feedback inside VR. It includes the main menu, mode entry screens, and in scene feedback such as labels and short info cards. The UI is designed to remain readable and to avoid covering the 3D model during exploration.

The UI is organized into four parts. These are:
• Main menu and global screens
• In module UI for learning and free review
• Quiz UI
• AI Tutor UI

### 5.3.3.1. Main Menu and Global Screens

The main menu is the entry point of the application. It provides access to Start Learning, Free Review, Test Quiz, Settings, AI Tutor, and About. Start Learning and Free Review use hierarchical category selection to determine which module content and model assets are loaded.

Settings is a global screen intended for configuration such as sound related options. The exact set of settings may be expanded later. About is a global screen that presents project summary, team information, contributions and versions.

### 5.3.3.2. In-Module UI for Learning and Free Review

In module UI supports exploration while the student interacts with 3D models. Learning mode shows labels and short info cards for the selected structure. Free Review follows the same exploration flow but does not show info cards or automatic explanatory text.

In module UI elements are listed below:
• A label that shows the selected structure name
• A short info card in learning mode that shows a brief description
• A minimal navigation element to return to the main menu
• A reset control that restores the module to its initial state

### 5.3.3.3. Quiz UI

Quiz UI is separate from modules and is reached from the main menu. It is designed for clear question presentation and quick answering.

Quiz UI elements are listed below:
• Question text area
• Answer options with selection feedback
• Result feedback such as correct or incorrect
• Controls for next question and exit to the main menu

### 5.3.3.4. AI Tutor UI

AI Tutor opens as a dedicated screen from the main menu. It supports voice-based interaction while showing text to keep answers clear in a classroom environment.

AI Tutor UI elements are listed below:
• Press to talk input control
• Live subtitles that show speech recognition output
• A control to play the answer using text to speech when available
• A clear unavailable state when the AI service cannot be reached

When the AI service is unavailable, the UI disables input and shows a short message. Core VR features remain usable.

## 5.3.4. Content Mapping

Content mapping connects three elements. The main menu selections, the 3D objects in Unity, and the local JSON content packaged with the application. The goal is to show the correct label and short description when a structure is selected in learning mode. The same mapping also supports quiz question selection by system and by all questions.

A minimal mapping approach uses stable identifiers.
• Each category that can be opened from Start Learning or Free Review has a module_tag
• Each selectable object inside a module has a structure_id
• JSON files store structure descriptions keyed by module_tag and structure_id
• Quiz question pools are stored keyed by system scope and may also support a combined pool for all questions
• Unity objects store identifiers through a small component so runtime lookup is simple

At runtime, the mapping follows a clear sequence.
• The student selects a category from the main menu
• The VR client loads the corresponding module content and model assets
• The content loader reads the JSON entries for that module_tag
• When the student selects a structure, the VR client uses structure_id to

request label and description data
• The UI layer shows the label and short info card in learning mode

Free Review uses the same module and structure identifiers but does not display info cards. The mapping still supports selection highlighting and label display.

Quiz mode uses a different mapping entry point. The student chooses a question pool option in the quiz screen. The VR client then loads the related pool from JSON. The All Questions option merges or selects a combined pool defined in the content package.

Module and structure identifiers are assigned and maintained during content preparation. The same identifiers are stored in JSON and in Unity objects, which keeps content mapping consistent for the current project scope.

### 5.3.5. Error Handling and Fallback Behaviors

The Unity client should remain usable when some content is missing or when external services are unavailable. Fallback behaviors are designed to keep the student in a valid learning state and to avoid blocking core exploration.

**Error handling follows two principles:**
• Fail safely by disabling only the affected feature
• Communicate clearly using short, non-technical messages in VR

**Typical cases and expected behaviors are listed below:**
• If a structure has no JSON description, the client still allows selection and highlighting, and shows only the label
• If a module content package is incomplete, the client blocks entry to that category and returns to the main menu with a short message
• If a quiz pool is missing for a selected option, the client disables that option or shows a message and returns to the quiz selection screen
• If the AI service is unreachable, the client shows an unavailable state and disables AI input, while learning, free review, and quiz remain usable
• If the AI response is slow, the client shows a loading state and applies a timeout, then shows a short message
• If speech recognition or text to speech is unavailable, the client keeps the text based interaction when possible and shows that voice features are unavailable

During development, errors should be logged consistently so the team can reproduce issues. During classroom use, messages should remain short and focused on the next action the student can take.

## 5.4. API Design

This section describes the minimal API between the Unity VR client and the AI backend on Azure. The API is used only for the AI Tutor feature. Core VR features such

as module exploration, selection highlighting, info cards, and quiz use local content and do not require the API.

The API is designed to be simple, stable, and easy to test. It uses HTTP over TLS and JSON messages. The client sends a question with module context, and the backend returns a grounded answer based on project provided learning content.

## 5.4.1. API Overview

The AI Tutor feature uses one endpoint. This endpoint accepts a question and returns a grounded answer. The backend uses a retrieval step over project provided learning content and then produces a response based on the retrieved text. This is the RAG approach in this project. It helps the system answer using the provided material instead of guessing from general knowledge. The AI Tutor is not structure aware. The request does not include selected structure fields.

## 5.4.2. AI Tutor Endpoints

The AI Tutor feature uses a minimal REST endpoint.

The Unity client will call this endpoint after integration is completed. The Azure based RAG system is already operational through a web interface using an anatomy textbook as the primary content source. The purpose of the endpoint is to accept a student question and return an answer grounded in the project learning content.

The AI Tutor is not structure aware. The request does not include selected structure information.

### 5.4.2.1. Request Schema

The request body is JSON. The schema is described as a planned contract for the Unity client.

The only strictly required input for answering is the student question. Additional fields may be added to support integration, debugging, and content scoping.

**Recommended minimal field is listed below:**
  • question as a string and required to generate an answer

**Recommended fields that may be used during Unity integration are listed below:**
  • session_id as a string to trace requests and support debugging
  • module_tag as a string to limit retrieval to a selected scope if the content is later split by systems or categories

**Design notes are listed below:**
  • If one textbook is used as a single content source, module_tag may be

omitted

    • If multiple content scopes are introduced later, module_tag helps keep answers relevant

    • session_id is not required for answering but helps identify which Unity session produced a request

### 5.4.2.2. Response Schema

The response body is JSON. The schema is described as a planned contract for the Unity client because Unity integration is a later step.

The main goal of the response is to return a short answer that can be displayed comfortably in VR. The response may also include supporting references when the backend can provide them.

**Recommended minimal fields are listed below:**
• answer as a string
• session_id as a string

**Optional candidate fields are listed below:**
• citations as a list of objects with short supporting snippets
• meta as a short object for non-personal diagnostics such as latency

**Design notes are listed below:**
• citations are useful to increase trust because they show a brief supporting excerpt from the learning content
• if citations are not available in the current backend setup, the response may contain only answer
• session_id helps the client match the response to the request during integration testing

### 5.4.2.3. Error Responses and Timeouts

The AI Tutor endpoint must fail safely because the core VR learning experience should remain usable even when the online service is unavailable. Error handling is designed to be predictable for the client and understandable for the user.

**General principles:**
- The VR client treats the AI Tutor as an optional feature.
- When an AI request fails, the client keeps the current module state unchanged.
- The client shows a short message that explains that the AI Tutor is unavailable and invites the user to try again.
- Errors are logged for debugging, but logs must avoid personal data.

**Planned error response shape:**
- error_code as a short stable identifier

- message as a user safe explanation
- session_id when provided in the request
- retry_after_seconds when a retry delay is recommended

**Expected error categories:**
- Invalid request: Returned when required fields are missing or values are not valid.
- Authentication or authorization failure: Returned if the endpoint later requires keys or tokens.
- Rate limiting: Returned when the service is overloaded or a client exceeds allowed request volume.
- Upstream AI failure: Returned when the hosted AI pipeline cannot produce an answer due to temporary issues.
- Internal server error: Returned for unexpected failures

**Timeout policy**: The client should use time limits to avoid blocking the VR experience.
- Connection timeout is short to detect offline states quickly.
- Total request timeout is moderate to allow retrieval and generation, but still protects interactivity.
- If a timeout happens, the client may allow a manual retry rather than automatic repeated retries.

**Client behavior on failure:**
- Disable or gray out AI Tutor entry points when the service is unreachable.
- Keep main menu, module browsing, selection, labels, and quiz features available.
- Avoid repeated popups. Prefer a single banner style message and an explicit retry action.

### 5.4.3. Security and Privacy Considerations

VR Anatomy is a single user VR application with an optional online AI Tutor. Security and privacy work focuses on reducing risk while keeping the system simple for an academic project.

**Data minimization:**
- The AI request should include only what is needed to answer the question.
- The system should not send selected structure identifiers because the AI Tutor is not structure aware.
- The system should avoid sending user identifiers. A short session_id may be used only for matching requests and responses.

**Personal data handling:**

- The VR application does not need personal profiles or accounts for the current scope.
- Voice input may contain sensitive information. The UI should warn users not to share personal data.
- If speech features are enabled in AI Tutor, audio should be treated as transient input and not stored by the VR client.

**Transport and endpoint protection:**

- If an API key or token is required in the future, it should not be hard coded in the Unity client.

**Logging and diagnostics:**

- Logs should help debugging without exposing user content.
- By default, logs should not store full questions or audio transcripts.
- If limited logging is needed during testing, it should be time bounded and access controlled.

**Abuse and reliability:**

- Basic rate limiting may be applied on the server side to protect availability.
- The client should implement safe retries with backoff and stop after a small number of attempts.
- When AI is unavailable, the client should disable AI Tutor while keeping core learning and quiz features available.

**Content safety boundaries:**

- The AI Tutor is intended for anatomy learning questions that relate to the provided textbook.
- The UI should set expectations that answers may be incomplete or wrong.
- The system should encourage students to verify critical information with course material or an instructor.

## 5.5. Deployment and Runtime Environment

This section describes how VR Anatomy runs during a typical session and how the optional AI Tutor fits into the runtime. The goal is a stable classroom style setup with a single headset and a single student at a time.

### 5.5.1. Runtime Setup and Execution Context

VR Anatomy runs as a Unity based VR application on a single headset. One student uses the headset at a time. The instructor is a secondary user who guides verbally and does not interact with the application directly.

**Runtime characteristics:**
- The core learning experience runs locally on the headset.
- Learning modules load 3D models from Unity assets.
- Labels and short info cards use local text content.
- Review Mode uses the same model assets but does not show info cards or automatic explanatory text.
- Quiz Mode is started from the main menu and runs independently from learning modules.

The AI Tutor is an optional feature accessed through the AI Tutor screen. When available, it connects to an Azure hosted backend over the network. If the AI service cannot be reached, AI Tutor is disabled while the rest of the VR application remains usable.

## 5.5.2. Offline and Online Operation

VR Anatomy is designed so that learning modules work without online services. Online access only improves the experience through AI Tutor.

**Offline operation:**
- Start Learning modules are available with 3D exploration and basic interactions.
- Selecting a structure still highlights it.
- Labels and short info cards still appear for selected structures.
- Review Mode works and keeps its rule set with no info cards or automatic text.
- Quiz Mode works as long as quiz data is available locally for the build used in testing.

**Online operation:**
- All offline features remain available.
- AI Tutor becomes available when the AI backend can be reached.
- If the AI service fails during a session, AI Tutor is disabled and the rest of the application continues.

## 5.5.3. Dependencies and Configuration

The project uses a small set of dependencies to keep the build stable and easier to test.

**VR client dependencies:**
- Unity project with VR interaction support
- XR plugins and device runtime required by the selected headset
- 3D model assets included as Unity assets

- UI assets for menus, labels, info cards, and quiz screens

**AI Tutor dependencies:**
- An Azure hosted backend that exposes the AI answer endpoint
- A retrieval setup that uses the indexed textbook content
- A language model service used by the backend

**Configuration approach:**
- VR client settings are stored in Unity project configuration and prefabs.
- Settings menu includes sound related options that are planned.
- AI endpoint base URL should be configurable and not hard coded for long term use.
- Secrets such as keys should not be stored in the VR client. They should be handled on the server side.
- Quiz and structure descriptions are planned to be exported to JSON later. This packaging is not finalized yet.

## 5.6. Design Decisions

This section explains the main design choices behind VR Anatomy. Decisions were made to support a stable VR learning experience, limit development risk, and keep the system testable within a graduation project scope.

**The project prioritizes:**
- Reliable core learning features that work without online services
- Simple interactions that students can learn quickly
- A modular structure that supports iterative content growth
- Clear separation between VR learning and optional AI support

### 5.6.1. Why Module-Based Scenes

The application uses module based scenes to keep content isolated and easier to manage.

**Key reasons:**
- Each module can be loaded and tested independently.
- Large 3D assets stay inside the relevant module and do not affect other modules.
- Scene separation supports parallel work. One team can work on UI while another team improves a specific module.
- Memory usage is easier to control because only the active module needs to be loaded.

- The reset button behavior is easier to implement. Reset returns the module to the initial state by clearing selection and restoring default arrangement.

## 5.6.2. Why JSON for Content

The project stores learning text and quiz content in JSON files to separate content from Unity code. These JSON files are bundled with the VR application and serve as the runtime source of truth for labels, short descriptions, and the quiz pool.

**Expected benefits:**
• Content can be updated without changing Unity scripts.
• Structure descriptions and quiz questions follow a consistent format.
• Core learning and quiz features can work offline using the packaged JSON content.

**Status and limits:**
• During development, quiz questions may be authored in an Excel file for convenience, but the VR client uses exported JSON at runtime.
• JSON files are shipped with the app as part of the local content package.
• 3D models remain Unity assets and are not part of the JSON content.

## 5.6.3. Why Review Mode Without Info Cards

Review Mode removes info cards and automatic explanatory text to support focused visual learning.

**Rationale:**
- It encourages students to rely on recognition and exploration rather than reading.
- It supports instructor guided sessions where explanations are given verbally.
- It reduces visual clutter and keeps the scene clean for examination.
- It separates learning from assessment. The same model can be reviewed without hints.

**Resulting behavior:**
- Only the selected model assets are shown.
- Selection highlighting and basic grab and rotate interactions remain available.
- No info cards appear after selection.

## 5.6.4. Why AI Tutor Is Optional and Not Structure-Aware

The AI Tutor is optional because the core VR experience must remain usable offline and without external dependencies. The AI pipeline currently works through a web interface, while Unity integration is planned later.

**Reasons for optional integration:**

- Classroom use must not fail when the network is unstable.
- Testing and demos remain possible without relying on online services.
- The system scope stays realistic for a graduation project.

**Reasons for not being structure aware:**

- The current AI setup is based on the textbook ingestion and retrieval flow.
- Passing selected structure identifiers would suggest precision that the system does not reliably support.
- Keeping requests minimal reduces coupling between VR interaction state and the AI backend.

**User experience rule:**

- If the AI service is not available, AI Tutor is disabled while modules and quiz remain available.

## 5.6.5. Performance and VR Comfort Decisions

VR comfort and performance are treated as core quality goals because the application runs on a headset and uses real time interaction.

**Performance decisions:**

- Keep scenes simple and avoid loading unnecessary assets outside the active module.
- Prefer optimized 3D models suitable for real time VR.
- Use stable lighting choices where possible and avoid expensive effects during interaction.
- Limit the number of on screen UI elements during exploration.

**Comfort decisions:**

- Avoid forced camera movement and sudden viewpoint changes.
- Prefer direct object interaction such as grab, rotate, release.
- Provide the reset button to quickly return to a known safe state.
- Keep UI readable and consistent in size and placement.

## 5.7. Limitations and Risks

This section lists the main limitations and risks of VR Anatomy within the current project scope. The goal is to make constraints explicit and define what may affect stability, learning and quality.

### 5.7.1. Technical Limitations

The project targets a single headset and a single user at a time. This keeps the system simple but limits usage scenarios.

**Main limitations:**
- No multiuser support and no shared session features.
- No instructor control panel. The instructor guides verbally outside the system.
- Limited hardware coverage. The project is tested on the chosen headset and configuration.
- Module content depends on Unity assets. Large assets may increase load times and memory use.

**Practical impact:**
- The application is suitable for guided demos and small classroom sessions.
- Porting to other devices may require extra XR configuration and performance tuning.

### 5.7.2. AI-Related Risks

The AI Tutor improves access to explanations, but it introduces risks because it depends on online services and generated text.

**Main risks:**
- Availability risk. Network or backend issues can disable AI Tutor.
- Answer quality risk. Generated answers may be incorrect, incomplete, or misleading.
- Context limitation. The AI Tutor is not structure aware, so it may not understand what the student is looking at in VR.
- Safety and privacy risk. Voice input may include personal data if users speak freely.

**Mitigation approach:**
- Keep AI optional and ensure VR modules and quiz work without it.
- Keep requests minimal and avoid sending structure identifiers.
- Avoid storing voice or question content in logs by default.

## 5.8. Conclusion

VR Anatomy is a Unity based VR learning application that supports interactive anatomy exploration for a single student using a single headset. The system provides module selection from a main menu, 3D exploration, structure highlighting, basic grab and rotate interactions, labels, and short info cards. Quiz Mode is available independently from modules, while Review Mode offers a clean study view without info

cards or automatic explanatory text. A reset action restores each module to its initial state to support repeatable practice.

The architecture cleanly separates core VR learning features from online AI support. The AI Tutor provides textbook grounded help for student questions using retrieval and answer generation. The AI component is optional. This ensures that modules, labels, info cards, Review Mode, and Quiz Mode continue to work even when network access or the AI service is unavailable.

This design keeps the project realistic for a graduation scope. It supports iterative content growth, stable classroom demos, and clear boundaries between interactive learning, review, assessment, and optional AI assistance.

# 6. Conclusion & Discussion

In this project, VR Anatomy was developed as a virtual reality learning application to support human anatomy education at the health vocational high school level. Learning anatomy primarily through two-dimensional resources can make it difficult for students to build a clear understanding of three-dimensional structures and spatial relationships. VR Anatomy aimed to address this challenge by providing an interactive VR experience where students can examine 3D anatomy models in an immersive environment. As a result, the learning process is supported through a more concrete, visual, and exploration-based approach rather than relying solely on reading.

The implemented application offers a structure where students can explore 3D anatomy models and follow a guided learning flow through dedicated modes. With classroom usability in mind, the experience is designed to be clear and accessible. Enabling students to interact with content and observe anatomical structures from different angles is valuable for both motivation and long-term understanding. In addition, an AI-supported assistant was integrated as a complementary support component, allowing students to ask questions during learning and receive short explanations. This approach helps students maintain focus within the learning context and can also serve as an additional aid alongside instructor-led sessions.

From a discussion perspective, one of the key strengths of VR-based learning is its ability to improve spatial understanding and engage students more actively. However, factors such as content scope, hardware conditions, and session duration can directly influence the overall experience. For this reason, the project was designed with a realistic and deliverable scope, with the main goal of producing a classroom-friendly, understandable, and expandable learning tool. The AI component was positioned as a supportive enhancement intended to strengthen learning flow by addressing student questions. At the same time, aspects such as answer accuracy, content alignment, and appropriate usage scenarios may require further evaluation in future stages.

In future work, VR Anatomy can be expanded by adding new anatomical systems and additional model sets, while assessment can be strengthened through more diverse question types and evaluation approaches. User studies with the target audience would also provide stronger evidence regarding usability, educational impact, and student experience. The AI-supported

assistant can be further improved through better content guidance, clearer explanation levels, and more education-oriented response behavior.

In conclusion, VR Anatomy provides a feasible solution that combines immersive 3D model exploration in VR with AI-supported guidance to support anatomy learning at the health vocational high school level. The project aims to make anatomy learning more visual, interactive, and motivating, while also establishing a solid foundation for iterative improvement and future content expansion.

# 7.References

[1] R. M. Lieu, A. Gutierrez, and J. F. Shaffer, "Student perceived difficulties in learning organ systems in an undergraduate human anatomy course," HAPS Educator, vol. 22, no. 1, pp. 84–92, 2018, doi: 10.21692/haps.2018.011.

[2] B. Wu, X. Yu, and X. Gu, "Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis," British Journal of Educational Technology, vol. 51, no. 6, pp. 1991–2005, 2020.

[3] H. Zekeik, M. Chahbi, M. Lamarti Sefian, and I. Bakkali, "Augmented reality and virtual reality in education: A systematic narrative review on benefits, challenges, and applications," Eurasia Journal of Mathematics, Science and Technology Education, vol. 21, no. 9, article em2699, 2025, doi: 10.29333/ejmste/16830.

[4] E. Mehmedova, S. Berrezueta-Guzman, and S. Wagner, "Virtual reality user interface design: Best practices and implementation," arXiv preprint arXiv:2508.09358, 2025.

[5] P. Hořejší, A. Lochmannová, V. Jezl, and M. Dvořák, "Virtual reality locomotion methods differentially affect spatial orientation and cybersickness during maze navigation," Scientific Reports, vol. 15, no. 1, article 26255, 2025.

[6] S. Fröjdman, User Experience Guidelines for Design of Graphical User Interfaces in Virtual Reality, M.Sc. thesis, Aalto University, 2016.

[7] K. Bogomolova et al., "Development of a virtual three-dimensional assessment scenario for anatomical education," Anatomical Sciences Education, vol. 14, no. 3, pp. 385–393, 2021.

[8] Unity Technologies, "Unity Manual," Unity Documentation, 2025. [Online]. Available: https://docs.unity3d.com/Manual/index.html

[9] Unity Technologies, "XR Plug-in Management and OpenXR," Unity Documentation, 2025. [Online]. Available: https://docs.unity3d.com/Manual/xr.html

[10] A. F. Johnson and A. W. Wiles, Unity 2023 Virtual Reality Projects: Build immersive VR applications with Unity XR, 3rd ed. Birmingham, UK: Packt Publishing, 2023.

[11] Unity Technologies, "Unity Machine Learning Agents Toolkit," Unity Documentation, 2024. [Online]. Available: https://github.com/Unity-Technologies/ml-agents

[12] Létourneau, A., M. D. Martineau, P. Charland, J. A. Karran, J. Boasen, and P. M. Léger, "A systematic review of AI-driven intelligent tutoring systems (ITS) in K–12 education," npj Science of Learning, vol. 10, article 29, 2025, doi: 10.1038/s41539-025-00320-7.

[13] Okonkwo, C. W., and A. Ade-Ibijola, "Chatbots applications in education: A systematic review," Computers and Education: Artificial Intelligence, vol. 2, article 100033, 2021, doi: 10.1016/j.caeai.2021.100033.

[14] Simoni, J., J. Urtubia-Fernandez, E. Mengual, D. A. Simoni, M. Royo, D. Egaña-Yin, et al., "Artificial intelligence in undergraduate medical education: An updated scoping review," BMC Medical Education, vol. 25, article 1609, 2025, doi: 10.1186/s12909-025-08188-2.

[15] Kurul, R., Öğün, M. N., Neriman Narin, A., Avci, Ş., & Yazgan, B. (2020). An alternative method for anatomy training: Immersive virtual reality. Anatomical Sciences Education, 13(4), 648–656. https://doi.org/10.1002/ase.1959

[16] Gloy, K., P. Weyhe, E. Nerenz, M. Kaluschke, V. Uslar, G. Zachmann, and D. Weyhe, "Immersive Anatomy Atlas: Learning Factual Medical Knowledge in a Virtual Reality Environment," Anatomical Sciences Education, vol. 15, no. 2, pp. 360–368, 2022, doi: 10.1002/ase.2095.

[17] Erolin, C., Reid, L., & McDougall, S. (2019). Using virtual reality to complement and enhance anatomy education. Journal of Visual Communication in Medicine, 42(3), 102–109. https://doi.org/10.1080/17453054.2019.1597626

[18] Chheang, V., Sharmin, S., Marquez-Hernandez, R., Patel, M., & Rajasekaran, D. (2024). Towards anatomy education with generative AI-based virtual assistants in immersive virtual reality environments. Proceedings of the 2024 IEEE International Conference on Artificial Intelligence and eXtended and Virtual Reality (AIXVR). https://doi.org/10.1109/AIXVR59861.2024.00011

[19] Alfarani, L. A., & Alharbi, A. (2025). Cognitive load measurement of using virtual reality headset (Oculus Rift CV1) to enrich the anatomy course and increase motivation among medical students. Medical Science Educator. https://doi.org/10.1007/s40670-025-02467-9

[20] Birbara, N. S., Sammut, C., & Pather, N. (2020). Virtual reality in anatomy: A pilot study evaluating different delivery modalities. Anatomical Sciences Education, 13(6), 671–683. https://doi.org/10.1002/ase.1921

[21] Izard, S. G., Juanes Méndez, J. A., & Palomera, P. R. (2017). Virtual Reality Educational Tool for Human Anatomy. Journal of Medical Systems, 41(5). https://doi.org/10.1007/s10916-017-0723-6

[22] Falah, J., Khan, S., Alfalahi, T., Alfalahi, S. F. M., & Chan, W. (2014). Virtual Reality medical training system for anatomy education. Proceedings of the 2014 Science and Information Conference (SAI 2014). https://doi.org/10.1109/SAI.2014.6918271

[23] Pais-Vieira, M. (2025). Learning anatomy using virtual dissections: Previous experience and future directions integrating artificial intelligence and multiple approaches. In Artificial Intelligence and Biological Sciences. iBiMED - Institute of Biomedicine, University of Aveiro.