EDUCATIONAL 3DANATOMY TECHNICAL DOCUMENT

Extended reality for educational anatomy: DIVAVR®, a new Oculus Immersive human Atlas with LLM

JF Uhl[1], JP Reyes Gonzalez[2], CA Rodriguez Herrera[3], A Nassif[1], S Bernard[4], J Jorge[5], P Nataf[1]

[1]Unesco Chair of digital anatomy - Paris cité University 45 rue des saints Pères – 75006 – Paris

[2]Universidad Nacional Autónoma de México, México City

[3]Instituto Tecnológico y de Estudios Sup. de Monterrey, Mexico City

[4]Chair of the BME Graduate School, Vice-Dean of Education, Faculty of Sciences - Université Paris Cité

[5]UNESCO Chair on AI & VR, Instituto Superior Técnico, Av Rovisco Pais S/N Lisboa, Portugal

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DOI: 10.24019/jtavr.257 - Corresponding author:Prof. Jean François Uhl, jeanfrancois.uhl@gmail.com

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Abstract Introduction: Immersive reality has emerged as a groundbreaking and promising approach for teaching anatomy, providing unique learning experiences while complementing traditional educational methods. Existing immersive atlas software offers valuable tools but can be limited in anatomical detail, interactivity, or affordability. Objective: creation of a novel educational platform featuring an immersive human atlas that integrates high-resolution anatomical slices from the Visible Korean Human dataset (male and female) into a dynamic 3D environment for the immersive reality mask Oculus Meta 3S. Moreover, DIVAVR® is the only software of its kind explaining the technical development of the tool. Description: this platform enhances anatomical visualization of original 3D mesh models built from real anatomical slices and incorporates a multimodal Large Language Model (LLM) that supports user interaction through text, voice commands (speech-to-text), and synthesized voice output (text-to-speech) in multiple languages. Conclusion: By combining precise anatomical slices with an interactive 3D model and an AI assistant, the atlas provides an enriched and comprehensive learning experience for medical education. A formal user evaluation with 46 participants is presented here. Compared to other powerful immersive platforms, DIVAVR® is designed to be affordable, easy to use, and multifunctional.

Keywords Immersive reality, anatomy education, anatomical Atlas, AI, LLM

1. Introduction

Teaching human anatomy is a fundamental pillar of training for medical professionals, particularly radiologists and surgeons. Traditionally, cadaver dissection has been the cornerstone of anatomy education. However, this approach faces multiple challenges, including an increasing number of students, ethical concerns, and the scarcity of cadavers.

These limitations have prompted a transition towards innovative teaching methods that use realistic 3D models built from high-resolution anatomical slices[1,2].

These digital tools, particularly those leveraging immersive technologies like virtual reality (VR), are reshaping the educational landscape.

A variety of anatomy learning software is now available on computers, tablets, and smartphones. Despite being accessible, these tools often exhibit inconsistencies in quality and anatomical accuracy, as most 3D mesh models are created by computer specialists rather than anatomists working from real data. Furthermore, few applications integrate truly immersive virtual reality environments,

which limits their ability to deliver an optimal educational experience.

Immersive virtual reality (IVR) is a computer-created, 3D digital environment that completely replaces the real world, via a visual head-mounted display. Its use for anatomy education offers several strong learning advantages that make it a transformative tool. It provides an enhanced spatial understanding, allowing students to explore 3D anatomical structures from any angle, which is difficult to achieve with 2D textbooks[3]. This fosters active and interactive learning, as students can manipulate, rotate, and dissect virtual models, leading to improved conceptual understanding[4]. Studies have demonstrated that VR-based education leads to improved knowledge retention[5], and the engaging nature of VR environments increases student motivation and satisfaction[6]. Furthermore, VR offers a personalized and inclusive learning path, allowing students to progress at their own pace in a comfortable environment[7]. It also democratizes access to high-quality anatomical resources, promoting accessibility and equity where cadavers are scarce. Finally, through virtual dissections and simulations, it supports practical skill development in a safe, controlled setting[7].

Building on these strengths, we propose a novel approach: an immersive human atlas that integrates real high-resolution anatomical slices from the*Visible Korean Human* dataset into a three-dimensional virtual environment. Our platform, DIVAVR®, combines this high-resolution anatomical data with interactive tools and a multimodal AI assistant, offering students a dynamic and comprehensive learning experience.

Software	Strengths	Features	Multiuser	Hardware	Weaknesses	References
3D Organon VR [8]	Cadaver images, quiz mode	Quiz, DICOM viewer, session sharing	YES	Meta Quest, PC VR	No close-up zoom	3d organon.com
Human Anatomy VR [9]	DICOM detailed muscle & nerves	3D atlas, DICOM, quiz, nerve branching layered dissection	YES	PC VR/AR (Varjo Quest)	Costly, limited cadaver	virtual med.com
VEDAVI VR Human Anatomy [10]		Virtual dissection bones, muscles ligaments	NO	Rift S, Rift	No organs and systems	
Dissection Master XR [11]	Ultra-high res, detailed dissections	Holographic atlas, adapted to robotics	YES	High-end PC VR (HTC Vive Pro)	High hardware cost	www.master-xr.eu
Surgery & anatomy VR [12]	Advanced simulation	Anatomy, dissection segmentation	YES	Meta quest		https:// medicalholodeck.com
Sharecare YOU Anatomy [13]	Excellent heart, kidney detail & animation	Laser pointers, ECG, blood flow, animations Yale university	NO	PC/Meta Quest	No cross-section slicing	Meta Store
Everyday Anatomy VR [14]	389 muscle movements, scalable models	Layer hiding, movements categorized	NO	Meta Quest, PC VR	No close zoom	Meta Store
Anatomy Explorer 2020 [15]	Cross-sections, cadaver database	Web Test Manager, fluorescence highlights	NO	Rift, Rift S	Low res Limited animations, dark visuals	anatomy explorer.com
Toltech VR VH dissector [16]	Photorealistic, MR capabilities	Data from visible human, Real-life datasets, MR	YES	Varjo XR-3, High-end PC	Expensive hardware	toltech.net
SurgicalAR [17] AnatomyX	Any specialty	Interactive atlas, educational use	YES	Apple vision pro		Medivis.com
DIVAVR™ [18-20]	Education	immersive atlas, educational use	NO	Meta Quest 3S		Diva3D.net
IRIS [21]	Easy to use affordable	built from real patient's Dicom data	YES	Meta Quest 3S	No quiz	Diva3D.net

Table I - The legend summarizes the main immersive virtual reality (VR) software dedicated to human anatomy. It includes key strengths, features, required hardware, weaknesses, and web references.

Overview of other available Immersive VR Software for Human Anatomy

This report (Table I)[8-21] summarizes the main immersive virtual reality software programs designed for in-depth study of human anatomy, highlighting their features, strengths, weaknesses, pricing and hardware requirements. We can highlight the following software programs:

3D Organon VR Anatomy[8] is notable for its interactive educational and immersive approach, allowing quizzes and multi-user sessions, although it suffers from unintuitive navigation in close-up views

Human Anatomy VR (Virtual Med)[9] offers advanced features, including integration of DICOM images and a highly detailed representation of the nervous system, but at high cost

VEDAVI VR Human Anatomy[10] stands out for its accurate rendering of the skeleton and muscles, ideal for basic virtual dissections.

Master XR plateform [11] provides innovative technologies to create rich XR experiences and Develop use cases and educational material for a better learning environment for robotics.

Surgery & anatomy VR (medicalholodeck)[11, 12] provides advanced tools for surgical simulation, AI-powered segmentation, and anatomy study, you can visualize, manipulate, and collaborate on medical content and images.

Sharecare YOU Anatomy[13] excels in cardiology and nephrology thanks to its realistic ECG and blood flow animations but remains limited by the absence of cross-sectional views.

Everyday anatomy[14] by Medis Media includes multilingual body's structures and function.

medecine virtual[15] is a 3D VR/AR anatomical atlas with a 3D DICOM module to view CT/MRI files used in several institutions worldwide.

Toltech VR[16] Built on real anatomy from the National Library of Medicine's Visible Human Project®, the VH Dissector platform provides an integrated environment for anatomical education and reference.

With the ability to interact with correlated 3D and cross-sectional views of over 2,000 anatomical structures through identification, dissection, assembly and rotation the VH Dissector helps students understand the complex three-dimensional structure of the human body. It offers exceptional realism thanks to very high resolution and mixed reality capabilities, but their adoption is hampered by prohibitive hardware costs.

MEDIVIS is a Full-body 3D anatomy education with augmented reality, a scalable enterprise-level solution for any institution that teaches core anatomy and related health science disciplines. **ANATOMYX®**[17] is a new, immersive and engaging way to explore the intricacies of the human body powered by augmented reality.

DIVAVR™ [18-20] is an Immersive human atlas with chatbot built from real anatomical slices dedicated for educational anatomy

IRIS™ [21] is a new Oculus immersive device for remote interactive collaboration of surgical experts using real patients case reports. A web platform enables importation and 2D visualisation of the patient's dicom data thanks to accurate and automatic anatomical segmentation. The 3D model (avatar) of the patient is then available for a remote and collaborative discussion using the Meta3s immersive reality mask.

Each of the above VR softwares has specific strengths that meet various educational or professional needs, but few like IRIS™ fully meets all criteria for immersion, functionality and affordability.

In summary: Best multi#user & educational tools are 3D Organon VR Anatomy which supports quizzes and instructor–student sessions Best for muscles & nerves, and Human Anatomy VR offers exceptional nerve detail and muscle animations.

Best heart & kidney interactivity: Sharecare YOU Anatomy stands out with ECG, blood flow, animations. Top-end realism: Dissection Master XR and Toltech VR on Varjo offer photorealistic visualization but at high cost and hardware requirements.

2. Materials and Methods

This section details the construction of the anatomical models, the technical implementation of the VR platform and its AI features.

2.1. 3D Anatomical mesh model construction.

The 3D anatomical model was constructed through the meticulous manual segmentation of **8,000 cryosection images** from the *Visible Korean Human* datasets, both male[2, 22] and female[23]. This process was first performed using **Winsurf software**[24], which allowed for high-precision contouring of each anatomical structure.

SYSTEMS	N	Polygons (thousands)	Names of anatomical elements
Integumentary	1	20	Skin
Skeleton	230	443	Head, spine, ribs, pelvis and limbs
Muscles	370	410	Head & neck, thorax, abdomen pelvis and 4 limbs
Ligaments	82	16	spine pelvis and 4 limbs
Respiratory	18	190	Right & left lungs with segments, trachea, bronchi pulmonary arteries, pulmonary veins
Heart	6	30	Left & right atrium, appendage & ventricles
Arteries	91	131	Head & neck, thorax, abdomen pelvis and 4 limbs
Veins	150	354	Sup. & inf. Vena cava, Azygos and Portal systems
Nerves	55	77	Thorax, abdomen pelvis and 4 limbs
Brain	52	87	cortex lobes, central grey nuclei, ventricles, pituitary gland, eyes, cranial nerves
Alimentary	25	51	Oesophagus, Gaster, duodenum, ileum, jejunum, ascending colon, transverse colon, descending colon, sigmoid, rectum, pancreas, Liver with VIII segments, Gallbladder, biliary tract
Urinary	6	22	Bladder, Right & left kydneys urethra & Ureters
Genital (man)	7	15	Prostatis, testis, deferents, vesicules seminales, penis
Genital (woman)	10	20	Uterus, Ovari, vagina,ligaments
Glands	9	9	Thyroid, Surrenals, Parotids, submaxillar, sublingual
SLICES	100	-	selected original anatomical slices
Total	1212	1875	

Table II - List of the 1212 anatomical structures included in the 3D mesh model, and 100 slices.

The cryosection images were obtained via a dedicated cryomacrotome, ensuring ultra-high-resolution and anatomically accurate cross-sectional visualization.

Following segmentation, the resulting mesh files were imported into **Blender**[25], a sophisticated 3D modeling software widely used for scientific visualization and XR development. Within Blender, extensive refinements were applied to optimize the anatomical models.

This included mesh decimation to achieve efficient polygon reduction, thereby ensuring compatibility with VR systems without compromising visual quality.

Surface smoothing techniques were employed to eliminate segmentation artifacts, while subdivision modeling preserved fine structural details critical for anatomical fidelity. This step was essential to ensure that the final 3D models were both visually accurate and computationally optimized for real-time rendering in VR environments.

A total of **1,212 anatomical structures** were segmented and reconstructed separately as 3D objects to create a comprehensive whole-body representation (Table II):

Skin, 230 bones, 370 muscles & tendons, 82 ligaments, 55 nerves, 91 arteries, 150 veins (lymphatics were not reconstructed), heart (6), brain (52), respiratory system (18), alimentary system (25), urinary system (6) genital man (7) genital woman (10), glands (9), skin (1) and anatomical slices (100) thus achieving an extensive and detailed virtual anatomical atlas.

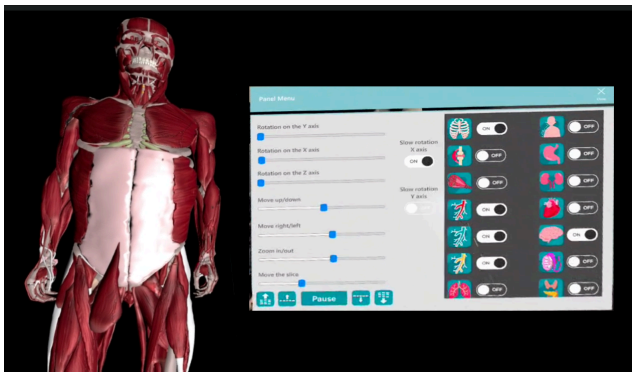


Fig 1 - Reconstructed 3D mesh model with bones and muscles with the panel menu. The left part controls the body manipulation (rotation, zoom, translate) and the right part the systems displayed. At the bottom, one can display and move the original anatomical slices of the body.

2.2. VR Platform and Interaction Development

The refined 3D models were imported into **Unity**[26], a leading real-time development engine that served as the foundation for integrating immersive functionalities, tailored for deployment on the **Oculus Meta 3S** VR headset. Advanced interaction mechanisms were implemented by leveraging Unity's XR Interaction Toolkit alongside key components from Microsoft's Mixed Reality Toolkit (MRTK). Specifically, the MRTK framework was used to handle the core logic for direct object manipulation, enabling intuitive rotation, translation, and scaling of the anatomical models via the VR controllers. These tools provide spatial tracking for precise manipulation and haptic feedback to enhance realism. Real-time rendering and optimization strategies were also employed to ensure that the application runs smoothly on standalone hardware while maintaining high-fidelity anatomical detail.

2.3. Integration of the Large Language Model (LLM) and Multimodal Features

A key innovation of DIVAVR® is its integrated multimodal AI assistant, which provides on-demand anatomical information through a sophisticated backend architecture.

- LLM Core: The system's core is powered by OpenAI's GPT-4o-mini model, accessed via its Chat Completions API. When a user selects an anatomical structure, the application dynamically constructs and sends a carefully engineered prompt to the API.
- Real-Time Text Streaming: To provide immediate feedback, the LLM's response is streamed to the display using Server-Sent Events (SSE), which renders the text progressively to create a smooth, real-time conversational effect.
- Multimodal Interaction: For voice input, audio commands are captured and transcribed into text using OpenAI's Whisper API. For voice output, the system employs Google Cloud's Text-to-Speech API, which automatically detects the language of the text to select a natural-sounding, language-appropriate voice (supporting English, Spanish, Portuguese and French).
- Content and Accuracy: The anatomical descriptions generated by the LLM were subsequently evaluated by anatomists to confirm their accuracy and suitability for medical education.

3. Building of the app with Unity® engine.

The development of DIVAVR® culminated in a stable, performant, and feature-complete immersive educational platform successfully deployed as a standalone application on the Oculus Meta 3S.

The primary technical results demonstrate high-speed interactivity, successful integration of a complex AI backend, and high-fidelity data visualization, all while maintaining a highly responsive user experience.

3.1. Implementation of a High-Performance and Intuitive User Interface

A central outcome of the development is a natural and immersive user interface that prioritizes fluid interaction. The system successfully achieves high-fidelity, real-time hand tracking, allowing users to interact with anatomical models through intuitive, direct manipulation gestures with negligible latency.

This level of responsiveness is critical for maintaining user immersion.

Core functionalities include 3D manipulation, zoom, spatial navigation, and body translation within the virtual environment, enabling users to explore the human body from multiple perspectives.

These features are seamlessly accessible through an interactive menu panel located adjacent to the anatomical model, as shown in Figure 1.

The menu panel is functionally divided into two sections: the left side controls body manipulation tools such as rotation, translation, and scaling, while the right side allows users to selectively display or hide entire anatomical systems.

This clear layout, validated during development, ensures efficient interaction and supports a detailed and systematic understanding of anatomical structures.

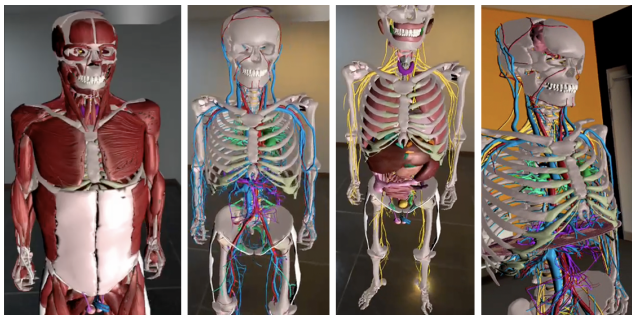


Fig 2 - Reconstructed 3D mesh model showing the selection of different systems (bones, muscles, arteries, veins, nerves) and organs.

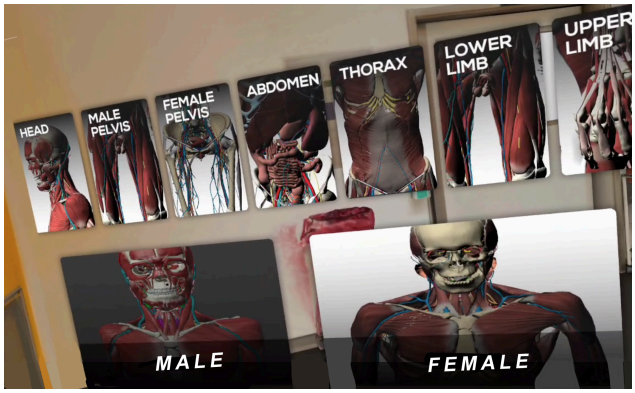


Fig 3 - The menu choice for the whole body reconstruction (male & female) and selection of the regions: head, pelvis, abdomen, thorax, lower and upper limb.

Examples of different systems and organs is shown on figure 2. Furthermore, the platform successfully allows users to isolate specific anatomical regions, such as the head & neck, abdomen, pelvis, lower limb, and upper limb (Figure 3). A key performance result is the system's ability to transition between the full-body model and these complex regional subsets in **under 2 seconds**, confirming an efficient asset-loading architecture that facilitates focused study without interrupting the learning flow.

3.2. Successful Integration and Performance of the Multimodal AI Assistant

To complement its visualization features, the platform integrates a Large Language Model (LLM) that provides detailed descriptions of selected anatomical structures. As shown in Figure 4, a dedicated menu panel delivers anatomical definitions in four languages, with an option for voice output. A primary technical result is the **immediate responsiveness of this feature, with an average latency of under 3 seconds** from user selection to the start of the LLM's text stream.

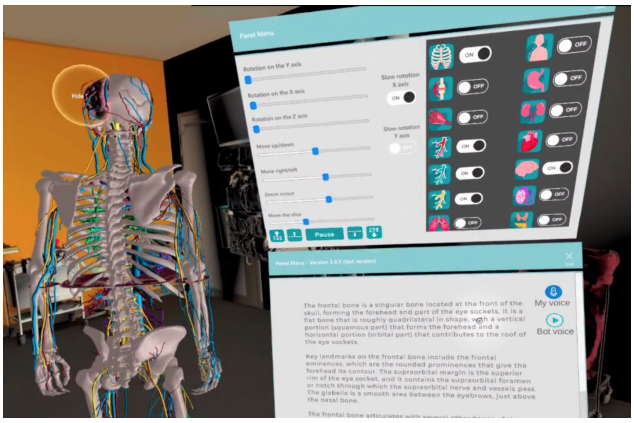


Fig 4 - On the right, the panel menu and bottom window with the description of the selected element with the chatbot (here the frontal bone). The audio is started with the button "bot voice". The speech interface is available through the button "my voice".

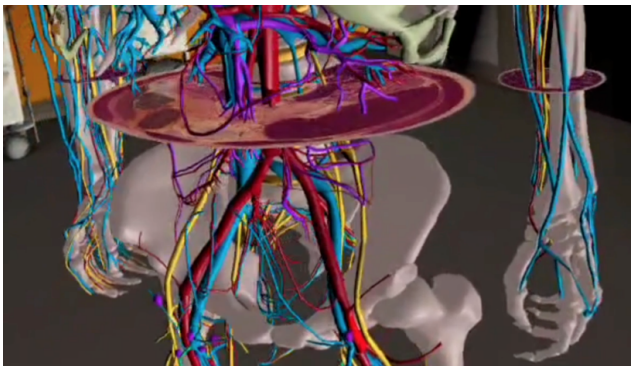


Fig 5 - Shows the display of the anatomical slice at the level of L3 inside the 3D mesh model with bones, vessels, and nerves.

This multilingual functionality enhances accessibility for global learners, while the voice command control allows users to interact and switch languages seamlessly. The voice-to-text module demonstrated a Word Error Rate (WER) below 8% for common anatomical terms, confirming its reliability. A unique tool-the "hide bones" feature-was also successfully implemented, rendering bones transparent in real-time to provide unobstructed views of deeper structures, such as the brain, without performance degradation.

3.3. Real-Time Visualization of Integrated Cross-Sectional Anatomical Data

A key innovation and technical outcome of the platform is its ability to integrate original axial anatomical slices directly into the 3D model (Figure 5). The system renders these high-resolution 2D textures within the 3D mesh in real-time without any discernible drop in performance or interactivity.

function	speciality	user's interface	Anatomy	LLM
student	anatomy	simplicity	Details	speed
M1	practitionner	need for help	textures	Quality (Fr, En, Sp)
M2	medical specialist	model interaction	missing (text)	Voice quality
MD	Engineering	speed	mistakes (text)	Nb of tests done
med speialist		menu access	remarks (text)	nb of mistakes
Teacher		Male body		
		Female body		
		Regions		

Table III - The cohort of students and the evaluated features.

Function	N	%	Speciality	N	%
Student	12	26,1%	anatomy	12	26,1%
Master 1	16	34,8%	Engineer	15	32,6%
GP	7	15,2%	other	19	41,3%
specialist	11	23,9%			
total	46	100%		46	100%

Table IV - Demographic of the 46 users

This result confirms that the platform can handle complex, multi-layered data visualization on standalone VR hardware. This feature successfully bridges the gap between traditional 2D cross-sectional imaging (such as CT or MRI) and 3D volumetric anatomy, fulfilling a central objective of the project and significantly enriching the educational experience by fostering a deeper understanding of anatomical relationships. **In summary**, the technical results confirm that DIVAVR® is a stable and performant platform.

4. Set up a user's study in order to evaluate the Oculus software.

4.1. The proposed methodology is the following: (table III)

- Participants: A cohort of 46 volunteer students present during the workshop of the master of BME (University Paris Cité). All signed a informed consent.
- Before the study, detailed instructions were given regarding the software use and a demonstration of the use of Meta3S mask. Each student could manipulate the tool during half an hour to be comfortable.
- Procedure: Anatomists and Engineers were asked to evaluate the quality of the user's interface: simplicity, interaction, speed, need for assistance. (table IV)
- The anatomical quality was also rated: graphic accuracy, textures, lacking elements
- Finally, the LLM was tested in 4 languages including voice quality of audio description.

4.2. Results of the user's evaluation study.

The overall rating is reported on table V.

Rates for interface, anatomy quality and LLM is very good: 7,9/10

User's interface	Mean/10	Anatomy	Mean/10	LLM	Mean/10
Simplicity	8,8	Details	7,6	speed	8,8
Need for help**	7,9	Textures	6,3	Quality Fr	9,0
Interaction	6,9	missing (text)		Quality En	8,6
Speed	8,2	remarks (text)		Quality Sp	8,0
Menu access	8,4			Voice quality	8,8
Male quality	9,0			Nb of tests done	>25
Female quality	9,1			nb of mistakes	none
Regions	8,7				
Axial slices	6,8				
MEAN rating	8,2		6,95		8,6

*Table V - Results of rating by 46 users: Overall rating score is very good: 7,9/10. All criteria were rated from 0 (very bad) to 10 (excellent). **The user was asking for a help or a manual during the study.*

Nevertheless, several users made some proposals for improvement: 30% of them asked to add an help at start and a manual of the functions.

They also suggested to add a selection without move of the elements and a display of slices on another window apart the 3D model.

Limits of our evaluation: comprehension, retention and educational effectiveness that were not directly assessed.

5. Discussion

Virtual Dissection Using Tablets and VR.

Virtual dissection represents a transformative alternative to traditional cadaveric dissection, leveraging augmented reality AR and VR to offer interactive learning experiences. Platforms such as Anatomy Studio have demonstrated how AR and VR can facilitate collaborative dissection through augmented 3D reconstructions[27-29]. These systems allow users to manipulate anatomical models with high precision, enhancing spatial understanding and knowledge retention.

The use of tablets and standalone VR headsets provides flexibility, enabling learners to engage in both independent and group-based explorations. Interactive features such as stereoscopic visualization, adjustable transparency, and dynamic slicing allow users to explore anatomical structures layer by layer.

Improved learning with immersive reality: Virtual dissection fosters a multi-sensory learning experience, integrating visual, auditory, and tactile feedback to enhance comprehension. Studies have shown that immersive technologies evoke strong emotional engagement, leading to higher retention of knowledge compared to traditional methods[19, 30, 31]. By combining real-time 3D models with tools for customization, annotation, and multilingual AI assistance, virtual dissection platforms are revolutionizing anatomy education.

Strong learning points of immersive VR in anatomy education.

1. Immersive VR in anatomy education offers several strong learning points, making it a revolutionary tool for both students and educators:
2. *Enhanced Spatial Understanding*: Immersive VR enables students to explore anatomical structures in three dimensions, allowing them to view organs and systems from all angles. This deepens their understanding of spatial relationships and how body parts interact, which is difficult to achieve with traditional 2D images or textbooks.
3. *Active and Interactive Learning*: Students can manipulate, rotate, and zoom in on anatomical models, fostering active engagement. This hands-on approach leads to improved conceptual understanding and retention compared to passive learning methods[4].
4. *Improved Knowledge Retention*: Studies show that VR-based anatomy education can lead to

statistically significant improvements in knowledge acquisition and retention, with sustained learning observed even weeks after instruction[5].

5. *Increased Motivation and Engagement*: VR environments are highly engaging, increasing student motivation, attention, and satisfaction. This heightened interest can lead to better learning outcomes and more positive attitude toward studying anatomy[6].
6. *Personalized and Inclusive Learning*: VR allows for individualized learning experiences, letting students progress at their own pace and revisit complex topics as needed. It also creates a more comfortable environment for those who may be uneasy with cadaver-based learning.
7. *Accessibility and Equity*: VR can democratize access to high-quality anatomical models and resources, especially in settings where cadavers or advanced lab facilities are limited.
8. *Practical Skill Development*: Immersive VR supports hands-on practice through virtual dissections and simulations, helping students develop practical skills in a safe, controlled environment[7].
9. *Positive Student Perceptions*: Across multiple studies, students report high satisfaction with VR as a learning tool, finding it easy to use and valuable for understanding complex anatomical concepts[8].

These strengths position immersive VR as a powerful supplement or alternative to traditional anatomy education, with particular benefits in spatial reasoning, engagement, and knowledge retention.

Conclusion

The 3D immersive interface of DIVAVR Meta3S atlas is a new tool in anatomy education, transforming traditional learning methods through cutting-edge virtual reality. By providing a **stereoscopic presentation of 3D visuals** and fostering **deep user immersion**, the platform eliminates external distractions, enhances focus, and engages learners through gamified experiences. Its ability to deliver a **multi-sensory, highly interactive environment** significantly enhances comprehension and retention, with the emotional impact of immersive VR further amplifying the learning process (not evaluated in our study).

Using the same 3d mesh model than the diva3D® virtual dissection table[19] built from the slices of the Korean visible human data[1, 2], this enhanced version of the immersive DIVAVR 3D *Atlas of the Human Body* introduces innovative learning opportunities, notably the integration of **original anatomical slices** within the 3D models, bridging the gap between cross-sectional imaging and volumetric anatomy. Furthermore, the DIVAVR® platform incorporates **artificial intelligence** through a multilingual Large Language Model that provides detailed anatomical descriptions in **French, English, Spanish and Portuguese** with an optional voice feature to support accessibility and global engagement.

By uniting high-fidelity visuals, interactivity, and AI-enhanced learning tools, this platform establishes itself as a comprehensive, dynamic, and effective educational resource, poised to revolutionize the teaching and understanding of human anatomy.

Ethics Statement

The anatomical models used in this study were derived from the public Visible Korean Human dataset. The original dataset was created with the consent of the donor and under the ethical approval of the Korean Institute of Science and Technology.

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