Mixed Reality ITS Powered by AI for Teaching Anatomy in Medical Schools

Submitted to: Professor Beverly Woolf Park, CompSci6910 Spring 2023

MAHBUBA TASMIN, CICS, UMass Amherst
MANAN TALWAR, CICS, UMass Amherst
JUNGWON KYUNG, College of Education, UMass Amherst

Fig. 1. Immersive Learning in a Mixed-Reality Screen

Anatomy education in medical and health professional programs faces challenges due to traditional teaching methods, declining resources, and limited hands-on experience. This paper proposes a framework for a Mixed Reality Intelligent Tutoring System (MR-ITS) based on the Microsoft Hololens device, which combines mixed-reality interaction with AI-powered guidance and assessment. The MR-ITS addresses the limitations of traditional anatomy education by providing an immersive learning experience through holograms, enabling virtual exploration of the human body. The system incorporates a large-language model-based "Virtual Tutor" for guidance, an activity recognition model for practical assessment, and an attention-tracking model. It utilizes the HoloAnatomy Software Suite and the Microsoft Hololens2 device. The MR-ITS aims to enhance engagement, improve knowledge retention, and automate practical assessments using activity recognition. By leveraging cutting-edge technology, the proposed MR-ITS offers a novel approach to anatomy education, providing an interactive and personalized learning environment for students.

CCS Concepts: • **Computing methodologies** → **Intelligent agents**; • **Applied computing** → **Interactive learning environments**; • **Human-centered computing** → **Accessibility technologies**;

Additional Key Words and Phrases: Intelligent Tutoring System, Interactive Holograms, Immersive Learning

1 INTRODUCTION

1.1 Motivation

Anatomy is usually considered to be the 'foundation of medical sciences' [Guimaraes et al. 2017; Pujol et al. 2016; Tubbs et al. 2014]. Traditionally, anatomy was considered to be a dull, labor-intensive subject, and was taught using surface learning approaches and rote memorization [Biggs 2003; Hopkins et al. 2011]. Anatomy teaching in medical and other health professional education programs is on the decline and 'has fallen below a safe level' in recent years [Ali et al. 2015; Tubbs et al. 2014]. Learning anatomy with cadaverous dissection has become almost non-existent in most medical schools owing to the shortage in the number of cadavers compared to the growing student numbers [Chen et al. 2018] In the United States Medical Licensing Examination (USMLE) Step 2 Clinical Skills Examination, the performance of the musculoskeletal anatomy is significantly poorer in comparison to physical examination performance in other domains, as presented in Figure 2 [Peitzman and Cuddy 2015].

Fig. 2. Poor performance in Physical Examination of Musculoskeletal Anatomy

Clinical domain	No. of encounters[b]	Physical examination, mean (SD)	History taking, mean (SD)
Neurological	8,377	51.4 (25.4)	80.7 (11.9)
Musculoskeletal	27,591	52.0 (27.3)	81.0 (14.3)
Cardiovascular	30,238	56.5 (27.0)	74.4 (14.5)
Respiratory	27,176	59.5 (24.0)	77.4 (16.2)
Gastrointestinal	28,385	72.7 (30.6)	79.3 (13.7)
All encounters	121,767	59.6 (28.3)	78.1 (14.7)

Abbreviations: USMLE indicates United States Medical Licensing Examination; SD, standard deviation.
[a]Results are based on a cohort of U.S. medical students from 2011.
[b]This column indicates the number of student–standardized patient encounters from the Step 2 Clinical Skills examination.

Teaching Anatomy lessons through a more engaged platform can be a solution to address the above-mentioned challenges. One of the breakthrough devices in the mixed-reality paradigm is "Microsoft Hololens", a device capable of mixed-reality interaction and nuanced control by humans. It allows the mixing of virtual reality with the physical world, which helps the students to learn in an immersive way. For medical students, one of the biggest advantages of using this device is its interactivity, which allows them to manipulate and explore the human anatomy in real time. The Hololens device makes learning anatomy fun and engaging and helps to understand the human body in a unique way. While it is a great standalone device for interactive lessons, it does not offer guided learning or mastery assessment of knowledge components i.e. the foundational aspects of an Intelligent Tutoring system. In this project, we are proposing a framework for a Mixed-Reality AI-powered ITS based on the Hololens device. One of the major challenges of teaching anatomy is the practical limitation of lack of resources which inhibits hands-on experience. The proposed ITS uses holograms to overcome this major limitation and provides opportunities for learning concepts in a virtual domain that can subsequently be applied in real-world situations. From a different perspective, such a system also provides a low-stake imaginary learning environment where students can practice concepts until they achieve mastery as well as with personalized guidance and feedback.

1.2 Proposed System

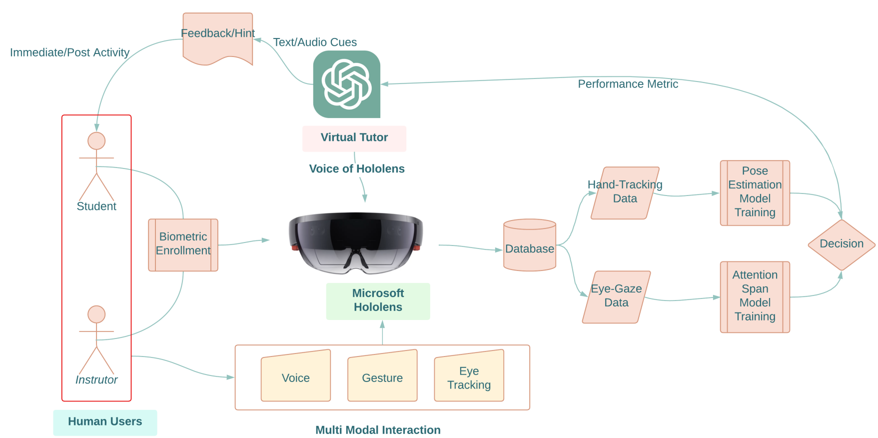
In this paper, we introduce a Mixed Reality Intelligent Tutoring System (MR-ITS) powered by AI. Prior research on the usability of holograms in interactive learning [Benjamin Bach et al. 2018; Moro et al. 2020; Walker 2013a; Yoo et al. 2022a] indicates that this MR-ITS will be useful for an immersive learning experience. The assessment framework of this ITS is based on "Activity-Recognition" from 3D interaction data in terms of the traditional practical assessment of physical examination of anatomy lessons in medical schools. To our knowledge and background study, this practical assessment module to assess mastery is the first of its kind to leverage activity recognition to accomplish the task. In addition, it will also include a large language-based chatbot trained specifically for the lesson contents, which will work as the voice of the system. The MR-ITS will consist of the following software and hardware components:

- A large-language model-based chatbot for guidance and feedback
- Activity Recognition model for practical task assessment
- Attention span estimation model
- The HoloAnatomy Software Suite [*HoloAnatomy [HoloAnatomy Software suite]* 2023]
- Microsoft Hololens2 Device [Microsoft Corporation 2023]
- Apache Solr as the Indexed Database
- Integrated Learning Management Systems

1.3 Example Interaction

This MR-ITS is designed to be operated by both instructors and students in a classroom setting. It can be operated by gestures or voice commands to explore lesson contents, and the students can utilize both audio and visual experiences to learn. Following is a step-by-step basic workflow of this proposed ITS:

Fig. 3. Example interaction of the Proposed ITS with Microsoft Hololens



- The instructor/student approaches the holographic screen and activates the system.
- The lesson content/virtual tutor appears on the screen, and the student can see it from different angles.
- The student can use hand gestures or voice commands to navigate through different anatomical investigation procedures with the help of the virtual tutor.
- The virtual tutor responds to the student's actions, providing guidance, feedback, or additional information.
- The lesson or the practical skill can be repeatedly practiced by the students to earn the mastery of the knowledge component.

1.4 Target Outcomes

This MR-ITS is built keeping in mind the current challenges of anatomy learning in medical schools. Following are the principle target outcomes from this system:

- Enhanced Engagement in Class
- Greater Knowledge Retention in Memory
- Automate the practical assessments using "Activity Recognition"

1.4.1 Learning Objective. In the context of our study, we are concerned with the anatomy of the human body. We provide a generalized template with learning objectives that can be used to generate content such as lessons and exercises in our proposed ITS. Inspired by the success of the open source LibreTexts [LibreTexts contributors 2023] Medicine online textbook for anatomy, we present the following learning objectives for a typical anatomy lesson.

Given an organ X, students should be able to:

- understand the structure of X by identifying and locating different components.
- understand the functions of each component of X independently.
- understand the working of X by accumulating the functions of each components of X.
- identify and detect structural defects and abnormalities in X.
- make inferences and derive conclusions based on data provided as well as visual cues from X.

While this template generates content and exercises for a specific organ X, it is scalable and can be easily extended to teach the anatomy of body systems where multiple organs interact with each other.

2 RELATED WORK

2.1 Holograms in Teaching

Recent research has explored the potential of holographic interventions in medical education, suggesting that holographic ITS can bridge the gap between theoretical knowledge and practical skills, offering an interactive learning experience [Benjamin Bach et al. 2018; Moro et al. 2020; Walker 2013a; Yoo et al. 2022a] suggests that HoloLens is a highly favored mixed-reality tool for this application. HoloLens functions as a head-mounted computer that enables users to see and hear an augmented world through a holographic platform. It is capable of producing a 3D map of the actual environment and can incorporate context into the design of tutoring courses. HoloLens can also provide accurate head tracking, which allows virtual objects to be anchored to the real world during the course [González et al. 2017].

In medical education, the HoloLens presents high-precision holographic images, allowing students to visualize human anatomical structures from all perspectives [Mitsuno et al. 2019; Moro et al. 2020]. Additionally, the device is hands-free and allows for manipulating holographic images via hand gestures, providing opportunities for advanced anatomical learning without the problems associated with using cadavers [Moro et al. 2020]. The immersive and interactive capabilities of the HoloLens also benefit students by providing an intuitive and natural interface, increasing spatial understanding and engagement with course material [Michael Hackett and Marcus Proctor 2018; Schez-Sobrino et al. 2020]. Furthermore, HoloLens can empower teams to work securely and enhance patient treatment by enabling health professionals to connect with remote experts, access patient data, and consult Magnetic resonance imaging (MRI) images in 3D at the point of care [Microsoft 2023].

2.2 Learning Theories

One of the pedagogical affordances of this holographic ITS is its capabilities for instruction [Huang et al. 2021]. Other advantages include hands-on [Moro et al. 2020], real-time assessment [Gonzalez Vargas et al. 2020], and immersion and interaction capabilities, which make HoloLens an intuitive and natural interface for students [Schez-Sobrino et al. 2020]. Besides, attention and engagement are enhanced using HoloLens, as demonstrated by [Michael Hackett and Marcus Proctor 2018]. Dynamic graphic visualizations are another benefit of the HoloLens, as [Benjamin Bach et al. 2018; Schez-Sobrino et al. 2020] noted. Moreover, VR headsets and wearable sensors promote interaction and collaboration between students and teachers as they work together to manipulate and respond to the hologram screen. Additionally, holographic ITS facilitates communication and interaction between students and teachers [Yoo et al. 2022a]. Overall, the potential benefits of holographic ITS demonstrate its ability to provide an immersive and interactive learning experience that bridges the gap between theoretical knowledge and practical skills [Michael Hackett and Marcus Proctor 2018]. These benefits align with several educational theories, including Vygotsky's social constructivism theory, Zone of Proximal Development (ZPD), and Piaget's cognitive constructivism.

2.3 Virtual Reality for Anatomy Lesson

The integration of Intelligent Tutoring Systems (ITS) based on Virtual Reality (VR) in medical education has created a paradigm shift in teaching anatomy [Fairén et al. 2020; Hill and Nassrallah 2018]. These technologies offer novel and innovative ways to engage learners, provide real-time feedback, foster self-learning and self-evaluation, and enhance the learning experience [Fairén et al. 2020]. Game/simulation-based learning and the Zone of Proximal Development (ZPD) are two theoretical frameworks that can guide the integration of Virtual Reality Intelligent Tutoring Systems (VR-ITS) for teaching anatomy. Utilizing games or simulations, game/simulation-based learning creates an immersive environment for learners, as demonstrated by the one-on-one tutoring system for anatomy education where students and instructors meet in a shared virtual reality [Saalfeld et al. 2020]. This approach can enhance student motivation and increase their willingness to learn by incorporating elements of fun, engagement, and challenge [Nevin et al. 2014; Ober 2016]. By incorporating principles like simulation, games can broaden the range of instructional design methods, as they facilitate the development of learners' critical thinking and collaboration abilities [Ellaway 2016; Hill and Nassrallah 2018]. VR-ITS is an ideal tool for self-learning human anatomy, providing the necessary learning support for students and instructor [Fairén et al. 2020]. This technology allows instructors to shift their role from being anatomy teachers to becoming facilitators of learning. This role change aims to create a more balanced student-teacher relationship and give the students the responsibility of taking control of their learning process.

3 CONTROL STRUCTURE OF THE ITS

3.1 Stakeholders

The human stakeholders of this system are Instructors and Students. They can access the system through biometric enrolment. Several options exist for biometric data enrolment in the system, such as iris scan, and head/hand/eye movements. The biometric data is not exposed to external devices or servers, it is stored on the device as the identification data for protection against any data breach. The iris authentication is performed based on the stored bit codes. Multiple users can also be registered simultaneously using the built-in support from the device.

3.2 Instructors

The instructors will be able to create and modify lesson plans, as well as select demonstration topics and exercises for each teaching session. They will also be able to assign tasks and work with the virtual tutor. Additionally, they will have access to the performance logs of their students, which will allow them to track their progress and adjust the course plan accordingly.

With their editor-level access, instructors will be able to design lesson plans and exercises that align with the specific needs of their students. They will also be able to use the performance logs to identify areas where students may be struggling, and provide additional support as needed. Details of their interaction are discussed in the sections 5.2 and 5.1.

3.3 Student

Students will have participation access to the ITS, which will allow them to practice with the hologram under the supervision of their instructors. They will also be able to view their own performance logs, which will help them track their progress and identify areas where they may need additional practice.

During practice sessions, the ITS will provide immediate feedback to the students in the form of hints and guidance from the VT. This will help students to better understand the material and improve their performance. The system will be designed to adhere to a classroom environment, with each student having their own individual profile and development log. The interaction will be supervised by the instructor, who will monitor the progress of each student and provide additional support as needed. Details of their interaction are discussed in the following sections 5.4 and 5.6.

3.4 Virtual Tutor

The virtual tutor will be a critical component of the MR-ITS to provide personalized learning experiences, immediate feedback, and detailed performance assessment to help students learn and excel in their medical education. The control structure of the VT will focus on the privacy protection of user data and serve the above-mentioned services effectively. Access controls will be put in place to ensure that the tutor can only access the data it needs to perform its functions and that sensitive data is protected from unauthorized access or manipulation. The detail of personalized feedback generation by the virtual tutor is discussed in section 5.8.

3.4.1 Data Access. The virtual tutor will have access to the lesson plans and course materials created by the teachers. In addition, the tutor can access student performance data to provide personalized learning experiences and detailed performance assessments.

3.4.2 Access Levels. : The access levels for the virtual tutor depend on its role within the ITS. The tutor has advanced-level access to the ITS, in order to perform functions such as monitoring student progress, modifying lesson plans, and providing feedback to students. However, access to sensitive data such as biometric enrollment data and personal information about students will be restricted to authorized human personnel only.

3.4.3 Data Handling. : The tutor will interact with students and provide guidance on their progress. It will record individual student performance data as part of guided learning and store the data on a local server. The stored location will be linked to the database.

3.4.4 Privacy Protection. : As before, the ITS will employ a range of security measures to protect user privacy. Access controls will be used to restrict access to sensitive data, such as biometric enrollment data and personal information about students. All data will be encrypted to prevent unauthorized access or interception. Additionally, the ITS will comply with relevant privacy laws and regulations, and will only collect and use data for the purpose of providing a high-quality educational experience.

4 DEMONSTRATION

In this section, we will describe the complete interaction flow between the proposed AI-powered ITS and the human stakeholders (students and instructors). We have included details on the medium of interaction, the virtual tutor's construction, lesson plan and deliverable on the ITS, enrollment on the system, data collection from the Hololens for performance assessment, and classroom-oriented design of the system.

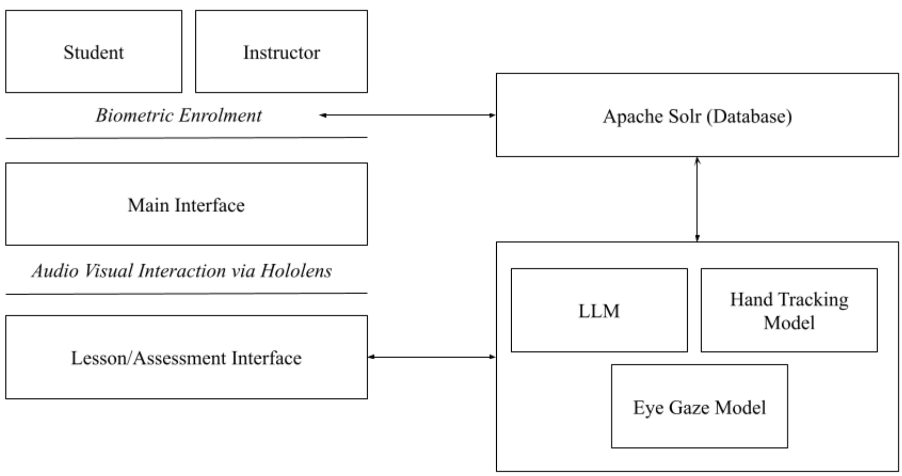


Fig. 4. High-Level Architecture Diagram of MR-ITS

This MR-ITS is designed to cater to multiple students' needs in a class. By providing each student with an individual profile and development log, instructors can tailor the learning experience to meet the needs of their students. The system is minimally supervised by the instructor, ensuring that students stay on track and receive the support they need to succeed. The users need to use the Hololens device to interact with the hologram screen. The use of it allows students and instructors to immerse themselves in the hologram screen, creating a more engaging and interactive learning experience. Using the MR headset, students and instructors can view and manipulate the hologram from different angles, which can help them better understand complex medical concepts and procedures.

Practical Task Assessment: Data Collection and Recognition: When working on practical sessions, students can use hand gestures to interact with the hologram screen. The Microsoft Hololens has a built-in hand tracking system that can detect hand activity through a coordinate system. The purpose of this is to recognize activity from the hand gesture data and conduct the performance assessment of each student.

Performance Analysis: Assisted Analysis from the ITS: Instructors will be able to view the detailed performance log of students, both from the assessment model and the hand-tracking data. The performance log can be used by instructors to gain insights into a student's learning progress. By analyzing the data, instructors can identify areas where students need additional support and adjust their teaching methods accordingly. This data can also be used to track a student's progress over time, which can be used to evaluate their performance and set new learning objectives.

Type of Hints: There will be two types of hints – *immediate* and *post-activity*. Immediate hints will be given during practice sessions, while post-activity feedback will be provided after the completion of an assessment session. This approach will allow the students to receive immediate feedback on their performance during practice sessions, and more detailed feedback after the completion of an assessment. These are discussed in sections 5.4 and 5.6. The hints provided to the student will be based on the movements and actions they perform during the practical task. The system will use activity recognition algorithms to analyze the student's movements and determine where they may be struggling or where they may need additional support.

5 SYSTEM INTERFACE

5.1 Instructor Dashboard Interface (Lesson)

The instructor dashboard provides the ability to instructors to define a curriculum for students and corresponding lesson material. The dashboard provides the instructors the ability to create new lesson contents. Since Solr is an indexed document retrieval system, virtually any form of documented content can be used as a lesson source. Consequently, individual instructors can use resources such as research papers, self-typed documents, online textbooks among others as material for their lessons. As described elsewhere, we initialize the ITS with contents from LibreText Anatomy, an open source anatomy textbook. Once the instructor introduces a new resource into the system, it is indexed by Solr and is available in its inventory. This way, Solr provides the flexibility to use existing resources as well as create new resources or combine both to create a new module.

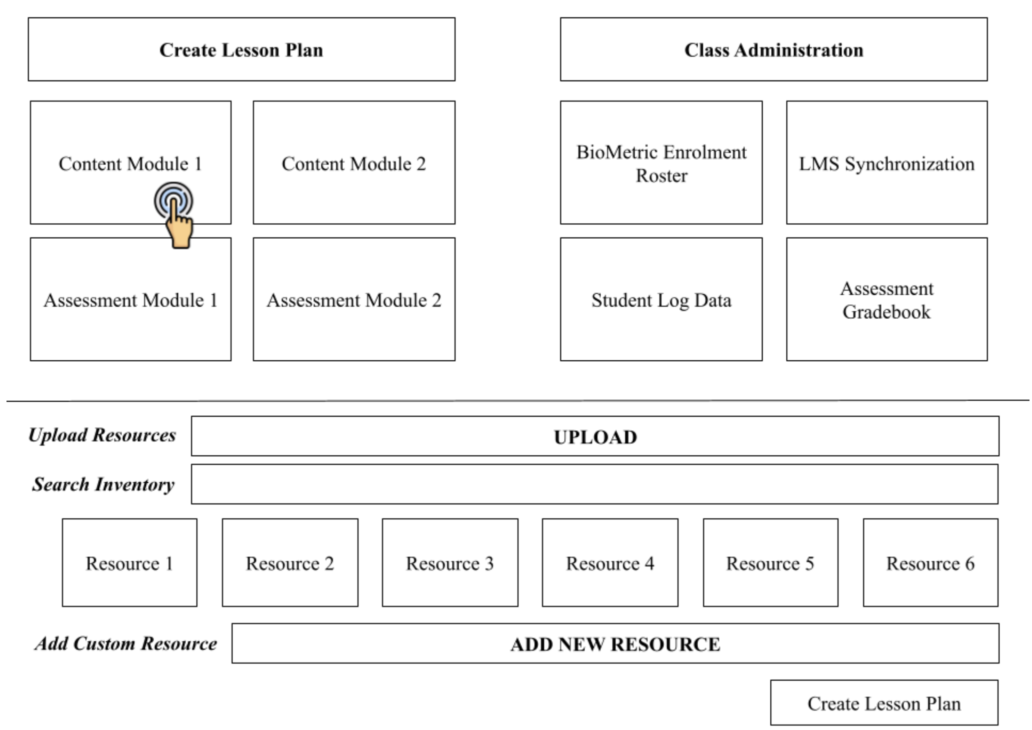


Fig. 5. Interface Prototype for Instructor Dashboard (Lesson)

5.2 Instructor Dashboard Interface (Assessment)

The instructor dashboard provides the instructors the ability to create new assessment contents. The process is nearly identical to creating new lesson content since index based systems like Solr are indifferent to the nature of underlying document. The only caveat is that an assessment comprises of both a prompt and an expected solution, which necessitates a template that defines the structure of the underlying document and populates it so that can be parsed easily. Our ITS provides instructors a variety of problem types to select from ranging from Multiple Choice and Objective Answer problems to conducting practical demonstrations in a 3D holographic environment. Our template is relatively simple for problem types that are not practical based; we provide a section for a prompt and a section for the solution. Since both these are necessarily text, they can be parsed separately during problem generation phase of the ITS. For practical based demonstrations, the solution prompt requires the instructor to simulate the practical (gesture) in the 3D holographic environment. As discussed elsewhere, the hand-tracking model can capture the gesture and its characteristics. These are stored in a compressed reconstructive format as the solution. Later, during problem generation, a sufficiently sensitive similarity metric is used to compare the mesh generated by the user's gesture with the mesh generated stored gesture in several iterations. Consequently, the similarity metric provides an estimate of how 'close' the user's attempt is to the actual solution and is reported as a measure of accuracy. Similar to lessons, once the instructor introduces a new assessment into the system, it is indexed by Solr and is available in its inventory.

5.3 Instructor Dashboard Administrative Interface

Finally, the instructor dashboard also provides administrative capabilities. This includes a biometric enrolment roster that stores the student information, the ability to synchronize with associated LMS, a log of student attempts sourced from the tables described elsewhere and an assessment gradebook sourced from the log of student mastery scores.

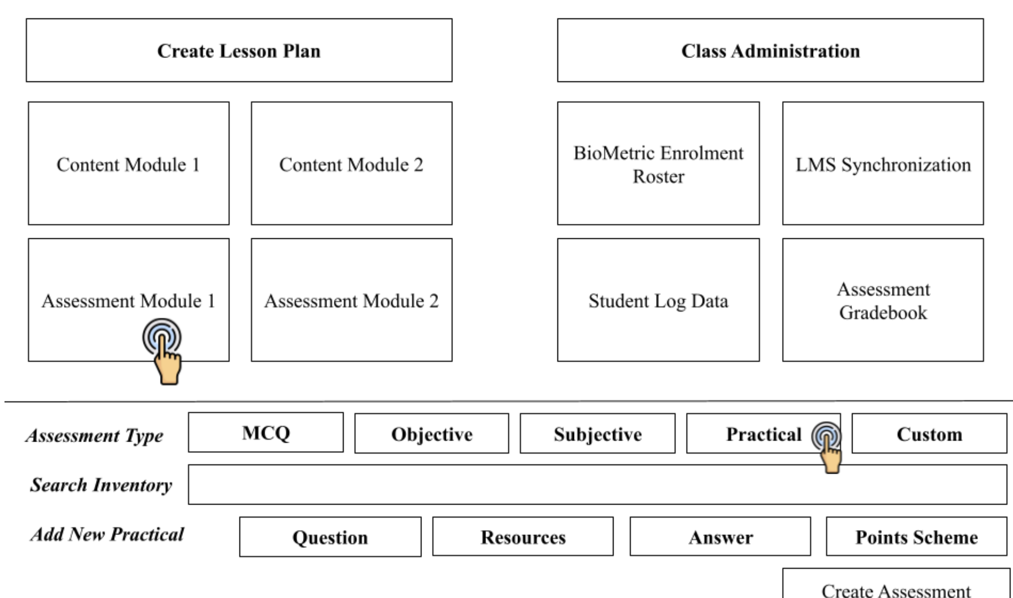


Fig. 6. Interface Prototype for Instructor Dashboard (Assessment)

5.4 Interface for Lesson Content and Guided Learning

Our proposed lesson interface comprises of a 3D immersive experience. For each organ, a three dimensional hologram is provided which is controlled by gestures. Users can rotate, resize and move the hologram to suit their needs. Users have the ability to tap on the hologram to learn about the specific components of the organ. A tap on the screen is detected via the hologram and the vector storing the tap coordinates is used to understand the location of the tap and the corresponding component of the organ is identified. The identified component is then passed to the GPT framework that generates content to teach the tapped component. Since each lesson focuses on a specific organ and the lesson documents are used to train GPT, it is always guaranteed that GPT will have sufficient information for any tap on that specific organ. Simultaneously, Solr queries more information such as stored diagrams and documents pertaining to the specific component that was tapped which accompanies GPT's output. Lastly, users are also provided a virtual chat agent where any remaining points of confusion can be clarified.

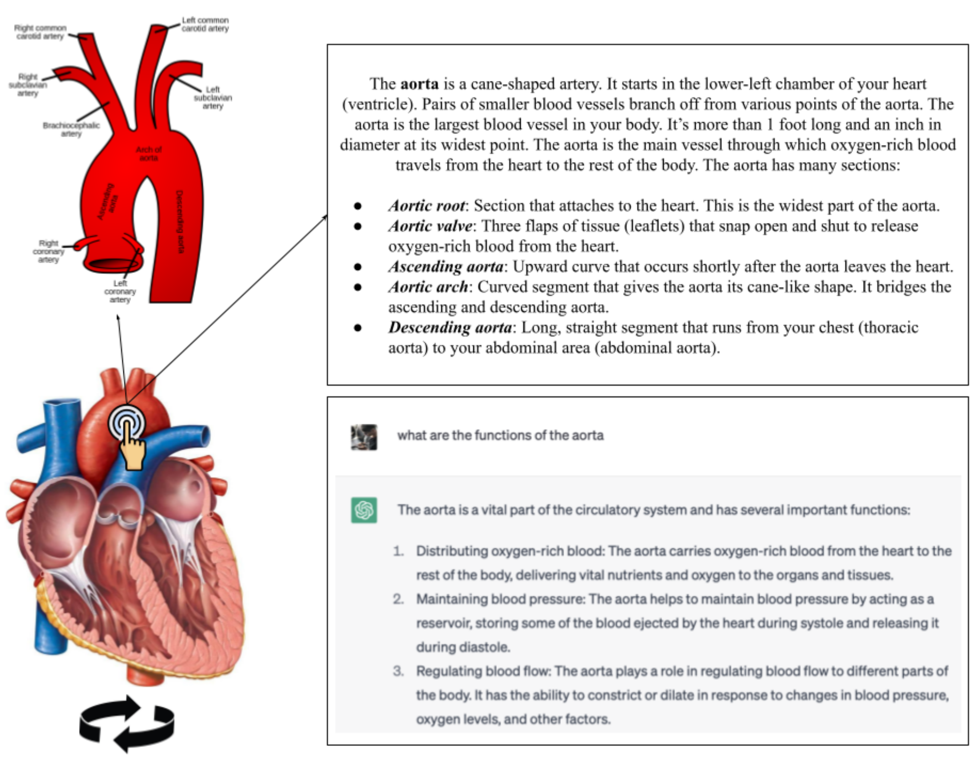


Fig. 7. Interface Prototype for Lesson Content and Guided Learning

5.5 Interface Prototype for Exercise Content Immediate Feedback

Our proposed exercise interface comprises of a 3D immersive experience. For each problem, a three dimensional hologram is provided which is controlled by gestures. Users can rotate, resize and move the hologram to suit their needs. Each problem may be accompanied by a text prompt. The goal of the exercise is to tap the correct component. A tap on the screen is detected via the hologram and the vector storing the tap coordinates is used to understand the location of the tap and the corresponding component of the organ is identified. Based on a comparison with the solution, it is determined if the tap was correct. An informative text message displays the result of the comparison. If the tap is incorrect, the identified component is passed to GPT which generates content explaining what the user's tap corresponded to and why it is incorrect. Users are then presented the opportunity to either try again or ask for a hint. If the user decides to ask for a hint, GPT is used to generate a hint with their previous attempts log from the table described elsewhere and actual solution as context.

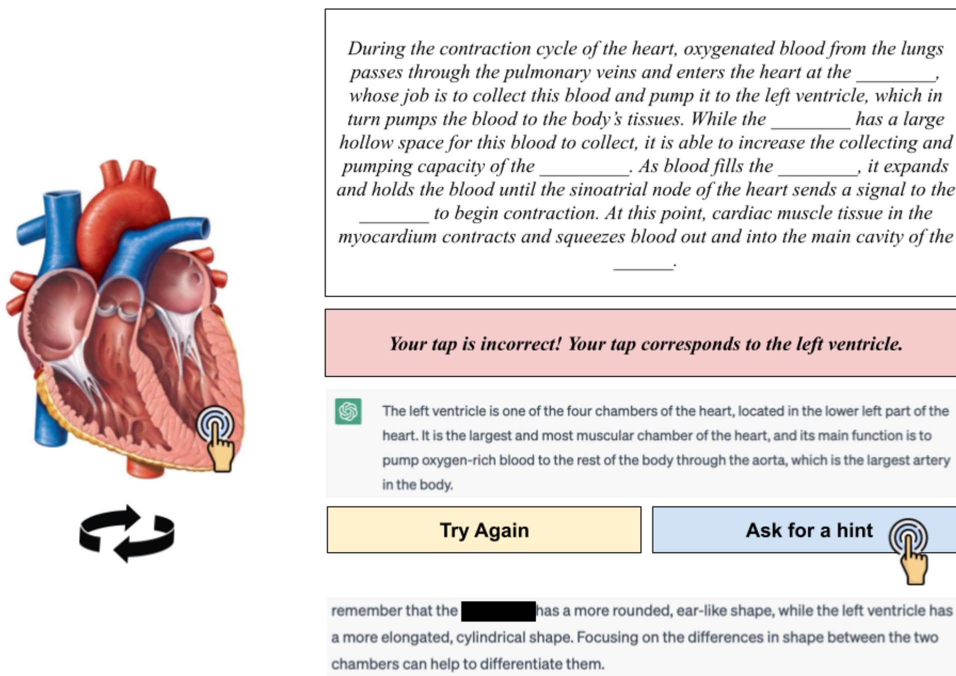


Fig. 8. Interface Prototype for Exercise Content Immediate Feedback

5.6 Post Activity Feedback Interface

Finally, we provide an interface that gives feedback to the user at the culmination of a lesson/assessment. The interface displays a mastery score which is calculated as the model score and is stored in the table described elsewhere as mastery log. This score is accompanied by a brief summary of the activities that the user mastered. The user is presented with themes of the assessments/lessons they excelled in based on their mastery score log. Likewise, a brief summary of the user's potential weaknesses is provided as a list of themes the ITS thinks the user did not master based on the mastery log data. The identified themes are then passed to GPT with the user's attempts log as context which generates content to reinforce and clarify the user's points of confusion by providing tailored feedback. Simultaneously, the themes are queried in Solr to search for indexed content such as visual aids that are displayed along with the output of GPT to supplement the content. Finally, based on the overall mastery score, the user is either allowed to continue to the next activity or may be asked to repeat the current activity.

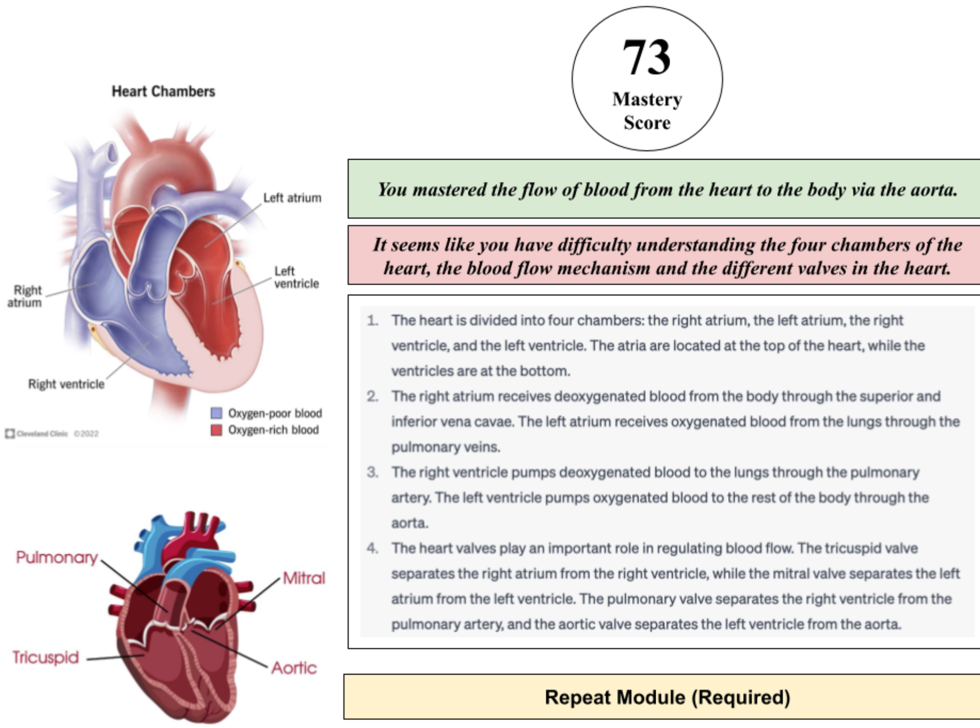


Fig. 9. Interface Prototype for Post-activity feedback

5.7 Assessment Module

The core of the Assessment Module is a hand-tracking model [Malik et al. 2021] developed at Facebook Research that can track high-fidelity hand deformations through highly self-contacting and self-occluding hand gestures, for both single hands and two hands.

Two assessment situations may arise in our proposed implementation. First, the student may be asked to label components within an organ. This is accomplished using tap/touch coordinates vector recorded by the HoloLens as described in data collection section. The coordinates vector is compared to a baseline coordinate vector derived from an accurate labeling by a human instructor. The distance between the two vectors is calculated using euclidean norm, which is used to provide feedback about the correctness of the user's tap. Since the vector stores both direction as well as magnitude, it is possible to provide feedback about the incorrect aspects of the tap such as how far the user is from a correct tap and can, therefore, be used to sequentially guide the user towards the correct tap by providing hints. By storing euclidean distance between different components at the expense of storage, it is also possible to provide very specific feedback pertaining to the incorrect tap such as what incorrect component was tapped among others.

Second, the user may be required to simulate hand gestures and techniques. The assessment of this activities are discussed in detail in section 7.2.

5.8 Personalized Feedback Module

The success of Large Language Models (LLMs) has ushered in an era of advanced generative text-based mechanisms for feedback generation. Consequently, we adopt the state-of-the-art Generative

Pre-Trained Transformer (GPT) model fine-tuned for topically relevant data as our primary feedback generator. Prior to a given session, we propose fine-tuning a GPT model using the collection(s) relevant to that specific topic, which is now possible owing to several frameworks such as gpt4all [Nomic AI 2022]. This ensures that the feedback is topically relevant and reduces the probability of the model producing erroneous feedback. This design choice also allows for enhanced performance since a fully-trained implementation of GPT will significantly slow down the ITS owing to its vast size.

There are two main kinds of feedback that we propose in our ITS. Firstly, we propose user-driven feedback. An advantage of GPT is that the user can ask for hints and clarification that are completely dependent on the user and not on their progress/success/failure w.r.t the ITS. Since we train the GPT model topically, users can virtually use it as a search engine much like ChatGPT. This allows user to generate hints on their own at any stage of learning. Secondly, we propose to provide tailored feedback generated using the sensory input collected. Since GPT is a generative model, with sufficient context we can use it to generate feedback without any templated mechanism.

The tailored feedback mechanism relies on sensory data obtained from HoloLens. For component labeling tasks, euclidean distance provides a way to identify mistaken labeling, which can be passed to GPT to tailor feedback using the topical knowledge that the GPT model is trained on. In essence, providing the mistake made by the user as input to the GPT and the correct labeling as the context would generate textual feedback that would address the specific mistake by the user and guide the user towards the correct solution. For hand-gesture simulations, with the correct simulation as context, it is possible to generate clues by modeling image similarity as an optimization problem where we aim for progressively higher similarity. The model generates feedback based on the similarity metrics computed in the assessment module.

6 DATA MANAGEMENT

At the core of our ITS is the efficient and effective use of data. In broad terms, our ITS necessitates storing and accessing two kinds of data:

(1) Topical Data: This factual data pertains to the content and the learning material that the ITS uses for generating problems and providing guidance and feedback. This includes lesson contents and training data for our feedback loop and problem-generation system.
(2) Student Data: This data is collected in real-time during user sessions that are used to personalize learning and feedback.

6.1 Topical Data

We propose Apache Solr [Apache Software Foundation 2023b], an index-based database server that can be used to store teaching resources that will subsequently be used by the proposed ITS to generate problems and feedback. Apache Solr is a free, open-source search engine based on the Apache Lucene [Apache Software Foundation 2023a] library.

Solr provides the ability to store documents efficiently. This allows educators to virtually use any learning material they have created within our proposed ITS. This not only enhances the credibility of our proposed system but Lessons, textbooks, research papers, and diagrams can easily be stored, indexed, and queried in Solr as documents stored within a collection. From an efficiency perspective, it is fruitful to store collections containing information relevant to a specific organ X clustered together to enhance querying as a SolrCloud cluster.

In our MR-ITS, the topical data is stored in the form of modules. Each module has a corresponding table called *Module Data*. This table comprises *module_id* which serves as a unique identifier for the current module and *theme* which stores the topic the specified module corresponds to. Each module

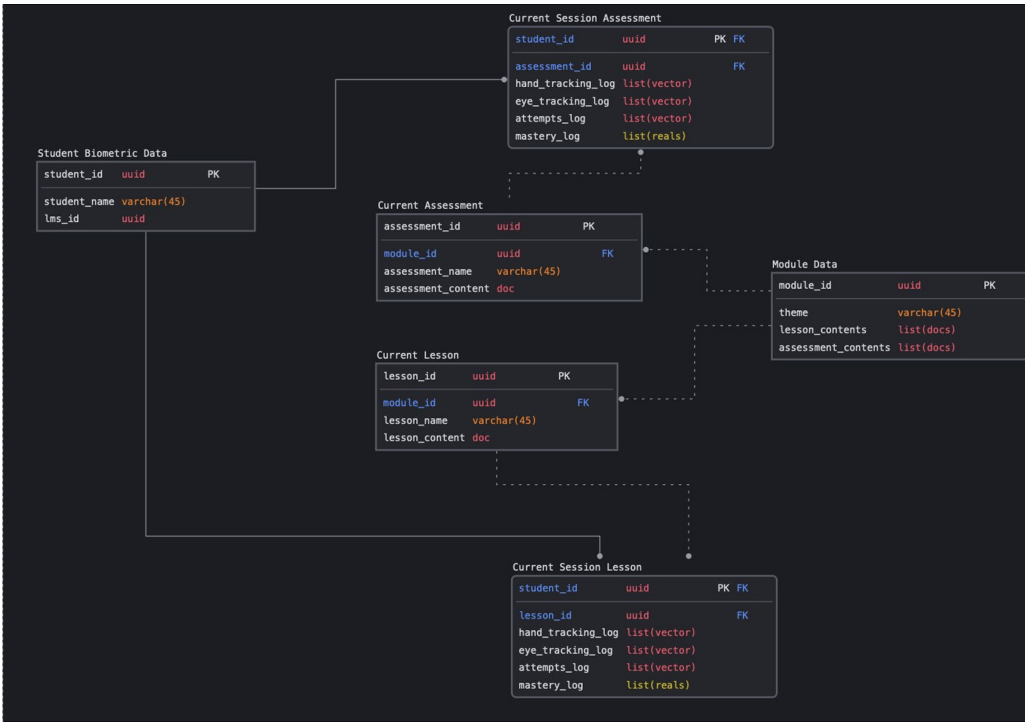


Fig. 10. Proposed Cached Storage Schema for the MR-ITS

is comprised of two components: lessons and assessments. Lessons store indexed documents used for instructional purposes while assessments stores indexed documents that serve as question banks in our ITS through which questions for assessments are selected. Consequently, the table for each module also stores two lists of indexed documents: *lesson_contents* storing lessons and *assessment_contents* storing assessments.

It may be noted that working with an entire module can be computationally expensive. To counter this, we propose two cached tables created for a specific individual session: *Current Assessment* and *Current Lesson*. During a given ITS Session, the *Current Assessment* table stores a single assessment out of the several possible assessments in the *Module Data* table which is presented to the user. This assessment has a unique identifier *assessment_id*, a name *assessment_name* and contents in the form of a single indexed document *assessment_content*. Analogously, during a given ITS Session, the *Current Lesson* table stores a single lesson out of the several possible lessons in the *Module Data* table which is presented to the user. This lesson has a unique identifier *lesson_id*, a name *lesson_name* and contents in the form of a single indexed document *lesson_content*.

6.2 Student Data

We collect two types of student data during learning sessions: eye gaze and hand gesture. As suggested in prior literature, eye gaze data provides valuable insights about the student's engagement with the ITS as well as overall attention and can be integrated into the feedback loop. Hand gesture data, on the other hand, is a critical component of our ITS used to assess and evaluate students. These data are automatically collected by the Hololens device through built-in API and stored on the local server for ensuring privacy.

6.3 Biometric Data

Since we opt for biometric enrolment in our proposed ITS, student identifiers can be stored independently in the form of a separate table *Student Biometric Data*. For each student, we store a unique identifier *student_id*, the name *student_name* and an LMS identifier *lms_id* that synchronizes the student data between the LMS and the ITS.

We propose two tables to store data recorded during learning sessions: *Current Session Assessment* and *Current Session Lesson*. For every assessment, the *Current Session Assessment* table stores the log of hand gestures for that specific assessment in *hand_tracking_log* as a list of Vectors, the log of eye tracking for that specific assessment in *eye_tracking_log* as a list of Vectors, a log of all user attempts in *attempts_log* as a list of vectors representing user taps on the holographic screen and a log of mastery scores corresponding to each attempt in *mastery_log* as a list of real numbers. In our proposed schema, the *Current Session Assessment* table is associated with the *Current Assessment* table. Practically, this means that for every assessment in a module, we have a table that records logs and data for that specific assessment in a cached format which is retained till the end of the assessment session.

Analogously, for every lesson, the *Current Session Lesson* table stores the log of hand gestures for that specific lesson in *hand_tracking_log* as a list of Vectors, the log of eye tracking for that specific lesson in *eye_tracking_log* as a list of Vectors, a log of all user attempts in *attempts_log* as a list of vectors representing user taps on the holographic screen and a log of mastery scores corresponding to each attempt in *mastery_log* as a list of real numbers. In our proposed schema, the *Current Session Lesson* table is associated with the *Current Lesson* table. Practically, this means that for every lesson in a module, we have a table that records logs and data for that specific lesson in a cached format which is retained till the end of the learning session.

7 BACK END MODULES

Traditionally, medical schools rely on the physical examination of anatomical lessons for evaluating the practical expertise of the students. The examination is proctored and evaluated in the presence of instructors since the students are operating in the cadaveric dissection lab to do so. This process requires the involvement of significant manual involvement of instructors and financial investment in the dissection lab, both of which make the process burdensome. In our proposed MR-ITS, we plan to leverage the existing interaction and data collection pipeline to automate the above-mentioned manual process to a significant extent. The ITS will include two major modules - Attention Tracking Module and an ml model for Activity Recognition. The data for these two components will be largely collected from the Hololens device itself. In this section, we will discuss at length the details of these two modules.

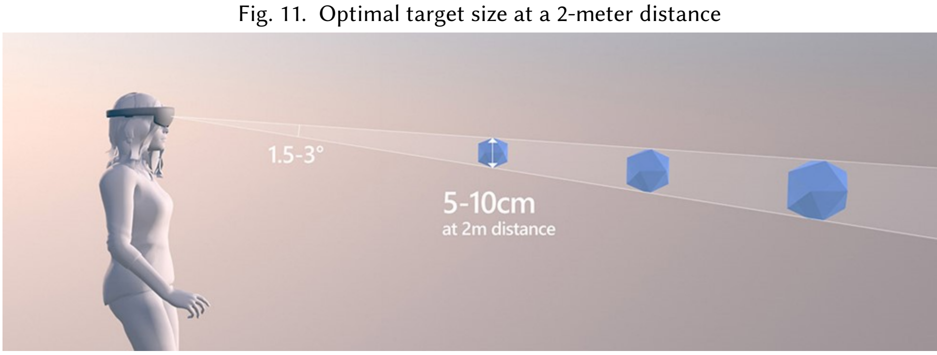
7.1 Attention Tracking Module

Measuring students' engagement in class has been a highly active research interest across the fields of tutoring systems, sensor systems, and in recent years machine learning. In a mixed-reality paradigm, the measurement of engagement can be pinpointed due to the capacity of the devices to accurately track head and eye movement. The Hololens device offers a new level of context and human understanding within the holographic experience, by providing the data about the user's scope of view.

The device comes with Head and Eye Tracking APIs built in. These two APIs work together to understand the Field of view and what the user is currently looking at. It also ensures the user's privacy and restricts the passing of any identifiable information such as biometrics. The eye-gaze data collection works like the following:

- Each user goes through an eye-tracking calibration session by looking at a set of holographic targets.
- The user grants the app permission to use eye-tracking information.
- The API returns information on the field of view of the user as a single eye-gaze ray (gaze origin and direction) at approximately 30 FPS (30 Hz).
- The predicted eye-gaze is approximately within 1.5 degrees in visual angle around the actual target (Figure 11.
- Each gaze sample is represented by a three-dimensional gaze vector, $v = (v_x, v_y, v_z)$ vectors. The raw gaze vectors are transformed into degrees of visual angle using simple trigonometry and Matlab's atan2d function [Aziz and Komogortsev 2022].
- It is also possible to collect individual (left and right) eye gaze vectors and to set the eye-tracking frame rate to 30,60 or 90 FPS using the extended eye-tracking API.

Fig. 11. Optimal target size at a 2-meter distance



The data collected in the above-mentioned way will be helpful for computing engagement metrics in class. Also, it will allow for individual scope of view in lesson content, which will be useful in tracking the contents where students required increased attention or lost focus. The built-in APIs are working as the ML model for collecting and stabilizing the field of view of each user. Therefore, our MR-ITS will have individual eye-gaze logs for each student.

7.2 Activity Recognition Model

In this section, we propose an "Activity Recognition" model for the assessment of practical examination conducted with the holographic screen of our MR-ITS. Here, we have used the dense hand surface tracking model from Meta [Malik et al. 2021] as the baseline model. To integrate the Hololens devices' data with the hand-tracking model, we propose the following modification in data collected from the device.

7.3 Gesture Data collection from Hololens

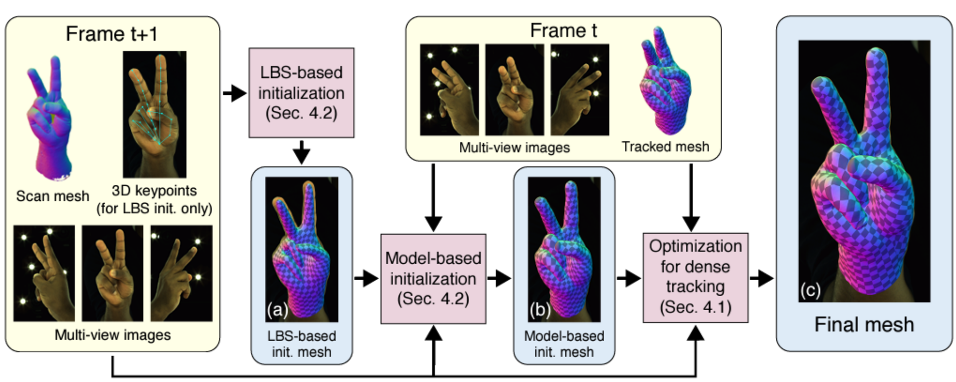
The hand tracking profile can be activated in the Hololens system and can also be customized according to hand representation. Figure 13a shows the basic blueprint of prefabricated hand mesh. The user data is identified against this prefabricated image. This feature gives us the 3D mesh input of the user's hand activity. The 3D keypoint derived from the hololens consists of the following data structure:

- The **gestureClass** containing a one Hot representation of the class of the gesture
- The **gestureData** containing the actual data which was captured by the Microsoft HoloLens. The gesture is represented as an array containing successively hand coordinates. The first

element of the gestureData array represents the location of the hand during the start of the gesture and the last element in the array represents the location of the hand during the end of the gesture.

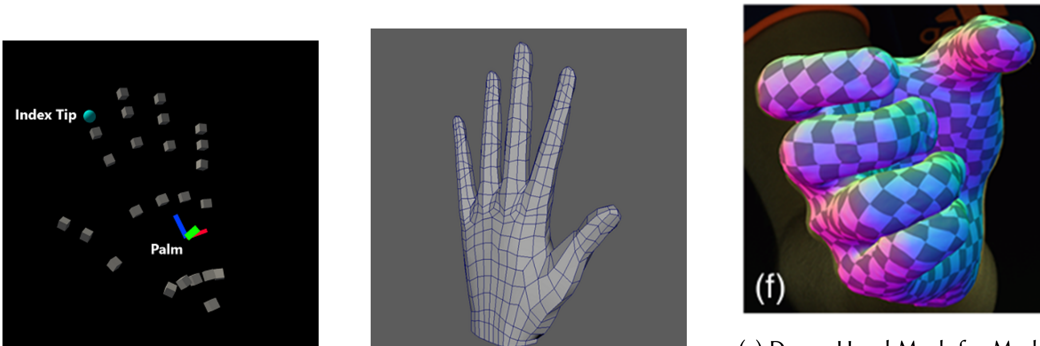
Tracking Hands in Mixed-Reality. :The latest research by Meta Virtual-Reality Team [Malik et al. 2021] introduces the first algorithm capable of tracking high-fidelity hand deformations through highly-self contacting and self-occluding hand gestures, for both single hands and two hands. This is a promising addition to the purpose of our research, where we are proposing to automate the assessment of anatomical practical tasks through machine learning. The hand tracking method takes input from the 3D key points and a 3D scan input to accurately identify the final mesh as presented in Figure 12.

Fig. 12. Dense Hand Tracking Method with 3D Keypoints and 3D Scan Mesh from VR



7.4 Train Models on Anatomical Activity from Mass Video/Images

Although there are numerous works on activity recognition from images, 3D key points, etc on various datasets, to our knowledge there has been no prior work on collecting datasets on practical anatomical tasks. Traditionally the instructors at medical school teach the students through the direct use of human organs or cadavers. The students are taught the delicate skills of handling anatomical procedures. In recent years, initiatives are being taken to collect digital image datasets of anatomy lessons. However, the learning assessment still remains manual and largely dependent on the instructor. To mitigate this gap, we propose to collect publicly available video-recorded class lectures on practical anatomy lessons, where the correct procedures are being shown.



(a) Palm Coordinates

(b) Generated 3D Hand Mesh

(c) Dense Hand Mesh for Model Input

Fig. 13. Generation of Dense Hand Mesh

We propose the following plan for training a benchmark model on practical anatomy from image inputs:

- Data collection: Collect publicly available video recorded class lectures on anatomy lessons
- 3D Keypoints: Localize key points of the hands and render visual effects over the hands using the Mediapipe Hand landmark detection model [Zhang et al. 2020].
- 3D Mesh Generation: Generate 3D mesh representation of image inputs using the GET3D model from NVIDIA [Gao et al. 2022] (Figure 13b).
- Dense Mesh Generation: Combination of the 3d Keypoints and the 3D generated mesh will produce the dense mesh as presented in Figure 13c. This will be the input to the model.
- Labeling: Label the frames of correct anatomical procedures (e.g, handling organs, assisting in surgical procedures)
- Train: Train a computer vision model similar to [Malik et al. 2021] to identify anatomical tasks. We will utilize transfer learning to create the new model, with new output layers for the target activities in anatomy physical assessments.

Now, when this model is trained, we can input the hand gesture data gathered from Hololens and improved upon by the dense hand tracking model by [Malik et al. 2021] to assess the accuracy of the task performed. The paper claims that the proposed algorithm is able to identify even fine-hand movements like sign language. A snapshot of example tasks are in Figure 14. This will revolutionize the process of practical task assessment across other fields of study as well. The multi-model gesture data collected from Hololens can be used in the proposed dense hand-tracking method for activity recognition, which is the practical task assessment in the scope of our proposed project.

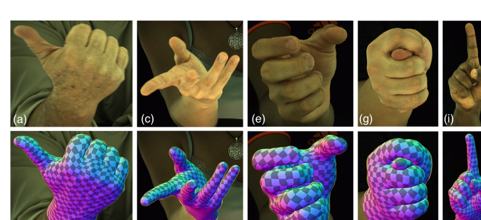


Fig. 14. Tracking Result for five different subjects of different hand shapes, ages, and appearance

8 SYSTEM EVALUATION

8.1 Individual Performance Evaluation

The evaluation part of our proposed AI-ITS focuses on assessing students' performance through a multi-modal approach. We propose a holistic performance evaluation that will leverage on the data collected from different modules of the ITS. The virtual tutor introduced in this project will have access to individual students' recorded activities. The data stored will follow the FERPA protocol to avoid any privacy breach for students.

The MR- ITS has scores from two different assessment fronts: theoretical examination score from integrated LMS and practical assessment score from the Activity Recognition model in section 7.2. The ITS also has logged information on student learning progress from logs of the virtual tutor. A combination of these scores will produce an overall performance score for each student. We also integrate the attention tracking data as the engagement score. In the case when a student performs poorly on certain topics, the attention tracking data will substantially help to unfold the situation and identify the lesson content that required higher attention or where the student lose track. The derived conclusion from this micro-analysis will help to create a personalized improvement guideline for the student. We will assess the following from the recorded activity log:

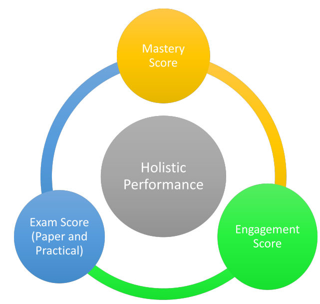


Fig. 15. Performance Analysis of Individual Student

- Timeline of Performance: The ITS will have the log of individual learning sessions of each student, as shown above in section 5.4. This will serve as a continuous progress metric of each student.
- Record-keeping of Theoretical Examination: The ITS will synchronize with the examination records from learning management sites like Gradescope/moodle to each student's records.
- Practical Assessment: The practical assessment performed within the holographic screen will be assigned a mastery score using the Activity Recognition model, as shown in section 5.6.
- Holistic Analysis: The ITS will produce a comprehensive analysis of students' performance from both the traditional exam records and the practical task assessment.

8.2 System Evaluation

To evaluate the efficacy of the system, we can conduct the following study based on a "Randomized Control Trial" principle. Participating students are divided into three sub-groups. The first two groups will be exposed to both MR-ITS and cadaveric dissection lab for learning Upper Limb and Lower Limb Anatomy. The order of using MR-ITS and dissection lab will be reversed. The third group will serve as a control group where they will learn both topics from the dissection lab. In the end, all three groups will appear for a final exam, which will be a combination of MR and cadaver-based practical exams of 60 minutes.

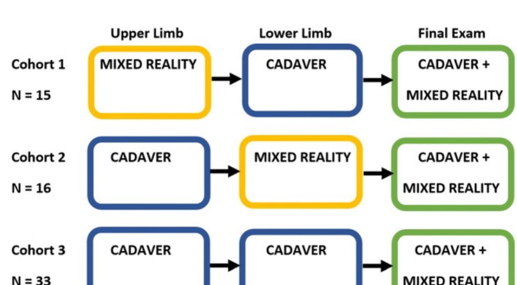


Fig. 16. Comparative Effectiveness Study: System Evaluation [Stojanovska et al. 2020]

9 DISCUSSION

9.1 Supporting Learning Theories

Audio-visual (AV) learning is an instructional method that involves presenting information through both auditory and visual stimuli [Pasqualotto et al. 2021]. Podolskiy [Podolskiy 2012] suggests that this approach can improve comprehension, retention, and transfer of information. Ulloa Salazar and Díaz Larenas [Ulloa Salazar and Díaz Larenas 2018] further explains that this can be achieved by using images to reinforce verbal presentations or by using self-standing multimedia elements like instructional movies or virtual reality simulations. Mayer's (2009) cognitive theory of multimedia learning explains how humans process information in working and long-term memory and how delivering information in a multimedia environment can enhance learning. Mathew and Alidmat [Mathew and Alidmat 2013] and Ismail et al. (2017) report that undergraduate students find audio-visual aids useful and that multimedia elements can enhance imagination and visualization. According to Cavaleri et al. [Cavaleri et al. 2019], personalised screen-capture video feedback that uses audio-visual media can be more effective in processing information due to Mayer's [Mayer 2009] theory of multimedia learning. The theory posits that presenting information in multiple modes can reduce cognitive load and aid in better information processing. Kuok Ho and dan Rangis o [Kuok Ho and Rangis 2018] suggests that AV aids promote learning by providing auditory and visual stimuli, facilitating the registration of information in short-term memory and consolidation with prior knowledge in long-term memory. Fleming's [Fleming 2006] Visual Auditory Kinaesthetic learning theory (VAK) suggests that different learning styles can be addressed by presenting information through visual, auditory, and kinesthetic modes. Ibe and Abamuche [Ibe and Abamuche 2019] support this theory with their findings that students taught using audio-visual materials achieved better than those taught using conventional methods.

9.2 Benefits of Mixed-Reality based ITS

The benefits of MR-ITS are consistent with Vygotsky's theory of social constructivism, the zone of proximal development (ZPD), and Piaget's cognitive constructivism. Vygotsky's theory of social constructivism emphasizes the role of social interaction in learning [Vygotsky 1978]. ITS encourage social interaction by allowing students to interact with the system, receive feedback, and interact with peers or virtual teachers, enabling collective knowledge building and collaboration [Dai and Ke 2022]. Furthermore, the MR-ITS is compatible with Vygotsky's Zone of Proximal Development (ZPD) in that it provides a tailored framework to bridge the gap between a student's current and potential developmental level [Aasekjær et al. 2023]. It provides personalized guidance and support to help students navigate ZPD and improve their proficiency [Kirch and Sadofsky 2021]. Additionally, MR-ITS can promote social interaction and active learning experiences and provide students with a framework [Kirch and Sadofsky 2021; Vygotsky 1978]. Piaget's theory emphasizes the active role of the learner in constructing knowledge and understanding through their interactions with the environment. [Piaget 1968]. ITS engages students in interactive activities, simulations and problem-solving tasks, encourages critical thinking and develops new knowledge [Ma et al. 2014]. Finally, the MR-ITS can enhance problem-based learning (PBL) and team-based learning (TBL) by providing individualized support that takes into account individual strengths, weaknesses, and learning styles [M. Hackett and M. Proctor 2018; Schez-Sobrino et al. 2020]. This alignment facilitates effective participation in PBL and TBL activities and supports problem-solving, teamwork, and collaboration skills.

9.3 Significance in Medical Education

The use of MR-ITS in medical education can reduce the cost of traditional methods, as cadaver labs and working with human body donors can be costly to maintain. Using MR-ITS, which offers virtual simulations and interactive learning experiences, the need for physical resources such as cadavers and human body donors can be reduced or eliminated, leading to potential cost savings [Moro et al. 2020]. Mixed reality offers the alternative to the one-time investment of a donated cadaver [Moro et al. 2020]. It can be also helpful for the challenges in resource allocation for practical skills development in medical education [B. Bach et al. 2018; Yoo et al. 2022b].

10 CONCLUSION

In conclusion, an AI-powered holographic smart tutoring system can represent the future of medical education. MR-ITS can transform the landscape of medical education, increasing opportunities for hands-on interaction and engagement with immersive learning experiences and environments. It can address the current limitations, offer a more effective and efficient learning experience, and cater to the needs of both educators and learners. The use of mixed reality can be a valid alternative [Walker 2013b] as it can increase engagement and improve practical skills [Moro et al. 2020]. Based on our discussion and our findings, we conclude that the proposed ideas to address limited resources in developing practical skills in medical education could have significant benefits for students in practice. By addressing the challenges, we can support a more effective and efficient medical education system that meets the needs of educators and students.

11 INDIVIDUAL CONTRIBUTION

We would like to acknowledge the contributions of the following individuals to the completion of this project:

11.1 Mahbuba Tasmin

Mahbuba has worked on the project's foundational ideation. She has identified the core functionalities to be included in the system to solve the addressed problem and planned the outline of the project accordingly. She has researched the technical details of the Hololens device, state-of-the-art of holographic technology, the latest machine-learning models available to address the assessment in a mixed-reality world, existing research on virtual-reality activity recognition, and the procedures of system evaluation. In the paper, she has worked on the following sections: **Abstract, Introduction, Control Structure of the ITS, Demonstration, Backend Modules, and Evaluation**. As the team lead, she distributed the rest of the work among the team-mates. She was also the major contributor for the preparation of project report, presentation slide and the short video.

11.2 Manan Talwar

Manan has worked on all the System Interface Prototypes and detailed the system's working principle. He has thoroughly studied the functionalities of Apache Solr Database to create a novel database schema and added the details of data storage. He has defined the learning objective, the interaction design of the proposed ITS, "Hints" and guided learning sections and designed the interfaces accordingly. In the paper, he has worked on the following sections :**Learning objective, System Interface, and Data Management**. He also contributed extensively to the project presentation slide and report preparation.

11.3 Jungwon Kyung

Jungwon has worked on exploring educational theories in conjunction with our proposed Mixed Reality Intelligent Tutoring System (MR-ITS). She conducted extensive research to identify relevant learning theories and bolster the claims put forth in our proposal. In the paper, she has worked on the following sections: **Abstract, Related Work, Discussion, and Conclusion**. She played an instrumental role in forming the team, kickstarting the initial communication and discussion, and facilitating the process with team-building efforts.

REFERENCES

Ed. by I. Akselbo and I. Aune. "Virtual Reality (VR) in Anatomy Teaching and Learning in Higher Healthcare Education." *How Can we Use Simulation to Improve Competencies in Nursing?* Springer, Cham. DOI: 10.1007/978-3-031-10399-5_10.

Aamir Ali, Zohaib N. Khan, Carolyn P. Konczalik, and Salwa El Sayed. 2015. "The perception of anatomy teaching among UK medical students." *Bulletin of the Royal College of Surgeons of England*, 97, 9, 397–400.

Apache Software Foundation. 2023a. *Apache Lucene*. Accessed April 6, 2023. (2023). https://lucene.apache.org/.

Apache Software Foundation. 2023b. *Apache Solr*. Accessed April 6, 2023. (2023). https://solr.apache.org/.

Samantha Aziz and Oleg Komogortsev. 2022. "An Assessment of the Eye Tracking Signal Quality Captured in the HoloLens 2." In: *2022 Symposium on Eye Tracking Research and Applications* (ETRA '22) Article 5. Association for Computing Machinery, Seattle, WA, USA, 6 pages. ISBN: 9781450392525. DOI: 10.1145/3517031.3529626.

B. Bach, R. Sicat, J. Beyer, M. Cordeil, and H. Pfister. 2018. "The hologram in my hand: How effective is interactive exploration of 3D visualizations in immersive tangible augmented reality?" *IEEE Transactions on Visualization and Computer Graphics*, 24, 1, 457–467. DOI: 10.1109/TVCG.2017.2745187.

Benjamin Bach, Ronell Sicat, Johanna Beyer, Maxime Cordeil, and Hanspeter Pfister. 2018. "The hologram in my hand: How effective is interactive exploration of 3D visualizations in immersive tangible augmented reality?" *IEEE Transactions on Visualization and Computer Graphics*, 24, 1, 457–467. DOI: 10.1109/TVCG.2017.2745187.

John Biggs. 2003. *Constructing learning by aligning teaching: Constructive alignment*. SRHE and Open University Press.

M. Cavaleri, S. Kawaguchi, B. Di Biase, and C. Power. 2019. "How recorded audio-visual feedback can improve academic language support." *Journal of University Teaching & Learning Practice*, 16, 4. https://ro.uow.edu.au/jutlp/vol16/iss4/6.

Deng Chen, Qi Zhang, Jian Deng, Yun Cai, Jiaping Huang, Fang Li, and Kun Xiong. 2018. "A shortage of cadavers: the predicament of regional anatomy education in mainland China." *Anatomical Sciences Education*, 11, 4, 397–402.

C.-P. Dai and F. Ke. 2022. "Educational applications of artificial intelligence in simulation-based learning: A systematic mapping review." *Computers and Education: Artificial Intelligence*, 3, 100087. DOI: 10.1016/j.caeai.2022.100087.

R.H. Ellaway. 2016. "A conceptual framework of game-informed principles for health professions education." *Advances in Simulation*, 1, 28. DOI: 10.1186/s41077-016-0030-1.

M. Fairén, J. Moyés, and E. Insa. 2020. "VR4Health: Personalized teaching and learning anatomy using VR." *Journal of medical systems*, 44, 5, 94. DOI: 10.1007/s10916-020-01550-5.

Neil D. Fleming. 2006. *V.A.R.K Visual, Aural/Auditory, Read/Write, Kinesthetic*. Bonwell Green Mountain, Falls, New Zealand.

Jun Gao, Tianchang Shen, Zian Wang, Wenzheng Chen, Kangxue Yin, Daiqing Li, Or Litany, Zan Gojcic, and Sanja Fidler. 2022. "GET3D: A Generative Model of High Quality 3D Textured Shapes Learned from Images." In: *Advances In Neural Information Processing Systems*.

Armando V González, Benjamin Jr Williamson, and Robert Sottilare. 2017. "Authoring Augmented Reality Scenarios for Intelligent Tutoring Systems with GIFT." *IEEE Transactions on Learning Technologies*, 10, 3, 360–370. DOI: 10.1109/TLT.2016.2628998.

Jose Carlos Gonzalez Vargas, Ramon Fabregat, Angela Carrillo-Ramos, and Teresa Jové. 2020. "Survey: Using augmented reality to improve learning motivation in cultural heritage studies." *Applied Sciences*, 10, 3, 897.

Bruno Guimaraes, Leandro Durado, Sergey Tsisar, José M. Diniz, Maria Dulce Madeira, and Miguel Angel Ferreira. 2017. "Rethinking anatomy: how to overcome challenges of medical education's evolution." *Acta Medica Port*, 30, 2, 134–140.

M. Hackett and M. Proctor. 2018. "The Effect of Autostereoscopic Holograms on Anatomical Knowledge: A Randomized Trial." *Medical Education*, 52, 1147–1155. DOI: 10.1111/medu.13729.

Michael Hackett and Marcus Proctor. 2018. "The Effect of Autostereoscopic Holograms on Anatomical Knowledge: A Randomized Trial." *Medical education*, 52, 1147–1155. DOI: 10.1111/medu.13729.

R. V. Hill and Z. Nassrallah. 2018. "A Game-Based Approach to Teaching and Learning Anatomy of the Liver and Portal Venous System." *MedEdPORTAL : the journal of teaching and learning resources*, 14, 10696. DOI: 10.15766/mep_2374-8265.10696.

HoloAnatomy [HoloAnatomy Software suite]. Retrieved from https://case.edu/holoanatomy/why-holoanatomyr/holoanatomyr-software. (2023).

Robin Hopkins, Glenn Regehr, and Timothy D. Wilson. 2011. "Exploring the changing learning environment of the gross anatomy lab." *Academic Medicine*, 86, 883–888.

Xin Huang, Fridolin Wild, and Denise Whitelock. 2021. "Design dimensions for holographic intelligent agents: A comparative analysis." *Journal of Educational Technology & Society*, 24, 2, 32–47.

E. Ibe and J. Abamuche. 2019. "Effects of audiovisual technological aids on students' achievement and interest in secondary school biology in Nigeria." *Heliyon*, 5, 6, e01812. DOI: 10.1016/j.heliyon.2019.e01812.

S. A. Kirch and M. J. Sadofsky. 2021. "Medical Education From a Theory-Practice-Philosophy Perspective." *Academic pathology*, 8, 23742895211010236. DOI: 10.1177/23742895211010236.

D. T. Kuok Ho and I. dan Rangis. 2018. "Effectiveness of audio-visual aids in teaching lower secondary science in a rural secondary school." *Asia Pacific Journal of Educators and Education*, 32, 91–106. DOI: 10.21315/apjee2017.32.7.

LibreTexts contributors. 2023. *LibreTexts: Medical*. Accessed April 6, 2023. (2023). https://med.libretexts.org/.

W. Ma, O. O. Adesope, J. C. Nesbit, and Q. Liu. 2014. "Intelligent tutoring systems and learning outcomes: A meta-analysis." *Journal of Educational Psychology*, 106, 4, 901–918. DOI: 10.1037/a0037123.

Muhammad Wajahat Malik, Angjoo Kanazawa, Weiqiang Zhang, Jingwan Yang, Srinivasa G. Narasimhan, and Yaser Sheikh. 2021. "Constraining Dense Hand Surface Tracking with Elasticity." In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 7853–7862. DOI: 10.1109/CVPR42600.2021.00828.

N. G. Mathew and A. O. H. Alidmat. 2013. "A Study on the Usefulness of Audio-Visual Aids in EFL Classroom: Implications for Effective Instruction." *International Journal of Higher Education*, 2, 2, 86–92.

Richard E. Mayer. 2009. *Multimedia Learning*. (2nd ed.). Cambridge University Press, New York, NY.

Microsoft. 2023. *HoloLens 2*. https://www.microsoft.com/en-us/hololens/industry-healthcare. Accessed: April 10, 2023. (2023).

Microsoft Corporation. 2023. *Microsoft HoloLens*. Accessed April 6, 2023. (2023). https://www.microsoft.com/en-us/hololens/.

Daisuke Mitsuno, Kazuki Ueda, Yusuke Hirota, and Miki Ogino. 2019. "Effective Application of Mixed Reality Device HoloLens: Simple Manual Alignment of Surgical Field and Holograms." *Plastic and Reconstructive Surgery*, 143, 2, 647–651. DOI: 10.1097/PRS.0000000000005215.

Christian Moro, Cynthia Phelps, Daniel Jones, and Zane Stromberga. 2020. "Using Holograms to Enhance Learning in Health Sciences and Medicine." *Medical Science Educator*, 30, 4, 1351–1352. DOI: 10.1007/s40670-020-01051-7.

C. R. Nevin, A. O. Westfall, J. M. Rodriguez, and et al.. 2014. "Gamification as a tool for enhancing graduate medical education." *Postgraduate Medical Journal*, 90, 1070, 685–693.

Nomic AI. 2022. *GPT-4-All*. https://github.com/nomic-ai/gpt4all. Accessed April 6, 2023. (2022).

C. P. Ober. 2016. "Assessment of student engagement when using a novel board game for teaching thoracic radiography to fourth-year veterinary students." *Medical Science Educator*, 26, 1, 39–42.

A. Pasqualotto, A. Cochrane, D. Bavelier, and J. Stroud. 2021. "A novel non-linguistic audio-visual learning paradigm to test the cognitive correlates of learning rate." In: *Proceedings of the Annual Meeting of the Cognitive Science Society* 43. Vol. 43. https://escholarship.org/uc/item/5pj9t90k.

Steven J. Peitzman and Monica M. Cuddy. 2015. "Performance in physical examination on the USMLE step 2 clinical skills examination." *Academic Medicine*, 90, 2, 209–213.

Jean Piaget. 1968. *Six Psychological Studies*. Trans. by Anita Tenzer. Vintage Books, New York.

O. Podolskiy. 2012. "Audiovisual Learning." In: *Encyclopedia of the Sciences of Learning*. Ed. by N.M. Seel. Springer, Boston, MA. DOI: 10.1007/978-1-4419-1428-6_317.

Sonia Pujol, Mona Baldwin, Javad Nassiri, Ron Kikinis, and Kitt Shaffer. 2016. "Using 3D modelling techniques to enhance teaching of difficult anatomical concepts." *Academic Radiology*, 23, 4, 507–516.

Patrick Saalfeld, Alexander Schmeier, Wouter D'Hanis, Hermann-Josef Rothkötter, and Bernhard Preim. 2020. *Student and Teacher Meet in a Shared Virtual Reality: A one-on-one Tutoring System for Anatomy Education*. https://doi.org/10.48550/arXiv.2011.07926. (2020).

Santiago Schez-Sobrino, Carlos Gómez-Portes, David Vallejo, Carlos González-Morcillo, and Miguel Á. Redondo. 2020. "An intelligent tutoring system to facilitate the learning of programming through the usage of dynamic graphic visualizations." *Applied Sciences*, 10, 4, 1518. DOI: 10.3390/app10041518.

Maja Stojanovska, Gary Tingle, Lijun Tan, Laurie Ulrey, Sally Simonson-Shick, John Mlakar, et al.. 2020. "Mixed reality anatomy using Microsoft Hololens and cadaveric dissection: a comparative effectiveness study." *Medical Science Educator*, 30, 173–178.

R. Shane Tubbs, Eric P. Sorenson, Anand Sharma, Brion Benninger, Norbert Norton, Marios Loukas, and Bernard J. Moxham. 2014. "The development of a core syllabus for the teaching of head and neck anatomy to medical students." *Clinical Anatomy*, 27, 321–330.

G. Ulloa Salazar and C. Díaz Larenas. 2018. "Using an audio-visual materials-based teaching strategy to improve EFL young learners' understanding of instructions." *HOW*, 25, 2, 91–112. DOI: 10.19183/how.25.2.419.

L. S. Vygotsky. 1978. *Mind in society: The development of higher psychological processes*. Harvard University Press.

R. A. Walker. 2013a. "Holograms as Teaching Agents." *Journal of Physics: Conference Series*, 415, 012076. DOI: 10.1088/1742-6596/415/1/012076.

R. A. Walker. 2013b. "Holograms as Teaching Agents." *Journal of Physics: Conference Series*, 415, 012076. DOI: 10.1088/1742-6596/415/1/012076.

H. Yoo, J. Jang, H. Oh, and I. Park. 2022a. "The potentials and trends of holography in education: A scoping review." *Computers & Education*, 186, 104533. DOI: 10.1016/j.compedu.2022.104533.

H. Yoo, J. Jang, H. Oh, and I. Park. 2022b. "The potentials and trends of holography in education: A scoping review." *Computers Education*, 186, 104533. DOI: 10.1016/j.compedu.2022.104533.

Fan Zhang, Valentin Bazarevsky, Andrey Vakunov, Andrei Tkachenka, George Sung, Chuo-Ling Chang, and Matthias Grundmann. 2020. *MediaPipe Hands: On-device Real-time Hand Tracking*. (2020). arXiv: 2006.10214 [cs.CV].