Advancing Anatomy Outreach: A Systematic Comparative Study of Mixed Reality, Computer-assisted, and Conventional Methods

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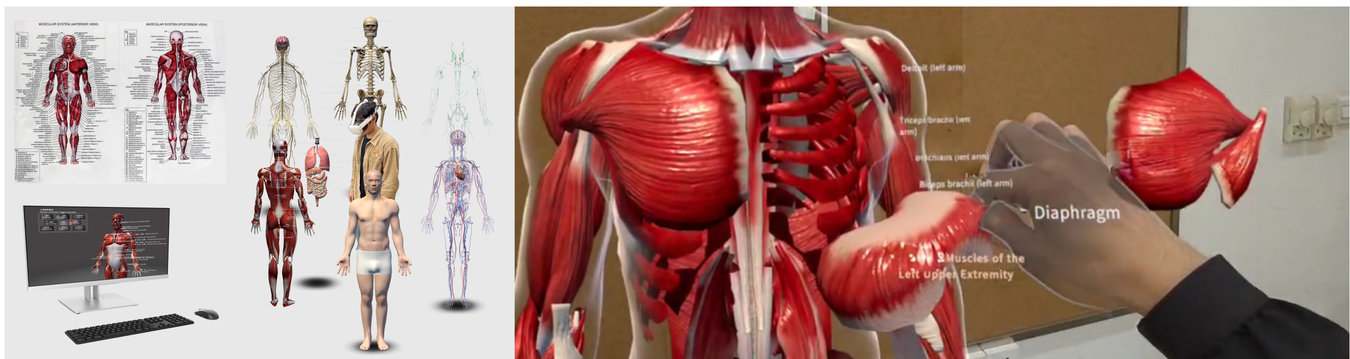

Figure 1: We explore innovative approaches to anatomy education by comparing three modalities for presenting eight human anatomical structures: traditional brochures (top-left), computer-assisted methods (bottom-left), and immersive mixed reality (right). Mixed reality facilitates direct interaction with anatomical models in a virtual-real fusion 3D space, which promotes active engagement and deeper conceptual understanding, representing a significant shift from passive to experiential learning.

Abstract

Anatomy outreach is vital for improving public knowledge of human biology and health, helping individuals understand anatomical structures and their significance in daily life. As advanced technologies continue to reshape the education landscape, immersive technologies, particularly Mixed Reality (MR) have demonstrated significant potential in science outreach. However, there remains a lack of comprehensive research examining the specific effectiveness of these technologies in the context of anatomical education for the public. In this study, we deliberately selected three representative outreach approaches—traditional brochures, computer-assisted methods, and MR, and designed and developed corresponding systems and experimental setups, designing comprehensive experiments for a thorough analysis and evaluation. The evaluation focuses on four key areas: Learning Outcomes, User Experience, System Usability, and Task Load. Results indicate that MR-assisted method stands out as the most effective, delivering superior user experiences and significantly higher learning outcomes. This not only provides strong evidence for the effectiveness of MR in anatomy outreach but also highlights the key interactive features that contribute to its impact, underscoring its potential in reshaping public science communication.

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CCS Concepts

• **Applied computing → Interactive learning environments**;
• **Computing methodologies → Mixed / augmented reality**;
• **Human-centered computing →** *HCI design and evaluation methods.*

Keywords

Anatomy Education, Mixed Reality, User Study

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1 Introduction

1.1 Anatomy outreach

Anatomy outreach refers to activities where academic institutions provide anatomy-related services to communities outside the universities. These activities aim to disseminate anatomical knowledge to various groups, including through educational outreach, public engagement, and scientific communication [Taylor 2020]. Laboratories and museums have been choices of anatomy outreach, offering hands-on experiences and direct observation of anatomical specimens. These environments have been shown to enhance knowledge acquisition [Falk and Dierking 2000; Moore and Brown 2007]. However, the improvements are often modest; few anatomical structures show statistically significant gains in pre- and post-test comparisons. Moreover, such outreach activities are resource-intensive and limited by the requirement for participants to be physically present, restricting accessibility and scalability. In contrast, the conventional approach of utilizing printed brochures represents a cost-effective and widely distributable alternative that can significantly enhance the accessibility of anatomical education. Though less immersive than in-person experiences, brochures remain a practical and foundational tool for outreach, particularly in resource-limited settings.

Emerging technologies such as the computer-assisted education and Virtual Reality (VR) provide immersive, interactive learning environments. Computer-assisted methods offer a practical and accessible approach to anatomy outreach, particularly for non-specialist audiences. Leveraging widely available hardware such as desktop and laptop computers, these methods support interactive and multimedia learning through tools like 3D models, virtual dissections, and annotated visualizations. Their scalability and cost-efficiency make them highly suitable for large-scale educational outreach. VR offers an immersive and engaging approach, which enables spatial understanding and interactive learning. Recent studies reported a 45% increase in student performance and 92% positive user feedback with Human Anatomy VR applications, which commonly feature model interaction and educational support [Baek et al. 2024]. These capabilities support both professional and non-professional learners, making the immersive technology a promising approach for anatomy education [Ferguson et al. 2015; Moro et al. 2017; Xu et al. 2022; Zhu 2016].

In recent years, with the rise of Mixed Reality (MR) technology, compared with the pure virtual environment in VR, the virtual-real fusion and interaction of MR has brought new vitality to the field. MR bridges the gap between virtual and physical experiences by overlaying digital content onto the real world. This allows users to engage with anatomical models in situ while maintaining contextual awareness of their environment. MR systems have shown promise in enhancing spatial cognition and engagement. While MR is characterized by its immersive integration of virtual and physical environments, its specific advantages over traditional methods, as well as its impact on user acceptance and learning outcomes, have yet to be thoroughly investigated in the field. A significant gap remains in understanding the impact of these methods on anatomy learning outcomes and experiences among the general public, despite their evident interest and limited prior knowledge [Taylor et al. 2018].

In this study, we undertake a systematic comparative analysis of the three most representative methods - printed brochures, computer-assisted tools, and MR application, with the aim of exploring the potential contributions of MR to science education and communication in human anatomy, and providing an evidence-based reference for future research in this domain.

Study design: Given the diverse demands of anatomy outreach ranging from accessibility and scalability to interactivity and educational depth, we design and develop brochures, computer-assisted software, and an MR software (as shown in Figure 1 and Figure 2) as the three modalities for comparative evaluation in terms of learning outcome and user experience:

- Brochures: as the baseline, the conventional brochure presents content through graphical and textual representations.
- Computer-assisted tool: a desktop-based system, this will be assessed for its interactive features and ability to simulate 3D anatomical structures.
- Mixed Reality (MR): as an immersive technology, it allows spatial interaction, offering both immersion and contextual awareness, which serves as a key focus of this study.

In the experiment session, participants and materials, task, procedure, data collection are to be elaborated, follows the result session interpreting data analysis result from 3 groups, including learning outcome and 6 scales of user experience, usability scale and 6 scales of task load. The discussion will analyze underlying factors influencing performance, evaluate the strengths and limitations of each method, and explore future applications based on their respective affordances. This work contributes to the growing research on MR in anatomy outreach by clarifying its specific advantages, challenges, and implications for non-professional learners, and aims to provides empirical validation and reference recommendations for designing more effective MR-based educational tools.

2 Related Work

The primary focus of this study is to demonstrate the role of MR in anatomy outreach and education through comparative research with traditional methods. Therefore, the investigation concentrates on the developmental trajectory of anatomical popularization media, the development of immersive technologies in anatomy, and the study on comparative analysis methodologies.

2.1 Development and challenge of anatomy education

Anatomy education has shifted from traditional cadaveric dissection to include modern digital resources like CT and 3D printing[Chytas et al. 2020; Petriceks et al. 2018; Taylor and Wessels 2024]. While dissection is irreplaceable for developing manual dexterity and empathy[Asad et al. 2023], it presents challenges such as ethical issues[Hildebrandt 2008], donor shortages[da Rocha et al. 2020], and student stress[Baratz et al. 2019]. Techniques like plastination[Klaus et al. 2018; Kurt et al. 2013] and foundational texts like Gray's Anatomy [of Neuroradiology 2005] have been crucial for disseminating knowledge. However, text-based learning is constrained by linguistic and cultural barriers, which can cause significant misconceptions, as seen in the translation of anatomical terms into Chinese[Cheung et al. 2023; Meyer and Cui 2019].

Advances in digital anatomy have promoted a more visual and immersive approach to understanding spatial relationships, which is crucial practice. Recently valuable tools had brought anatomy to wider public learning which is extended reality[Pearlstein et al. 2021; Sugiura et al. 2019].

Extended reality(XR) encompasses Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), as well as any future realities that may emerge [Palmas and Klinker 2020]. VR is a fully computer-generated virtual environment which is immersive and interactive. AR overlays digital content onto the real physical world. MR is a hybrid that combines the ability of VR and AR. A bibliometric analysis of 990 articles revealed that the most significant growth in VR-related Scopus index occurred in 1998, with a 190.90% increase[Wiyono et al. 2022]. Recent research can diminish parts of the human body from the video stream using RGB-D cameras has been developed, which could potentially improve learning effects by attracting users' attention to virtual information and improving visual perception[Ienaga et al. 2016]. The Immersive Virtual Anatomy Laboratory participants increased 55.95% in vocabulary scores and reduced 18.75% in task completion times compared to the group using lectures, textbook readings, and dissection[Kadri et al. 2024], VR as a tool was reported with perceived usefulness and positive attitude[Kadri et al. 2024], improvements in understanding and memorization[Al-Hor et al. 2024].

However, these investigations largely target professional learners, such as medical and nursing students. Limited research explores the application of MR for the general public. MR technologies combine the physical and virtual worlds to create interactive learning environments, enabling learners to visualize anatomical structures in three dimensions and interact with them. For example, users can manipulate virtual organs or observe their relationships within the human body while maintaining a sense of physical context, providing a comprehensive understanding of spatially complex subjects such as anatomy. Unlike traditional methods or computer-based applications, MR enables users to visualize and manipulate anatomical structures in space, fostering deeper cognitive engagement and schema construction. Mixed Reality is also a safer choice compared to Virtual Reality approach since it supports video see-through of real world environment, users need no time to react if any obstacles are close. Therefore, we posit that MR represents a more suitable pathway for multi-scenario science popularization applications, which is precisely the hypothesis this study aims to substantiate.

2.2 Evaluation: task-oriented and experience-oriented

Most of the study of anatomy education mentioned above introduced pre and post test into their experiment as summative assessment in anatomy outreach, it is quantitative and effective in data collection and data analysis. The assessment is serve to maintain academic standards (achieved mainly through marking and grading), as commonly practiced in most institutions of higher learning [Samarasekera et al. 2020]. Taking consideration of the cultivation of cognitive schema construction, cognitive load, learning attitude, and professional emotion associated with complex problem-solving situations in order to achieve a more comprehensive evaluation and improvement of knowledge, skills, and attitudes in the learning process [Pardo et al. 2019]. The experiment of this work is considered as task-oriented to evaluate task load, system usability.

As for evaluation of task load, NASA-TLX was developed by the Human Performance Group at NASA's Ames Research Center over a three-year development cycle that included more than 40 laboratory simulations. It is widely used in various domains, including aviation, healthcare, and other complex socio-technical domains [Hart and Wickens 1990]. This survey provides six dimensions of workload: *Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, Frustration*, each has a question in a scale of 0 to 100 based on perceived importance. It is now used across many industries. The System Usability Scale (SUS) is a widely used tool for evaluating the usability of systems, products, or services [Brooke 1995]. It is developed in the late 1980s by John Brooke at Digital Equipment Corporation, consisted of 10 questions, five scales from strongly disagree to strongly agree. Result of this survey varies from 0 to 100, with a good index of 68.

On the other hand, for more factors that take into account, as well feedback are crucial to iteration of system interaction, user experience questionnaire [Laugwitz et al. 2008] is important to be integrated in the experiment as a part of experiment-oriented evaluation. UEQ includes both usability and emotional satisfaction, consists of 26 questions and measures user experience across six dimensions: *Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, Novelty.* It is suitable for a wide range of products and services and can be used for benchmarking and cross-cultural studies.

3 Problem Statement

Within the above context, we propose the following research questions (**RQ1, 2**) and hypotheses (**H1-4**):

RQ1: How do different display platforms (brochure, desktop, and MR) affect learning outcomes in anatomy education?

RQ2: What are the differences among these platforms in terms of user experience, usability, and task load, and to what extent does MR truly offer advantages?

Based on insights from previous studies and literature, we propose the following hypotheses:

H1: MR platforms lead to significantly higher learning outcomes compared to brochures and desktop applications.

H2: MR platforms provide a more attractive user experience as measured by UEQ scores.

H3: MR platforms will provide a more practical user experience as measured by UEQ scores.

H4: Task load associated with MR platforms will differ significantly, with higher physical loads compared to brochures and desktop applications.

4 Material Design and Development

4.1 Brochure, Desktop, MR applications

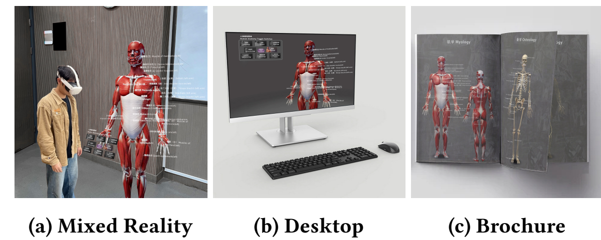
The anatomy outreach content used in this work was derived from the Gray's Anatomy [Gray and Lewis 1918], which is extensively utilized in anatomical education and research. The Chinese translations appearing in the materials follow the book of Systematic Anatomy[Liu 2007], which is a standard medical textbook in China. Based on this uniform content, we designed and developed three formats: a *Printed Brochure*, a *Desktop Application*, and an *MR Application*. Figure 2 presents the physical representations of these three formats. The content are the same among brochure, desktop and MR to ensure comparability. The Brochure comprises eight A4-sized pages featuring full-color illustrations and accompanying text. For the Desktop group, the devices used is a PC with a screen resized to the same resolution as the MR group per eye, MR group uses Meta Quest 3 which provides a resolution of 2064x2208 pixels per eye with a setup to hand pose only input.

As for desktop and MR groups, the materials share same digital contents including anatomical 3D assets and the menu design. We develop this program by using *Unity 2022.3.47.f1*. Desktop uses mouse and keyboard as input to move main camera, the anatomical objects clicked by the mouse will pop out, Meta XR SDK 68.0.0 is employed to develop the immersive interaction functions in MR, which allows to access to different hand interaction methods within Unity, this project uses *Grab*, *Pinch* and *Poke*(index finger press). Grab and pinch are to grab out the human anatomical objects, poke is used to press the menu button in mixed reality environment.

The primary digital asset is a comprehensive anatomical 3D model of the human body structure. This model was created in Blender 4.1, with segmentation and labeling based on Gray's Anatomy. Python scripts were developed to reduce poly count and optimize texture files, ensuring the models perform efficiently in the MR environment. Models were exported in FBX format for easy integration into Unity. The model is a six feet height bald man, we divide it into the following anatomical systems, allowing each system to trigger interactions independently: Osteology(bones), Myology(muscle), Surface(skin), Syndesmology(connective issues), Angiology(vascular system and heart), The Lymphatic System, Neurology, Splanchnology(organs).

As in brochure (see Figure 2c), the eight parts are presented in eight pages, each depicts a front view (Field of View=30), hidden objects are presented on the same page too.

There are **55** objects within the human anatomical model which can be grabbed out or interacted, each is attached with a text name in both Chinese and English, others were be set as static and can be seen.



(a) Mixed Reality (b) Desktop (c) Brochure

Figure 2: Experimental material of Mixed Reality, Desktop and Brochure groups

4.2 Additional materials

Information sheet, consent form. Give an adequate introduction to the research background, information, ethic review result, researcher information and contact. All participants are required to carefully read and sign these before experiment starts.

Survey, questionaire, interview. The survey is designed base on the versions used in the experiment in Lancaster University[Taylor et al. 2018] and Hong Kong[Cheung et al. 2023], used in pre-test and post-test, in order to calculate the learning outcome after the experiment. This research keeps most of the question items while replaced few widely known objects like brain (with a correct rate of 100% in the Lancaster University experiment). Questionaires and interview questions will be introduced briefly in next section.

5 Experiment

5.1 Participants

A between-group design was employed, recruiting 70 participants aged 12-40, 38 male, 32 female with little or no background in anatomy or surgical education. 41 participants reported having previous experience of using HMDs. Participants were randomly assigned to one of three groups with each group using their respective platform to learn anatomy.

To mitigate the impact of demography variables on the results, each group had a similar distribution of participants across key demographic characteristics, such as age, gender, and education level. The sample have to be stratified to ensure diversity in age, gender, and educational background. External variables that could influence the outcomes, such as distracting visual or auditory stimuli in the experimental space, were well controlled by either removing or avoided.

All participants were provided with information sheet, consent form, confirming their lack of professional background in anatomy or related fields, they are fully aware this is anonymous, their personal information can not be identified, they can stop or quit anytime during the experiment.

5.2 Task

Participants were tasked with a 15-minute learning session on human anatomy using one of three platforms: the brochure, desktop, or MR application. Participants in brochure group are required to read the brochure of human structure page by page following this order: **Surface, Osteology, Angiology, Splanchnology, Myology, Syndesmology, Neology, The Lymphatic System**. The

desktop group is required to use mouse to click on menu to browse in the same order, the MR group is required to click the menu by index finger following the same order. In each part, they should be looking into the structures with text and remember as much as they can.

5.3 Procedure

The experiment was structured into five distinct phases as shown in Table 1, each with a specific duration and purpose, to assess participants' learning outcome and experience across different platforms: Mixed Reality (MR), Desktop, and Brochure. First, there was a 1-minute introduction. It outlined the experiment's purpose and procedure, then in a 2-minute pre-test, participants were required to draw the positions of 20 human structures to evaluate their baseline anatomical knowledge. In the 15-minute experimental phase, the MR group participants interacted with a virtual human model wearing Meta Quest 3, clicking on menus to browse human parts from Osteology to the Lymphatic System, finding and grabbing objects within each part. The Desktop group had a similar experience but through a 2D screen paired with keyboard and mouse to click the objects. The Brochure group read through eight pages of human anatomy, studying the structures sequentially. After the experimental phase, there was a 5-minute survey and interview session. Participants completed questionnaires assessing user experience, system usability, and task load. A subset of participants also underwent semi-structured interviews to gain qualitative insights. The final phase, a 2-minute post-test, same as the pre-test to measure the anatomical knowledge after the experiment.

5.4 Data Collection

Pre-test score: During the pre-test phase, participants were asked to complete a written test assessing their baseline knowledge of human anatomy. This phase is crucial as it establishes a foundation for measuring the learning gains from each platform (Brochure, Desktop, and MR). **User experience, usability and task load:** Participants were invited to complete three questionnaires: the System Usability Scale (SUS), NASA-TLX, and the User Experience Questionnaire (UEQ). These tools evaluate usability, cognitive workload, and user experience, respectively. Including multiple validated scales ensures a comprehensive assessment of each platform, beyond learning outcomes. **Semi-structured interviews:** To gain qualitative insights, semi-structured interviews were conducted after the questionnaires. These interviews allow participants to articulate their experiences, challenges, and preferences in their own words, enriching the quantitative data. **Post-test score:** After the experimental phase, participants complete a test identical to the pre-test to measure knowledge retention and learning outcomes. This direct comparison allows researchers to quantify the effectiveness of each platform. Additionally, the use of the same test minimizes variability, ensuring that observed differences are due to the platform rather than inconsistencies in the assessment tool.

6 Result

The study collected data from 22 participants in the traditional brochure group, 24 participants in the computer-assisted group, and 24 participants in the MR group.

6.1 Learning outcome score

In terms of learning outcomes, the total scores for the three groups followed a normal distribution. For each of the 20 anatomical object on the pre and post test, participants' learning outcome were scored in three categories: **-1**: Correct answer on the pre-test but incorrect on the post-test. **0**: Both pre-test and post-test answers were either correct or incorrect. **1**: Incorrect answer on the pre-test, but correct on the post-test.

Shapiro-Wilk of normality and the Levene's test of homogeneity were performed on the total scores for MR(*M=4.79, SD=2.15, n=24*), computer-assisted group(*M=2.73, SD=1.92, n=22*), brochure group(*M=4.00, SD=2.22, n=24*), thus data are normally distributed. Figure 3 shows learning outcome scores on 20 human structures, learning outcome of 3 structures are significant better in MR, one is better in traditional brochure. Three groups learning outcome score passed normality and homogeneity test thus a one-way ANOVA was conducted to compare the mean total scores across the three groups $F(2, 70) = 15.68, p < 0.001$. Effect size calculated using η^2 were observed as $\eta^2 = 1.99$, with Tukey's Post Hoc Test used to further analyze significant differences. The results showed that the MR group had significantly higher scores than the desktop group with a p-value of 0.033. However, no significant differences were found between the brochure group and the other two groups. Regarding the individual anatomical structures, the scores are categorized data, did not follow a normal distribution, so non-parametric tests were applied. A Mann-Whitney test was used to analyze pairwise comparisons between the three groups for the 20 anatomical structures. Among these, the MR group showed significantly better scores than the brochure and desktop groups for adrenal(*z=-2.10.00, p=0.031*), pancreas(*z=-3.40.00, p=0.016*), and sternum(*z=-2.34, p=0.065*). The brochure group outperformed the others for the levator scapulae(*z=-2.74, p=0.046*). See the result in Figure 3

6.2 User experience

The User Experience Questionnaire (UEQ) results revealed significant differences across the three groups (Brochure, Desktop, and MR) in six scales. Each scale was scaled from -3(most negative) to +3(most positive), and analyzed using T-Test to determine significance of two groups out of three. Results can be seen in Figure 4. The findings are summarized below:

Attractiveness: Participants in the MR group reported higher attractiveness scores (M=2.23, SD=0.81) compared to the computer-assisted group (M=1.75, SD=0.78), $p < 0.01$ and Brochure group (M=0.95, SD=0.89), $p < 0.01$. **Perspicuity**: The MR group also outperformed the other groups in perspicuity(M=1.50, SD=1.14), with a significant difference compared to computer-assisted(M=0.95, SD=0.80), $p < 0.01$ and Brochure(M=0.45, SD=0.94), $p < 0.01$. **Efficiency**: Efficiency scores followed a similar pattern, with the MR group(M=1.67, SD=1.23) scoring significantly higher than both the computer-assisted(M=0.86, SD=0.70), $p < 0.01$ and Brochure groups(M=0.38, SD=1.15), $p < 0.01$. **Dependability**: Dependability scores were significantly higher for MR(M=2.04, SD=0.88) compared to computer-assisted(M=1.43, SD=0.69), $p < 0.01$ and brochure(M=1.05, SD=1.28), $p < 0.01$. **Stimulation**: On this scale, the MR group(M=2.07, SD=0.92) showed a marked improvement over both computer-assisted(M=0.94, SD=1.24) and Brochure(M=0.50, SD=1.32), $p <$

Procedure	Description		
1 **Introduction**, 1 min	Introduction to the purpose and procedure of the experiment.		
2 **Pre-test**, 2 min	Participants will complete a pre-test requiring them to draw positions of 20 human structures to assess their baseline knowledge of anatomy.		
	Mixed Reality	Desktop	Brochure
3 **Experimental Phase**, 15 min	3.1 Click on menu to browse human parts from Osteology to the Lymphatic System.	3.1 Click on menu to browse human parts from Osteology to the Lymphatic System.	Read 8 pages of human anatomical structures one by one.
	3.2 In each part, find objects one-by one.	3.2 In each part, find objects one-by one.	
	3.3 Grab objects.	3.3 Click on objects.	
4 **Surveys and interviews**, 5 min	Fill User Experience Questionnaire, System Usability Scale, NASA Task Load Index. Semi-structured interviews will be conducted with a subset of participants for qualitative insights.		
5 **Post-test**, 2 min	Participants will complete a post-test which is exactly the same as pre-test to assess their knowledge of anatomy after the experiment.		

Table 1: Procedure detail of the experiment in MR, desktop and brochure groups

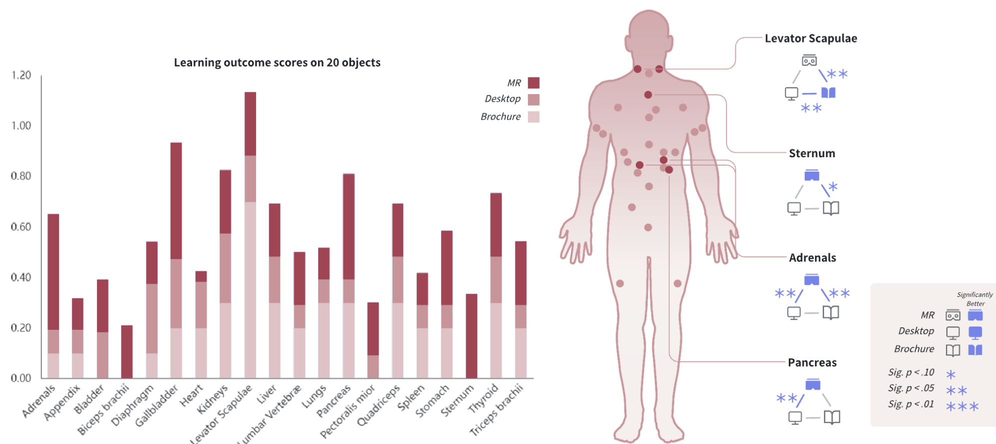


Figure 3: Learning outcome score in 20 anatomical objects with position pointed out, adrenals score in MR is higher than both desktop ($p < 0.05$) and brochure ($p < 0.05$), pancreas score in MR is higher than desktop ($p < 0.05$), sternum score in MR is higher than brochure ($p < 0.10$), levator scalpula score in brochure is higher than both desktop ($p < 0.05$) and MR ($p < 0.05$).

0.01. Computer-assisted group scores higher than brochure, $p < 0.10$. **Novelty**: The MR group(M=1.92, SD=1.08) showed a marked improvement over both computer-assisted(M=1.35, SD=1.06) and Brochure(M=0.53, SD=1.17), $p < 0.01$. Computer-assisted group scores higher than brochure, $p < 0.10$.

6.3 Usability and task load

The System Usability Scale (SUS) measures usability by having participants rate 10 statements on a 5-point Likert scale, and the scores are then converted to a single composite score ranging from 0 to 100, where higher scores indicate better usability, score greater than 68 is perceived as good usability. The Mann-Whitney

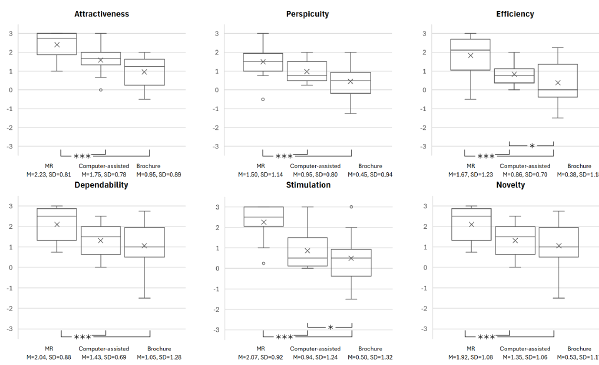


Figure 4: User experience questionnaire scores in six scales among three groups.

U test results indicated there are no significant differences between MR(M=73.33, SD=16.61) and computer-assisted(M=74.58, SD=12.24), (*z=-0.36, p=0.327*), MR and brochure(M=65.75, SD=17.48), (*z=-1.89, p=0.214*) brochure and computer-assisted(*z=-0.89, p=0.180*). Task load was evaluated across six dimensions (mental demand, physical demand, temporal demand, effort, performance, and frustration). The Mann-Whitney U test identified significant differences between MR(M=41.39, SD=14.94) and computer-assisted(M=42.43, SD=12.67), brochure(M=44.83, SD=11.09), turns out MR scores higher than computer-assisted group at performance scale(*z=-1.46, p=0.067*) and scores lower at frustration scale(*z=-1.92, p=0.092*). There are no other significant differences other than performance and frustration. See detailed results in Figure 5.

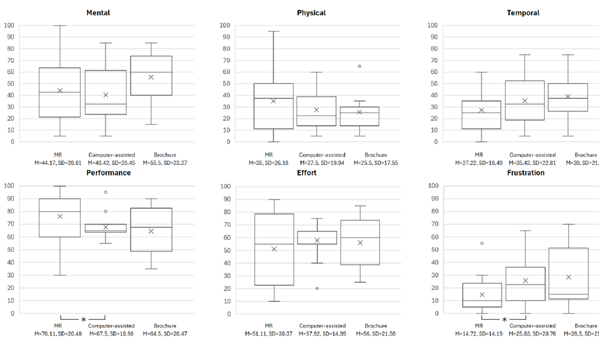


Figure 5: NASA-TLX task load scores in three groups.

7 Discussion

Learning outcome. Since the MR group is not significantly scores better then brochure group, **H1** is not fully supported in such way. This suggests that while MR provides an edge in enhancing learning outcomes, its advantage depends on the type of anatomical structure being studied. Notably, MR excelled in complex, spatially obscured structures like the adrenal glands, pancreas, outperforming both brochure and desktop. This underscores the importance of interactive and exploratory features in an environment that integrates virtual and physical elements, which compensates for limitations inherent in 2D, screen-based 3D displays, and fully virtual environment.

User experience. The results from the UEQ scale confirmed that MR provided a highly engaging experience, scoring significantly higher in the six dimensions of Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty, $p < 0.01$, as depicted in Figure 4. **H2** of better attractiveness and **H3** of more practical are strongly supported. **H4** hypothesis about physical activity requirement is not supported due to the test result in 5. No significant differences were detected while the mean score in MR is higher than other two groups. The standard deviation of effort scale in MR group is relatively higher, the reason could be reflected in 65% of MR participants report that hand interaction is unresponsive from time to time, and they can't properly click the menu buttons with index finger.

Limitations and future work. The grab gesture is most often used by participants in MR group, our MR application supports grab and pinch at the same time, and in the experiment pinch is a default option provided by researcher, participants are more willing to grab. This is a finding need to be noted for future development or design in other scenarios need interactions. This is likely because most human structures are grab size, therefore, in future improvements, the gesture methods should be adjusted in response to the size of the interactive elements. While this study focused on short-term learning outcomes, future research should examine the long-term retention of anatomical knowledge acquired through different modalities. Conducting follow-up assessments weeks or months after the initial learning session could help determine whether MR-based learning leads to better retention compared to traditional methods. Understanding the durability of knowledge retention would be crucial in assessing the true impact on anatomy education.

8 Conclusion

The findings offer preliminary insights into the effectiveness and experience of MR, desktop, and brochures in anatomy education for the general public, as demonstrated by the evaluation metrics: Learning Outcomes, User Experience Questionnaire (UEQ), System Usability Scale (SUS), and NASA-TLX. Comparative analysis were applied to check the paired significance. The MR group showed significantly better learning outcomes than the desktop group ($p = 0.033$), but no significant differences were found between MR and brochure, or between brochure and desktop. This suggests that MR is particularly effective for learning complex, hard-to-visualize structures like the adrenal glands and pancreas due to its interactive 3D features. MR also provided a more engaging user experience, scoring significantly higher across all six UEQ dimensions. All three platforms were rated similarly in usability based on SUS scores. In terms of task load, MR users reported higher performance and lower frustration compared to the desktop group. This study contributes on anatomy outreach by providing empirical evidence on the effectiveness of MR platforms compared to traditional methods. The findings are expected to guide the development of innovative immersive tools for anatomy education, benefiting

educators, learners, and designers in creating effective educational experiences.

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