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Multi-user Interaction in Collaborative Virtual Multi-class for Metaverse

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ABSTRACT

Multi-user Virtual Reality (VR) technology that supports multi-class has effectively addressed challenges in traditional face-to-face learning, including constraints related to location, time, and pandemics. This innovation is anticipated to deliver substantial cost savings across fields such as education, medical care, training, and industry. This study introduces a Unity-based multi-user collaborative virtual classroom model, themed around an anatomy laboratory, enabling users to interact within a shared virtual environment while supporting the creation of additional classrooms for diverse educational purposes. The system architecture consists of three layers: the application layer, which facilitates user interaction through 3D avatars and collaborative tasks; the framework layer, supporting multi-user communication and 3D anatomical model manipulation; and the engine layer, leveraging Unity and Photon Engine for multi-user functionality and device integration. The prototype was evaluated using the Technology Acceptance Model (TAM) with 30 first-time users, demonstrating strong reliability and validity across key dimensions: Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitude Toward Using (ATT), and Behavioral Intention to Use (BI). PEOU scored the highest (4.46 ± 0.56), indicating ease of use, while BI scored slightly lower (4.21 ± 0.60), suggesting opportunities for improving engagement. These findings highlight the potential of the Anatomart VR application to enhance anatomy education through an innovative, immersive and collaborative learning environment.

1. Introduction

The metaverse offers significant potential for creating shared virtual spaces that support various activities, particularly in education. By leveraging immersive and interactive digital environments, the metaverse enables real-time interaction among users, fostering collaboration and engagement. Mueen Uddin *et al.*, highlight its effectiveness in enhancing student engagement and learning outcomes through the integration of Virtual Reality (VR) and Augmented Reality (AR) technologies, creating personalized and immersive educational settings [1]. Similarly, Hyanghee Park *et al.*, emphasize the metaverse's capacity to promote collaborative learning by facilitating shared virtual environments that foster a sense of community among learners [2]. Furthermore, J. Lopez-Belmonte

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et al., demonstrate the adaptability of these virtual spaces to accommodate diverse learning styles and paces, promoting inclusivity and accessibility [3]. Despite these advantages, Caitlin Curtis and Claire E. Brolan raise concerns regarding data privacy and ethical challenges, which remain critical issues to address for equitable access and safe use of the metaverse in education [4].

VR enhances multi-user learning experiences by providing safe, immersive, and interactive environments tailored to various educational needs. It enables both symmetric and asymmetric collaborations, such as motor rehabilitation scenarios where therapists guide patients through precise tasks using low-latency networks [5]. VR's ability to simulate controlled environments, such as medical procedures like lumbar punctures, has proven effective in improving skill acquisition and knowledge retention, especially for novice learners [5]. Emotional engagement further enhances the learning process, with VR environments designed to capture and adapt to user emotions, thereby improving outcomes and catering to diverse personality traits [6]. Additionally, the integration of technologies like eye-tracking and machine learning optimizes VR environments by analyzing performance and predicting user behavior, enabling more personalized learning experiences [7].

Multi-class, multi-user VR environments have gained attention for their ability to replicate real-world collaborative scenarios, enriching learning outcomes and engagement. Initiatives like Project Mobius demonstrate the value of situated learning, where users interact in shared virtual spaces to enhance educational experiences [8]. Other systems, such as a 3D multi-user platform for studying butterflies, highlight the potential of VR to improve user enjoyment and system effectiveness, though further refinement is needed to optimize user interfaces [9]. Applications in specialized training, such as electrical substation simulations, showcase VR's ability to reduce risks and provide realistic, collaborative environments for concurrent training [10]. A multi-user cross-platform VR prototype for secondary schools in Malawi underscores VR's adaptability to diverse educational contexts by addressing challenges like limited access to electricity and the internet [11]. Despite these advancements, technical limitations, network performance, and user interface design remain key challenges, underscoring the need for continued research and development to fully realize the potential of multi-user VR systems [12].

Multi-class VR environments have emerged as powerful tools for enhancing collaborative learning by fostering immersive, interactive, and socially engaging experiences [13]. They support embodied social translucence, facilitating shared understanding and collective problem-solving [14]. Asymmetrical VR systems empower instructors to seamlessly guide and interact with students in VR, further enhancing the collaborative process [15]. Real-time interactions within VR environments cultivate a sense of co-presence and social presence, crucial for effective collaboration [16]. Additionally, VR enables global collaboration, uniting learners across geographical boundaries [17].

Recent studies further highlight the potential and challenges of VR technologies. Hashim *et al*., demonstrated how generative AI enhances VR by creating dynamic, personalized, and immersive environments, though issues such as computational demands and ethical considerations remain unresolved [18]. Hashim *et al*., emphasized the role of animation in improving immersion and presence within VR, identifying gaps in user-centered design and the need for empirical validation to improve usability [19]. Saifulizam *et al*., underscored the importance of user experience in VR prototyping, emphasizing how immersive design fosters engagement but noting challenges in hardware limitations and network performance [20].

Building on these insights, this research aims to develop a VR application that supports multi-users with the capability to create multi-class environments tailored to specific learning needs. By improving network efficiency, enhancing user interaction with personalized content, and increasing accessibility, this study addresses current limitations and advances VR as a tool for collaborative and inclusive education.

2. Methodology

The design of this multi-user collaborative virtual classroom system consists of three main abstract layers: the application layer, the framework layer, and the engine layer (see Figure 1). The application layer is responsible for managing the specific features required in this virtual classroom system. The framework layer is responsible for implementing the main functions of the system. Meanwhile, the engine layer handles technical aspects such as device input/output, basic interaction, visualization, simulation, network communication and software and hardware component integration.

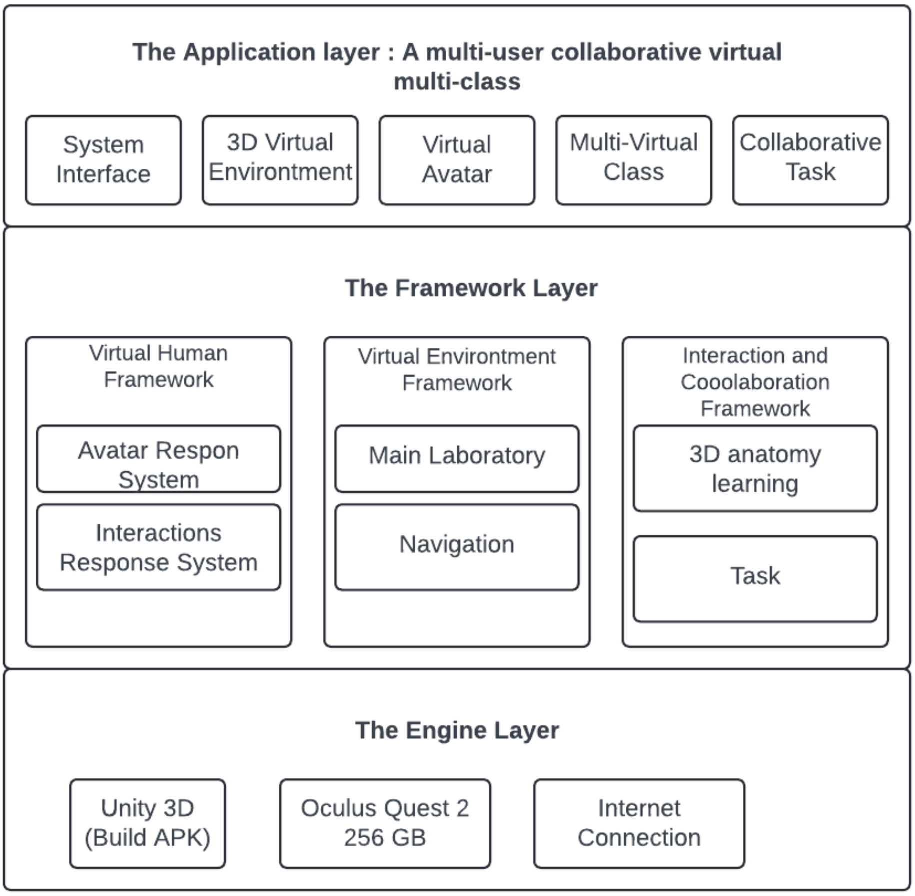

Fig. 1. Block diagram of the development framework for multi-class that supports multi-user

2.1 The Application Layer for Multi-class Multi-user

The system provides the necessary system User Interface (UI) and virtual environment for the virtual classroom, as well as pre-set 3D avatar models to enhance environmental immersion. Users, represented by their 3D avatar models, enter the environment to complete collaborative tasks with other users' avatars. As shown in Figure 2, the system pre-creates several 3D avatar models to perform specific tasks within the virtual classroom, enriching the virtual environment and enhancing immersion.

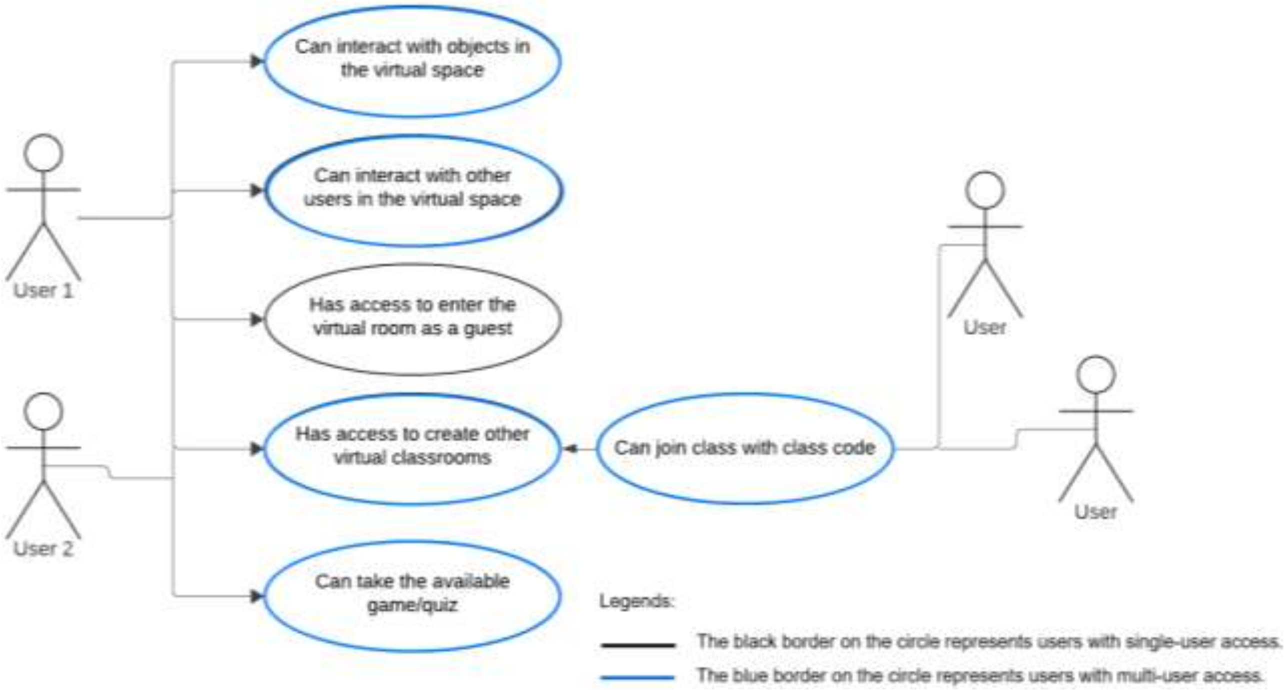

Fig. 2. Composition diagram of a collaborative virtual class for multi-users

The virtual environment includes a visual system UI that aids user interaction and a space that enables multi-user collaborative tasks. The system provides two types of virtual classroom joining features: first, users can join independently to learn in their own class, and second, users can join by entering a class code created by the teacher. The black border on the circle represents users with single-user access, while the blue border on the circle represents users with multi-user access.

2.2 Framework Layer
2.2.1 Virtual human framework

Figure 3 illustrates the framework of virtual humans. In this system, users who join a virtual class will be represented by default with a 3D avatar model. Users can set the name of their 3D avatar before entering the virtual space. System interaction within the virtual environment utilizes joystick controls from Oculus. With these controls, users can interact with 3D objects, including grabbing, rotating, scaling, and selecting navigation options. Another prominent interaction feature is the ability for users within the same room to directly communicate with each other.

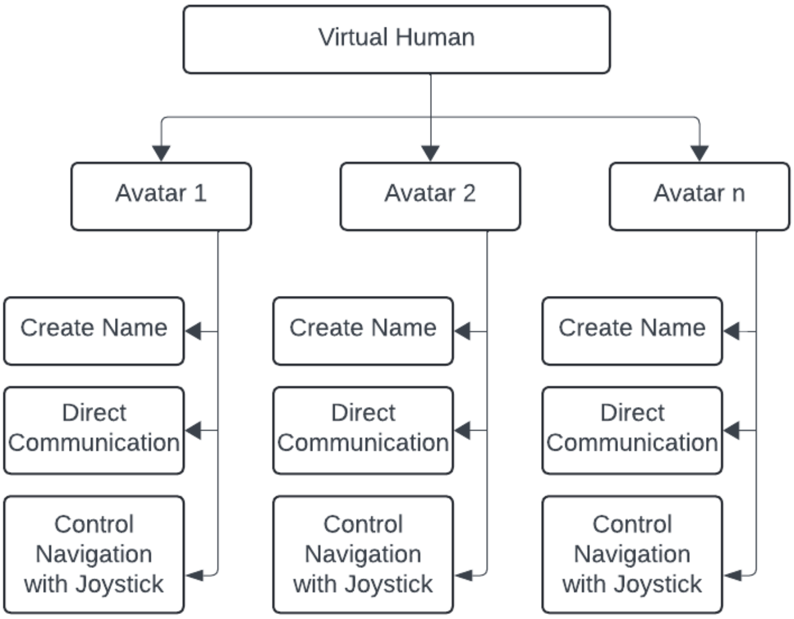

Fig. 3. The framework of virtual human

2.2.2 The virtual environment framework for multi-user and multi-class

The virtual environment framework for multi-user and multi-class primarily consists of a laboratory room equipped with 3D anatomical models categorized according to the learning objectives. In this main room, users can select an anatomical organ they wish to study. A learning guide is also available in this room. When a user selects an organ, they are directed to a dedicated room containing only that specific organ for study. Within this specialized classroom, navigation tools are provided to explore the organ's parts in detail, as well as access to quizzes. Both the main room and the specialized rooms support multi-user learning.

2.2.3 The interaction and collaboration framework in the virtual class for multi-users

The interaction and collaboration framework in the virtual class for multi-users provides a virtual environment for users to interact and collaborate. Users can freely select and manipulate anatomical 3D models for learning purposes. Users within the same virtual room can directly communicate with each other. Users can also create their own virtual classrooms and invite other users to learn without disrupting other classes. Users can take quizzes independently and maintain privacy while completing tasks shows in Figure 4.

Fig. 4. Complete virtual class with quiz tasks

2.3 The Engine Layer in Multi-class and Multi-user VR

The development of the multi-user virtual class application is done using the Unity application with C# programming language. Multi-user and multi-class collaboration is developed by utilizing the assistance of a cloud server, namely Photon Engine. This cloud server supports multiplayer functionality and direct communication between players. The developed Unity application is then exported to an APK that supports the library for Oculus Quest 2. The application can run on portable devices and requires an internet connection. Oculus Quest 2 with a storage specification of 256 Gigabytes is capable of running the virtual class application.

One significant distinction between Unity and Unreal Engine lies in their usability and learning curves. Unity is often regarded as more user-friendly, especially for beginners. It utilizes C#, which many developers find easier to learn compared to Unreal's C++ programming language [21, 22]. This accessibility makes Unity a preferred choice for educational purposes and for developers who may not have extensive programming backgrounds [23]. Conversely, Unreal Engine is recognized for its high-quality rendering capabilities and advanced graphical features, making it suitable for projects that demand superior visual fidelity [24]. Unreal's robust rendering engine supports a range of post-processing effects, which can enhance the overall aesthetic of a game [24]. Performance is another critical aspect where both engines exhibit strengths and weaknesses. Studies have shown that while Unreal Engine often excels in rendering complex graphics, Unity can perform better in scenarios requiring rapid iteration and deployment across multiple platforms [25,26]. Unity's ability to deploy to various target platforms using the same codebase is a significant advantage for developers aiming for a broad reach [27]. In contrast, Unreal Engine's performance is particularly notable in high-end gaming and applications that leverage its advanced graphical capabilities [26]. In terms of specific applications, both engines have been utilized effectively in various domains beyond traditional gaming, including VR and AR development. Unity's versatility makes it a popular choice for educational tools and simulations, while Unreal's graphical prowess is often leveraged in cinematic experiences and high-fidelity VR applications [28].

Photon Engine is an innovative technology that enhances multi-user interactions and network efficiency, particularly in applications such as gaming, VR, and collaborative environments. By leveraging photonic integrated circuits (PICs), Photon Engine significantly reduces latency and supports high-speed data processing, making it ideal for applications requiring instant feedback, such as multiplayer gaming and virtual collaboration [29,30]. This technology also offers superior energy efficiency, utilizing photonic systems to lower power consumption, which is crucial for large-scale implementations with reduced environmental impact [31,32].

3. Results

3.1 Virtual Class Interface System

The development of the interface was carried out using Unity 3D tools, complete with a virtual environment in the form of an anatomy laboratory. On the main application menu, users will be presented with navigation to create a name and choose a collaborative class. Collaborative classes can be directly selected as a guest or create their own virtual class and share it with other users. After determining the class, users will enter the main room in the form of an anatomy laboratory which displays human organs in 3D. If the user selects one of the anatomical organs, they will then be placed in a special room to study the selected anatomical organ. And when finished, the user can exit according to the navigation buttons provided. Figure 5 shows the initial menu for selecting a class and avatar name. Figure 6 shows the main anatomy laboratory room for multi-users.

Fig. 5. The initial menu for selecting a class and avatar name

Fig. 6. The main anatomy laboratory room for multi-users

3.2 3D Virtual Environment in the Virtual Class

The 3D virtual environment is designed to resemble an anatomy laboratory at the Faculty of Medicine, UNS. The 3D models for the virtual environment include lab benches, tables and chairs for participants, cabinets for storing laboratory equipment, lamps with white light spectrum, glass windows, and wooden doors shows in Figure 7. The presentation of these 3D models aims to create a comfortable atmosphere for users, making learning more enjoyable. Navigation is designed based on user habits in a laboratory setting; for example, the door is labeled "Exit" as a navigation sign to leave the virtual room. Anatomical organs are labeled so that users can select them to learn the names of their parts.

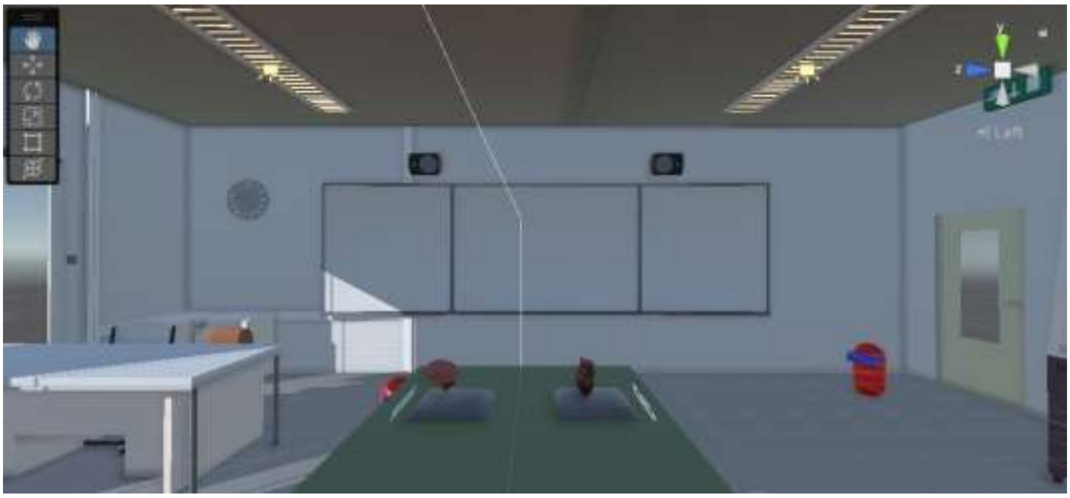

Fig. 7. 3D virtual environment complete with original room components in the laboratory

3.3 Virtual 3D Avatar

In the creation of 3D avatar models, a 3D human mesh is provided. Users can input a name for the avatar generated by the system. Avatar creation utilizes XROrigin within Unity. Inside the virtual class, users can see other users represented by their respective avatar models. The presented avatar models are complete with all the parts of a typical human. Figure 8 shows an avatar model within the virtual classroom environment.

Fig. 8. Avatar models in virtual classroom environments

3.4 Multi-Class Virtual for Multi-Users

In the development of multi-class functionality, Unity was used and connected to a cloud server that supports multi-user games. The cloud server used is Photon Engine, capable of accommodating 2000 users simultaneously in real-time with a traffic capacity of 60 TB per month. In the development of this virtual class prototype, the developer mode was utilized, allowing up to 20 users to join at the same time with an internet traffic capacity of 60 GB per month. Figure 9 illustrates multiple users joining a virtual class created by a teacher.

Fig. 9. Illustrates multiple users joining a virtual class created by a teacher

3.5 Collaborative Tasks in the Virtual Class

Collaboration in the developed application is realized in two conditions: collaboration in learning 3D anatomy models and collaboration in answering quiz tasks. Collaboration between users can be carried out by utilizing XROrigin and the multi-user support features found in the cloud server, namely Photon. The collaboration that can be practiced between users includes viewing the names of anatomical parts and showing them to other users through verbal communication. Communication can be done using the microphone on the Oculus and then relayed to the cloud server to be amplified to other users. Another form of collaboration is that users can work on quizzes together in the virtual environment through voice communication to answer quiz questions. The duration of user collaboration can be recorded by the system, and the learning duration can be communicated to the users. Figure 10 demonstrates the collaborative process of learning anatomy through labeling and answering quiz questions.

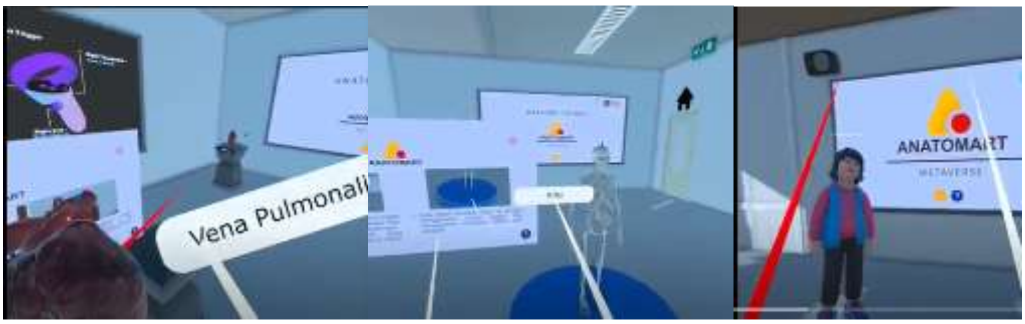

Fig. 10. Demonstrates the collaborative process of learning anatomy through labelling and answering quiz questions

3.6 User Experience and Engagement Evaluation

This study also evaluated the prototype of the developed VR application using the TAM (Technology Acceptance Model) method [33]. The evaluation involved 30 users, the respondents consisted of 16 males and 14 females, representing a balanced gender distribution. The average age of the participants was approximately 20.93 years, reflecting a predominantly young audience. Notably, all respondents were first-time users of the Anatomart VR application, having no prior experience utilizing VR technology for learning anatomy.

The TAM, employing a Likert scale questionnaire to assess key metrics such as Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitude Toward Using (ATT), and Behavioral Intention to Use (BI) [34]. Table 1 presents the categorization of questions based on these constructs, where each group of questions is specifically designed to measure the respective aspect of the model. This structured approach ensures that each dimension captures the relevant perceptions, attitudes, and intentions of users regarding the VR application being analyzed.

Table 1
The categorization of questions based on these constructs

No.	Dimension	Question
1	PU	I find it easy to learn how to use the Anatomart VR application.
2	PU	I can use the Anatomart VR application to facilitate my anatomy learning.
3	PU	I can complete anatomy learning more quickly using the Anatomart VR application.
4	PEOU	I can understand well how to interact with the Anatomart VR application.
5	PEOU	I can explore the anatomy room using the Anatomart VR application easily.
6	PEOU	The interactive buttons and menus in the Anatomart VR application work smoothly.
7	ATT	I feel comfortable using the Anatomart VR application.
8	ATT	I enjoy using the Anatomart VR application.
9	ATT	I think the Anatomart VR application is not boring.
10	BI	I use the Anatomart VR application for an extended duration, more than 15 minutes.
11	BI	I learn based on the information provided by the Anatomart VR application.
12	BI	I am proficient in using the Anatomart VR application easily.

Table 2 presents the calculations for each dimension in the TAM method, including validity values, reliability values, statistical analysis results, and interpretation of the findings. The validity formula is presented in Eq. (1), and the reliability formula is presented in Eq. (3).

$$r_{xy} = \frac{n\sum X_i Y_i - (\sum X_i)(\sum Y_i)}{\sqrt{(n\sum X_i^2 - (\sum X_i)^2)(n\sum Y_i^2 - (\sum Y_i)^2)}} \quad (1)$$

The correlation coefficient r_{xy} is computed based on the number of respondents (n), the score of each individual item (X), and the total score for all items (Y). To evaluate the statistical significance of the correlation, a t-test is performed. The significance is determined by comparing the calculated t-value (t-count) with the critical t-value from the t-table. If t-count exceeds t-table, the correlation is deemed significant, confirming the item's validity. The formula for calculating t-count is shown in Eq. (2).

$$t_{count} = \frac{r_{xy}\sqrt{(n-2)}}{\sqrt{1-r_{xy}^2}} \quad (2)$$

To assess the reliability of the test, the Cronbach alpha Eq. (3) can be used.

$$r_n = \frac{n}{n-1}\left(1 - \frac{\sum_{n-1}^{n} S_i^2}{S_t^2}\right) \quad (3)$$

Where, R_n is a reliability coefficient, *n* is many items, S_i^2 is a variance of i question, S_t^2 is a total score variance.

Table 2
The calculations for each dimension in the TAM method

No.	Dimension	Validity (Range)	Reliability (Cronbach's Alpha)	Descriptive Analysis (Mean ± SD)	Interpretation
1	Perceived Usefulness (PU)	0.55 - 1.00	0.82	4.42 ± 0.68	PU demonstrates excellent consistency, indicating users generally find the application useful.
2	Perceived Ease of Use (PEOU)	0.49 - 1.00	0.78	4.46 ± 0.56	PEOU has high reliability, showing that users find the application easy to use.
3	Attitude Toward Using (ATT)	0.40 - 1.00	0.77	4.31 ± 0.62	ATT reflects positive user attitudes toward the application, with reasonably good reliability.
4	Behavioral Intention to Use (BI)	0.37 - 1.00	0.72	4.21 ± 0.60	BI indicates high intention to use the application, though validity between questions is slightly weaker compared to other dimensions.

The results from the TAM analysis highlight key insights into user perceptions of the VR Anatomart application. PU exhibited strong reliability (alpha = 0.82) and validity (range: 0.55–1.00), indicating that users find the application highly beneficial for learning anatomy. PEOU scored the highest average (4.46) and demonstrated high reliability (alpha = 0.78), reflecting users' consensus on the ease of navigating and interacting with the application. ATT scored an average of 4.31 with good reliability (alpha = 0.77), showcasing a positive user sentiment toward using the application. BI showed slightly lower reliability (alpha = 0.72) and validity (range: 0.37–1.00), with an average score of 4.21, suggesting users' intention to adopt the application while leaving room for further improvements to enhance user engagement. Overall, the findings indicate that the VR Anatomart application is well-received and holds significant potential for enhancing anatomy education.

3.7 Longitudinal Study of the Anatomart VR Application

Based on the analysis of respondent data and user feedback, this study demonstrates that the Metaverse VR Anatomart application has significant potential to enhance anatomy learning. One of the key findings from user measurements includes the statement, *"I can complete anatomy learning more quickly using the Anatomart VR application."* This statement reflects PU as a critical construct in the TAM. The statistical analysis of PU exhibited strong reliability (alpha = 0.82) and validity (range: 0.55–1.00), indicating that users find the application highly beneficial for improving the efficiency of anatomy learning. These metrics underscore the application's capacity to provide meaningful support in educational contexts, making learning faster and more effective.

However, to assess its long-term effectiveness and ensure sustained benefits, we recommend conducting a longitudinal study. This study will involve tracking student performance and engagement in both virtual and real-world scenarios over several months. The primary focus will be on measuring knowledge retention and skill application over time, as well as evaluating the impact of VR-based collaborative learning. Additionally, the study will assess user experiences, including challenges such as visual impairments and side effects like dizziness and nausea. By combining the findings from the current study with insights from a longitudinal evaluation, we can gain a more comprehensive understanding of the application's effectiveness and identify areas for further improvement. Therefore, this research provides a strong foundation and is worthy of further development to ensure that the Metaverse VR Anatomart application can deliver optimal and sustained benefits to users in the long term, while continuously adapting to user needs and educational advancements.

4. Conclusions

This research successfully implemented a multi-user virtual classroom system in the metaverse, utilizing Unity and the XR Origin feature to enable immersive and interactive experiences. The system demonstrated effective multi-user collaboration within a virtual environment by leveraging the Photon Engine cloud server, which supports multiplayer functionality and direct communication between users. TAM analysis revealed strong reliability and validity across key dimensions, with PEOU achieving the highest score, indicating that the system is intuitive and user-friendly. BI, while slightly lower, highlighted opportunities to further enhance user engagement. The virtual classroom system supports collaboration in learning anatomical organs and enables users to create their own virtual classrooms, inviting others to join based on specific learning schedules. However, challenges related to internet network traffic usage remain, suggesting the need for future research to optimize network utilization for seamless collaboration. This innovative system provides a transformative approach to conventional learning models, allowing users to collaborate and interact effectively in a virtual environment while maintaining privacy, paving the way for more accessible and engaging educational experiences.

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