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Feasibility of teaching and assessing medical students in the metaverse: design and features for its learning efficiency

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Abstract

The metaverse is known as the hypothetical iteration of the Internet as a single, connected, universal and immersive virtual world that can be accessed via immersive technology devices. One approach to this concept can be achieved through the use of multi-user immersive virtual reality applications.

Immersive virtual reality (IVR), which uses gadgets that allow the user to visualize and interact in an enveloping way, is a very attractive technology for teaching purposes. There are many references in the scientific literature about its use for this purpose, including encouraging results in the field of medicine. However, there have not been enough studies assessing how much this type of technology really contributes to learning medicine.

This work investigates the feasibility of using the metaverse as an educational tool in medicine. We propose a multi-user immersive virtual reality application for implementing a scene of the metaverse in which medical students are taught. Our work considers that in order to ensure this type of technology is useful in the education of medical students, the technology itself (multi-user IVR) must be designed and implemented for a medical student profile. They usually spend too much time for adapting themselves to use and manage this kind of technology when they are exposed to it for learning. The technology should not be a barrier to acquiring, or disseminating the academic contents themselves. It should act as a catalyst that enhances the speed and capacity for learning medical educational topics. Thus, we present design and user experience specifications that we implemented in an anatomical dissection room in the metaverse, and with which we conducted experiments with 114 sixth-grade medical students. Our results indicate that, based on the design and user experience characteristics that we propose in this paper, the metaverse can indeed serve as a useful and effective educational resource whose technological complexity is no barrier to medical teaching.

Keywords: Medical education, Metaverse, Immersive, Virtual reality

1 Background

The concept of virtual reality (VR) has been around since the last third of the 20^{th} century and includes many different types of technology, software and hardware, which model the user's interaction with a digitally designed artificial scenario: a virtual environment. However, this concept reached its maximum splendour when the VR devices with components such as glasses and controllers appeared, which naturalize the user's vision and interaction within the virtual environment, as well as systems that allow for body tracking or tactile sensation. Due to the realism with which it creates the feeling of being immersed in the virtual environment, this type of virtual reality is called immersive virtual reality (IVR).

This type of VR offers a great capacity and potential for being used as an educational tool in several areas of knowledge (Carruth, 2017; Jensen and Konradsen, 2018; Chen et al., 2023). It allows for the development of constructivist educational and experience-based learning methods, creating scenarios that visually emulate real environments in which the students, who feel immersed in them, perform and develop tasks that increase their understanding of academic content, or perceive educational aspects that, without actually carrying out the activity, are hard to acquire using traditional methods. Moreover, today, there are many immersive, versatile, user-friendly, low-cost VR devices that facilitate the approach and access to this technology in educational centres (primary and secondary schools, universities, etc.).

All this means that nowadays it is possible to consider the practical implementation of the metaverse concept (Kye et al., 2021; Wang et al., 2023; Chen et al., 2023), using multi-user immersive virtual reality (IVR) applications.

In health sciences degrees, and in medicine in particular, everything seems to indicate that this type of technology is very useful from an educational point of view (Pottle, 2019; Hicks et al., 2021; Barteit et al., 2021; Castro et al., 2022; Sandrone, 2022; Kala, 2022; Castro et al., 2023; Massetti and Chiariello, 2023; Ahuja et al., 2023; Lewis et al., 2024). Moreover, recent results propose it as an powerful and useful tool for learning basic medical subjects at the degree level (Iwanaga et al., 2023; Moro, 2023) or, even, for training and doing the clinical practice (Bansal et al., 2022; Werner et al., 2022; Skalidis et al., 2023; Wu and Ho, 2023; Zattoni et al., 2023; Rabotin et al., 2023).

However, it is not entirely clear that this is the case and that its use improves educational processes and the learning of subjects specific to these types of degrees (medicine, nursing, etc.) (Jensen and Konradsen, 2018; Hussain et al., 2021; Ryan et al., 2022a, b). In fact, the medical students usually spend much of the learning time adapting themselves to manage and use the technology itself, consequently, the classroom's time does not result in an efficient manner of learning.

In this paper, we look at this less explored aspect of multi-user IVR, introducing the design of the metaverse in the classroom. The issue we address is examining whether the capacity offered by the metaverse, as a multi-user IVR application, adds value to the education of future medical professionals and whether, indeed, its use enhances learning and does not, by the very use of the technology, constitute a barrier to learning. In our experience with several immersive learning applications (our own or third-party), we have noticed that medical students are not especially interested in learning technology per se, or how to use it, but want to study clinical content related to patients. Therefore, the technology that is used in their educational process should not condition or limit the content or objectives of their healthcare learning.

In our opinion, and based on the experiences with the use of technology for medical education (Ballesteros et al., 2014; Ballesteros-Ruiz et al., 2013; Castro et al., 2022, 2023; Rodriguez-Florido et al., 2023), the metaverse, as multi-user IVR, adds value to the educational and learning process of future medical graduates, but that its use and characteristics should be designed carefully and with an in-depth knowledge of the student profile we are targeting. Underlying VR technology should aid and support learning, and its use, or technical complexity, should not be a barrier to achieving this goal. By using multi-user IVR, we do not intend to convert medical students into technology enthusiasts or technically advanced users of this technology. We simply expect that the technology's capabilities will facilitate their learning of medicine and help teachers assess the academic content. The metaverse allows "the patient" to be brought closer to the medical student and, therefore, it is a very attractive tool for learning medicine.

Similarly, as can be seen in any references in this paper and, in turn, in bibliographic citations in them, IVR technology has been used in medicine as an individual study or learning method. The student interacts individually in a virtual scenario without having any contact, as they would have in a classroom or a laboratory, with their teacher or classmates. This is why, given the capacity of the technology, we are interested in finding the interest in and usefulness of the metaverse as a teaching space in which to extend this limitation. In medicine, teaching is usually carried out with groups of students who do their practicals in collaboration with and tutored by a teacher. Consider, for example, how students learn about anatomy in laboratory practicals. There are usually groups of students working with phantom models of human anatomy, cadaver parts or directly with complete cadavers. Therefore, it seems useful to propose a teaching tool in the metaverse that helps educate medical students, multiplying the integrating and facilitating effect of a common virtual environment.

1.1 Objective of our work

The main objective of this paper is to study, on the basis of measurable experimental results, whether teaching medicine in the metaverse, implemented through a multi-user IVR, is a useful tool for the students' education or if the technology itself, due to its complexity or problems in dealing with it, is an obstacle to learning. In a way, we aim to find out whether teaching in the metaverse leads to students being more occupied with being able to deal with the virtual environment than focusing on the academic content itself.

Our paper proposes how to design and implement the user experience of medical students in the metaverse. We also propose metrics, within the metaverse, which parametrize data on the students' mobility, handling and interaction within the scenario, as well as their subjective perceptions after the experience.

In any case, it is important to bear in mind that our study does not propose that this type of technology replaces traditional or physical methodologies or tools, but rather that it can be used as an additional tool to existing ones, complementing them or promoting their evolution.

The article is organized as follows: We begin with this introductory section that puts into context the scope and objective of our work. Then, we present a section on material and methods where we describe our purpose, the experimental environment we propose, the software and hardware tools we use, and the design and features of our application. Next, we continue with the results section, in which we present the data obtained and how they were processed in terms of statistics. We end with other sections relating to the discussion, conclusions and the future lines of our work.

2 Material and methods

2.1 Purpose and experimental environment

In order to achieve our goal and implement the experiments that allow us to measure the desired parameters within the metaverse, we shall need to define a multi-user IVR that emulates a teaching scenario in medicine.

In general, in medicine the resource that has historically been used for teaching is the human cadaver. Although there are several legal, health or logistics support restrictions relating to its use in teaching, today it continues to be a resource highly sought after by medical students and teachers. In this context, and in agreement with several teachers at our University's faculty of medicine, the idea emerged to use the capacity of multi-user IVR technology to model a human dissection scenario within the metaverse. Therefore, our scenario in the metaverse consists of a dissection room in which up to four students and one teacher can participate simultaneously, whilst the contents of the virtual environment can be projected to other users (outside the metaverse) through a projector, screen or multimedia streaming system.

2.2 Multi-user immersive VR

In this work, we implement the metaverse (Chen et al., 2023; Kye et al., 2021; Wang et al., 2023) as a multi-user IVR application, which allows several users to connect in the same 3D virtual environment, guaranteeing the participants the feeling of presence, immersion, interactivity and communication in real time.

In our proposal, we create a virtual dissection teaching room in which the participants are introduced through immersive VR devices, with a virtual head-mounted display and movement controllers in their hands, in order to act within the metaverse. These types of VR devices, which are readily available on the market, facilitate the creation of a fully immersive atmosphere that immerses the user in the desired metaverse scenario.

In order to develop our virtual dissection room in the metaverse, we made use of several open-source resources available on the Internet. On the one hand, for the virtual modelling of the complete human anatomy, we based ourselves on the Z-Anatomy project (https://www.z-anatomy.com/), post-processing the 3D objects (optimization of the size and detail of the 3D objects, grouping of the 3D objects into structures of the human anatomy according to academic interest, etc.) of the human anatomy and structuring them as an external resource for the graphics engine used to develop the application.

On the other hand, we used other open-source 3D objects for modelling the scene (furniture, work table, etc.), and for the avatar of each participant.

To integrate these 3D models and create the interactive application, the Unity3D graphics engine (https://unity.com/) was used, implementing our features with scripts in C# language and including external development kits: OpenXR (https://www.khronos.org/openxr/) for use with VR and Mirror Networking (https://mirror-networking.com/)

for the collaborative feature (capacity for multi-user connection, adding participants, starting group sessions for the participants in a coordinated manner and synchronizing all the actions among the different participants coherently).

In our experiments, we used four commercial immersive VR devices (see Fig. 1 for details), which are operated by four students, or three students and one teacher, one desktop or laptop computer running Microsoft Windows 10, with a conventional graphics card (Intel(R) UHD Graphics 620), an average processor (Intel(R) Core(™) i7-8550U CPU @ 1.80 GHz 1.99 GHz) and 16 Gb of RAM, which serves to monitor and control the metaverse scene and its participants from the outside, and a standard router to create a local WiFi network through which all devices are connected in a common wireless network. In case it is of interest, the signal from the desktop or laptop computer can be transmitted to an external projector or a multimedia system in order to give an overview of the metaverse scenario to other students who are in the physical world.

To organize, version and store our software and resources of the software application, we use the GitLab version development and control system (https://about.gitlab.com/).

2.3 Design in medical learning environments

The learning environments designed for medical education should bear in mind the fact that the teaching tools used that emulate the human body, or any of its facets, should not interfere with the objectives or content for teaching medicine. This is even more important if the tools used are implemented using emerging technologies (e.g. Virtual Reality, Augmented Reality, etc.).

In our experience, medical students are usually reluctant to use emerging technologies in their study or training processes, since they consider themselves to be inexperienced in the use of these technologies and the latter take them away from their main interests: everything related to patient access and healthcare practice. It should be remembered that medical students have a high academic profile, but, although they are still digital

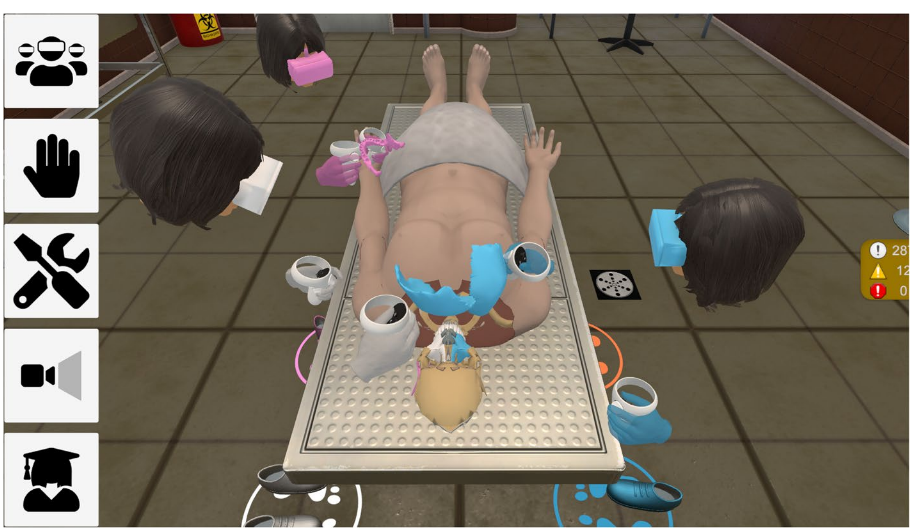

Fig. 1 Screenshot of the metaverse taken during of the experience. Note the bone anatomy coloured with the identifying colours of each user within the metaverse scenario

natives and daily users of technology, they are not particularly interested in the technological development or use of electronic devices. They can accept it for learning purposes if it does not pose a barrier to accessing their interests.

So, we consider that the design of a scenario in the metaverse for medical education should minimize the effect of the use of the technology itself as opposed to its educational purpose. The student should not view the proposed technology as an obstacle to their accessing learning, but should perceive it as a vehicle that allows them to access that knowledge quickly, efficiently and enjoyably.

The same applies to the teachers using this type of technology. These are people experienced in the classic medical teaching methodologies and, even if they are trained in the use of technology, it should not be an obstacle to its use in the classroom.

For this reason, we include a computer (desktop or laptop) in our design of the scenario in the metaverse. With the keyboard and mouse, the computer can be used to monitor, control and activate actions within the metaverse without actually being in it. This facilitates the management of the system from the outside (physical world) whilst still being present in the events and actions taking place inside (the metaverse). Moreover, this computer's video output can be connected to a projector or a multimedia system that projects the metaverse scenario (virtual dissection room) to students who are not in it, but are in the physical world.

Finally, we think that the use of any medium or tool, utilized in medical teaching, should be justified and not become a matter of fashion or trend. In this respect, the metaverse should be capable of parametrizing and measuring the actions performed by each of the students immersed in it. The approach in the design will allow us to measure and assess the student's skills or knowledge, by means of the computerized recording of metrics defined for this purpose.

2.4 Features in the medical metaverse

The features of the metaverse in a medical education environment must be those that maximize the user experience and minimize the effects of the immersive technology itself, providing an educational tool that is technologically transparent for the medical students, that is, they are not involved in a complex manner to access their learning lesson.

In this respect, in our work we propose:

1. Naturalizing: The aim is to define the features that naturalize the students' behaviour within the metaverse and make them forget that they are in an artificial scenario, focusing their attention on the proposed academic content.

   That feature can be achieved by making it easier for students to use the technology in the metaverse and only considering the features that the multi-user IVR offers us for channelling the learning. An illustrative example of this consideration is the use of the hands in the metaverse through the operation of the VR controls. Usually, in IVR environments the controls (buttons) on the VR controller are converted into the hand movements of the user holding it and, in the metaverse, they can see their virtual hands for picking up and letting go of objects by pressing these buttons.

However, in our first experiences (see later section on results) we empirically verified that this type of unnatural emulation (the controller that the student holds does not look like the hand) confuses the medical student and makes training in and remembering the use of the VR controllers quite complex, which in turn complicates interactions within the metaverse excessively. So, although we initially disabled all the buttons on the VR controller, except the larger and easily accessible ones, this did not minimize the confusing effect mentioned above. Therefore, we decided to leave only one of the buttons enabled, the one closest to the index finger of each hand, and to display the model of each VR controller and the hand holding it virtually (see Fig. 1), so as to reproduce in the virtual environment what the students see physically before going into the metaverse and then use inside. By activating the button closest to the index finger on each hand as an actuator, the student can pick up (pressed) or release/let go (not pressed) objects within the metaverse.

This is the point when the students felt really comfortable and we noticed an improvement in the speed, skill and the use of their hands in the metaverse. Clearly, what was happening was that, in this case, the technological interface to emulate our virtual hands was limiting the physical perception that the medical student had on their hands and, therefore, their ability to use them. However, if the physical interface that they support subsequently matches the controller they have in the metaverse to interact with the objects and other users, their skills and handling are improved.

It is a clear of example of what defines this proposed feature for the use of applications in the metaverse in medicine.

2. Identifying: With this feature we are referring to the fact that each student in the metaverse has to have a way of self-identifying with his or her "virtual self" (VR avatar). We propose that when the student logs in to the metaverse, they are assigned a unique colour (blue, white, pink or orange) for their VR avatar (head, hands and legs). Subsequently, the teacher can register them with their first name and surname, according to the colour they have been assigned. In this way, there is an anonymization within the environment and it is easier for the teacher to manage and order the actions within the teaching scenario in the metaverse.
3. Positioning: The aim is to locate and reference the medical students within the metaverse. In general, medical students who are not used to this type of experience are often surprised when they enter the metaverse and this makes them a little uneasy. This unease and uncertainty must be channelled in order to ensure the students focus on the learning objective. When they enter the metaverse, the students find themselves in an open space, which they know is artificial but, due to the versatility of the immersive technology, makes them feel a little insecure. For this reason, taking advantage of the assignment of colour and their identification within the application (colour versus name), they are offered guides to help them locate themselves within the teaching scenario in the metaverse.
4. Measuring: The parametrization of each student's actions is required within the metaverse to obtain metrics. These quantifiable values will help us know how the medical students perform in the metaverse and assess their acquisition of the aca-

demic content taught. In our proposal, we suggest using group metrics (statistical behaviour of the students), or individual metrics (individual behaviour of each student), obtained within the metaverse. In addition, subjective assessments are made through post-experience questionnaires.

5. Collaborating: This involves having visual resources that facilitate the group of students' collaboration and interaction within the metaverse. In our case, the scenario is a virtual anatomic dissection room.
   To this end, within the application we considered including features that allow users to visualize in a user-friendly way what one of the students (selected by the teacher) is viewing specifically, general indications for carrying out tasks or providing teaching, and visual information on the results obtained (metrics) for each of the students after the activity proposed by the teacher.
6. Controlling: This involves providing the teacher, without interfering directly with the experience, with a system for monitoring the teaching in the metaverse, where they can clearly identify each student, know what they are doing and seeing, and be able to propose activities, exercises or challenges to carry out within the metaverse. To achieve this, the application developed includes the possibility of seeing the metaverse scenario in a large number of cameras preconfigured or personalized by the teacher, observing and sharing with the other students outside the metaverse what any of the students are looking at, taking screenshots, configuring the anatomical resources that you prefer to use (the virtual cadaver model can be used in its entirety or, for teaching purposes, just represent certain parts of the anatomy), moving the table where the virtual cadaver is to bring it closer to one of the students and turn the virtual cadaver to work on the area of interest (anterior, posterior or lateral), as if you were in a dissection room in the physical world.

2.5 Experiments and data collection

In order to be able to investigate the viability of using the metaverse for medical teaching, we developed a series of experiments that measure the students' behaviour within the modelled scenario. Subsequently, we carried out an anonymous survey of the experience. The statistical processing of these data will allow us to interpret the results and draw conclusions.

The implementation of the experiences in the metaverse always follows the same protocol: the entire system is connected to a shared WiFi network and the students are taken into a metaverse scenario using the VR head-mounted devices and the hand controllers. The teacher connects from the laptop running the desktop application and, from there, controls and monitors all the students taking part in the experience, as well as the specific activities that he/she wants to perform with them. If the teacher prefers to participate in the metaverse in person, he/she will have a virtual tablet in which he/she can access the same controls as he/she uses from the desktop application outside the metaverse. In fact, the teacher's role can be duplicated, with one of the teachers acting in the metaverse, with access to the virtual control tablet, and another in the desktop computer application in the physical world.

In order to measure the validity of the features described in the previous section, which we propose for medical teaching applications in the metaverse, our application provides:

- Collaboration between users. The students can see each other and interact with the scenario represented in the metaverse, so that they perform the virtual experience as a group. More specifically, they can hear each other's own voices directly, if they are in the same physical location, or via the speaker on the head-mounted devices if they are in separate physical locations. They can also move around and exchange objects with one another, using the VR controllers that are emulated within the metaverse and that reproduce their own hands holding these VR controllers. As explained in the previous section, this way of providing manual interaction in the metaverse maximizes the naturalization of movements and their use.
- User identification. Each student who connects to the metaverse is identified, depending on the time when he/she joins, with a colour (blue for the first, white for the second, pink for the third and orange for the fourth). This allows us to obtain individual information and capture his/her metrics.

Within this context, and in order to measure specific actions to obtain statistical results in this regard, we designed three activities within the metaverse scenario, through which we will obtain parametric measures that quantify the naturalization, identification, positioning and measurement of our study population.

The first activity aims to measure how the medical students position themselves in the metaverse. To this end, once they are immersed in the metaverse, as described above, they are asked to place themselves on a footprint on the floor of the scenario presented in the metaverse in accordance with the colour that identifies them. So as to reference himself/herself in the first person in the metaverse, according to the perception he/she has of his/her body in the metaverse, the student looks at the position of his/her feet and adjusts the virtual models of his/her footwear to the position of the footprint. Bear in mind that the student always has a reference to his/her limbs with regard to his/her head, monitored by the VR glasses, and his/her hands, monitored by the VR controllers.

When the teacher observes, from the desktop application, that each student is in place, he/she asks him/her if he/she is positioned and clarifies that this is going to be their working position throughout the entire session (see Fig. 1), bringing the activity to an end. At that moment, the application captures the parameters indicated in Table 1.

With these two parameters we aim to measure how the medical students perceive and move around in the metaverse. Very high time values will indicate a lack of skill in identifying their virtual reference feet and their position with regard to their head and hands, so it will take them longer to position themselves where they are asked to do so. The distance gives us an idea of the precision with which the user perceives his/her position in the metaverse concerning a reference within the latter. If the distance is high, it presumes the user lacks the ability to position themselves in the metaverse. Ideally, an agile and skilled user in the metaverse should have very low time and distance values.

The second activity aims to familiarize the medical student with the VR controllers and with the use of their hands within the metaverse. To do this, the teacher explains

Table 1 Parameters acquired from the first metaverse positioning activity

Parameter name	Description
Time (s)	Total time from the enabling of the activity until the users are positioned on the corresponding footprints at a distance of under 15 cm from the centre of the reference on the ground.
Distance (m)	Distance from the centre of an imaginary circumference that surrounds the user in the metaverse and the centre of the circumference that contains the ground reference footprints.

that the VR controller is limited to using the button associated with the index finger, so that pressing it means picking up/holding a virtual object and releasing it indicates letting go of/freeing the virtual object. After this explanation, they are asked to pick up, at the student's choice, any tissue from the virtual cadaver model and pass it on to their experience partners. While this activity is active, the application measures the number of clicks made by each user and the total duration of the experience.

Although these two parameters (number of clicks and total time) are not aimed at obtaining relevant information, they do allow us to check experimentally the naturalization of the use of the VR controllers that the medical students acquire and, subsequently, by means of an anonymous, subjective questionnaire, to ask them about this issue.

The third and last experiment that we carry out within our proposal is to measure how students interact with one another in the metaverse. To this end, an anatomical model of the human skeletal system of the head is shown—see Fig. 1—in which the students have to identify the tissues coloured in their identifying colour and take them to a position close to their body. At this point, the tissues will change colour to that of another student participating in the experience, at which point the students have to exchange tissue models in accordance with their identifying colour. Finally, when the students take the tissue models that their classmates have transferred to them, these models return to their initial colour and the students must once again exchange them, in line with the colour that identifies them, so that each student places them back in the corresponding anatomical area.

In this last step, which involves replacing the tissues in their anatomical position in the virtual cadaver, and to facilitate the placement process, the models of the virtual hands of the participants in the metaverse change colour in line with the status of this process: red, if the student is far from the tissue relocation area, yellow if he/she is near the zone where the tissue to be returned to its original position is located, and green if it is already more or less in the correct area. In this last status, green, the student can release the VR controller button and the tissue will automatically be relocated in its original position.

In this third activity, the parameters described in Table 2 are measured.

The time measurements give us an idea of the agility of the students for interacting with the objects, with each other and for performing a practical dissection illustration activity in the metaverse. Very high measurements of these times infer that the medical students find it difficult to perform this action within the metaverse.

Table 2 Parameters captured from the third handling and interaction activity in the metaverse

Parameter name		Description
Time (s)	Time of Screenshot (s)	The time it takes the student to pick up each of the tissues that correspond to their colour.
	Time of Transfer (s)	The time it takes to transfer them to their classmate in the group with the corresponding colour.
	Time of Location (s)	The time it takes the student, after the previously described sequence, to replace the tissue in its natural anatomical position.
Frequency		Number of times that the virtual hand of each student is in the red, yellow and green status.
Status of the Sequence		Controls the moment in the described process of the activity at which the student finishes. For each virtual tissue, a status is defined within the sequence of steps to be performed in the activity: 0 to pick up, 1 to transfer, 2 to pick up again, 3 to reposition and 4 to end the sequence. Ideally, all students should finish the activity in status 4.

The frequency with which their hands in the metaverse switch between the colours red, yellow and green, as described above, gives us an idea of the student's knowledge of anatomy and the difficulty in applying that knowledge within the metaverse. A high value for when the virtual hand is red implies anatomical ignorance, whilst a high value for the virtual hand in yellow measures the user's difficulty in repositioning the tissue in its area of origin. The frequency for the virtual hand in green will be high if the student has not understood that, when it is this colour they can release the button on their VR controller so that the application itself repositions the tissue in its place.

As for the status of the sequence, it is only intended to have a control signal in which it is possible to know if there is a student who has not finished the sequence proposed in the activity and if this number of students is high.

Finally, to finish the data acquisition process, and after carrying out the virtual experience, the students complete an anonymous questionnaire that aims to measure their subjective perception of the use of the metaverse for learning. This questionnaire, which is attached as an Additional file 2 to this article, was designed following the recommendations in the literature (Harris et al., 2020) and adapting other experiences from the bibliography that had been validated statistically and that pursued objectives similar to our work (Tcha-Tokey et al., 2016). Our adaptation is based on matching the questionnaire to our specific objective, to the VR tools we used and the questions we considered most appropriate for our study.

3 Results

To obtain our experimental results, preliminary tests of our educational environment were carried out in the metaverse with first and third year medical students, within the context of a first year technical subject (Physics and Medical Technology) and a third year clinical subject (Otolaryngology and Medical and Surgical Stomatology), respectively. These tests allowed us to fine-tune the implementation of the application in the metaverse with multi-user IVR technology, the teacher's means of control and management through the desktop computer and the modelling and the appearance of the dissection environment (model of the cadaver and anatomical parts, naturalization of the technology, etc.) for medical students.

As a result of these preliminary tests in a real academic environment, the technology, its performance, the definition of the experiments and the data collection, the identification of improvements and the convergence of the design and the implementation described in the previous sections were refined, and the research could be formally conducted with a new study group of medical students.

3.1 Population of study

The experiments described in one of the previous sections were conducted with students in the 6th year Clinical Rotation subject (135 students), obtaining results from the anonymous questionnaire for 79 (58.50%) students and metrics in the metaverse environment for 114 (84.40%).

The difference between the number of students who filled out the survey after the experience in the metaverse (79) and the actual results obtained from the metaverse activities (114) is due to the fact that some of the students forgot to complete the questionnaire.

The sessions were organized in groups of 10–12 students, which were formed in advance by the students themselves. Of these, in each practical session, the first 3 or 4 were selected at random (the maximum number of participants in the experience is 4 and the teacher always participated via the application on the desktop computer), and they were the ones who participated in it without having any prior information. The rest of the students in each group, who watched the development of the experience of their initial companions and took advantage of the teacher's explanation and the view from their desktop application, knew what the practice consisted of in order to subsequently carry it out. For this reason, in our statistical analysis, we shall make a distinction between the metrics obtained by the first students and the rest.

3.2 Statistical assessment

In our statistical assessment, the categorical variables were summarized in frequencies and percentages and numerical variables in means and standard deviations or in medians and interquartile ranges (IQR = 25–75 percentile) depending on whether or not the assumptions of normality were met. The percentages were compared using the Chi-squared test (χ^2). Means were compared using the t-test and the medians using the Wilcoxon tests for independent data. The statistical significance was set at $p < 0.05$. Cronbach's alpha was used to measure the validity of the questionnaire, and 95% confidence intervals were calculated using bootstrap. The statistics program used was R.

3.3 Outcomes

The results obtained come from the experiments, previously described, on this study population. The questionnaire is attached to this document.

a) Metrics from the metaverse practical experiments:

Table 3 Parameters and statistical results of the first activity in the metaverse

Parameters	Total Sample $N = 114$	First in the Group $N = 42$	Rest of the Group $N = 72$	Significance $P < 0.05$ *P*-value
Initial Distance (m)	0.23 (0.15; 0.33)	0.31 (0.18; 0.48)	0.22 (0.14; 0.30)	0.0142
Final Distance (m)	0.07 (0.04; 0.11)	0.08 (0.06; 0.14)	0.05 (0.03; 0.10)	0.0058
Time (s)	5.39 (2.87; 8.75)	9.04 (7.22; 15.42)	3.80 (1.03; 5.94)	< .0001

Table 4 Parameters and statistical results of the third handling and interaction activity in the metaverse

Parameters	Total Sample $N = 114$	First in the Group $N = 42$	Rest of the Group $N = 72$	*P*-value
TimeCapturePart1 (s)	15.33 (5.67; 33.58)	23.51 (16.57; 43.33)	8.32 (4.31; 22.65)	< .0001
TimeCapturePart2 (s)	23.93 (12.28;47.81)	34 (23; 60)	16.78 (8.72; 37.98)	0.0004
TimeTransferPart1 (s)	10.80 (4.13; 35.68)	14.10 (5.32; 52.10)	7.38 (3.86; 25.72)	0.0732
TimeTransferPart2 (s)	9.52 (3.95; 33.20)	13.67 (5.62; 36.10)	7.04 (3.63; 29.66)	0.0852
TimeReturnPart1 (s)	5.79 (2.66; 13.27)	9.04 (4.35; 16.06)	4.73 (1.88; 8.45)	0.0074
TimeReturnPart2 (s)	5.72 (2.23; 12.99)	8.85 (3.75; 19.24)	4.47 (1.49; 8.80)	0.0029
TimePlacementPart1 (s)	17.74 (5.77; 31.10)	21.37 (12.62; 34.25)	16.26 (4.97; 27.50)	0.0787
TimePlacementPart2 (s)	14.62 (2.74; 41.87)	23.86 (9.00; 56.64)	11.47 (1.96; 31.31)	0.0332
Red virtual hand frequency	1.00 (0.00; 2.00)	1.00 (0.00; 1.00)	1.00 (0.00; 2.00)	0.6667
Yellow virtual hand frequency	8.00 (5.00; 13.75)	8.50 (6.00; 12.75)	8.00 (5.00; 14.25)	0.8991
Green virtual hand frequency	7.00 (4.25; 10.00)	6.00 (5.00; 9.50)	7.00 (4.00; 10.00)	0.8405

Table 3 shows the values obtained from the statistical analysis of the first activity carried out and associated with the measurement of the medical students' ability to position themselves in the metaverse. It shows the initial position (in metres) with regard to the centre of the reference footprint (see Fig. 1), the final position (in metres) when the student is located at a distance of under 0.15 m and the time (in seconds) required to get into the desired position. At this threshold distance of 0.15 m, the timer for each user stops and counts the time needed to perform the activity. In the event that, before the teacher has finished the task, the student moves further than 0.45 m from the centre of this reference footprint, the timer will be activated, adding the additional time that this student was outside the 0.15 m threshold, prior to the completion of the activity.

In the second activity, concerning the instructions for the use of the VR controllers and, therefore, their hands in the metaverse, no objective metrics relevant to our study were pursued, but rather the aim was to familiarize them with the VR controllers and their experience of subjective appreciation to be measured through the subsequent questionnaire.

In any case, it should be noted that when following the instructions given by the teacher, more clicks were detected on the right hand controller than on the left.

Table 4 shows the results of the third activity associated with the measurement of the interaction of the medical students with the scenario and with each other. It shows the values of the time parameter (in seconds) and the frequency parameter, described in Table 2.

For the frequency, also described in Table 2, there were 49 students that never had a red (the frequency of the red hand is 0), as there were no significant differences between one and the other frequency values (red, yellow and green) if they belonged to the first or the next in the group.

As for the status of the sequence, mentioned in Table 2, a total of 99 (86.80%) students reached the status of 4 for the first anatomical part and a total of 87 (76.30%) for the second anatomical part, detecting no significant differences between the first and the following group.

On the other hand, they completely finished the task (sequence status equal to 4, for the first and second anatomical parts), with 84 students (73.68%) correctly putting back into the virtual cadaver both anatomical parts associated with their user colour. Of these 84 who completely finished the task, there were 39 (46.40%) who had none in red (the red hand frequency was 0).

b) Survey about the metaverse experience:

Cronbach's alpha of 0.92 [0.89; 0.95] was used to measure the validity of the questionnaire. Table 5 shows the Cronbach's alpha values for each of the subscales in the survey, with confidence intervals of 95%.

Using Box Plot diagrams, Fig. 2 shows the mean values of each of the subscales coded from 0 to 4. Note that in the questions of the subscale called "Emotional", the lowest values on the scale are the ones that assign a better rating. The isolated black dots are single values that are obtained from the statistical processing of the data.

As for the questions with a binary answer (Yes/No), in the "capturing attention" section, 77 (97.50%) of the students agree that the visual quality of the virtual scenario facilitated their attention in the metaverse. Regarding whether the use of the VR controls/controllers distracted them from performing the tasks assigned in the VR applications, 74 (93.75%) answered that they were not affected by the use of these devices to perform the tasks. A total of 72 students (91.10%) students agreed that the visual quality of the scenario facilitated their attention and, moreover, they did not feel affected by the use of the controls/controllers.

Table 5 Cronbach's alpha values for each subscale in the survey

Subscales	Cronbach's Alpha	Nº of items	IC95%.low	IC95%.upper
Presence	0.84	6	0.78	0.90
Immersion	0.78	4	0.68	0.85
Concentration	0.82	10	0.76	0.87
Handling the environment	0.80	3	0.60	0.91
Emotional	0.86	10	0.74	0.91
Usability	0.61	3	0.35	0.80
Technological enthusiasm	0.61	4	0.45	0.73
Assessment	0.77	5	0.63	0.86

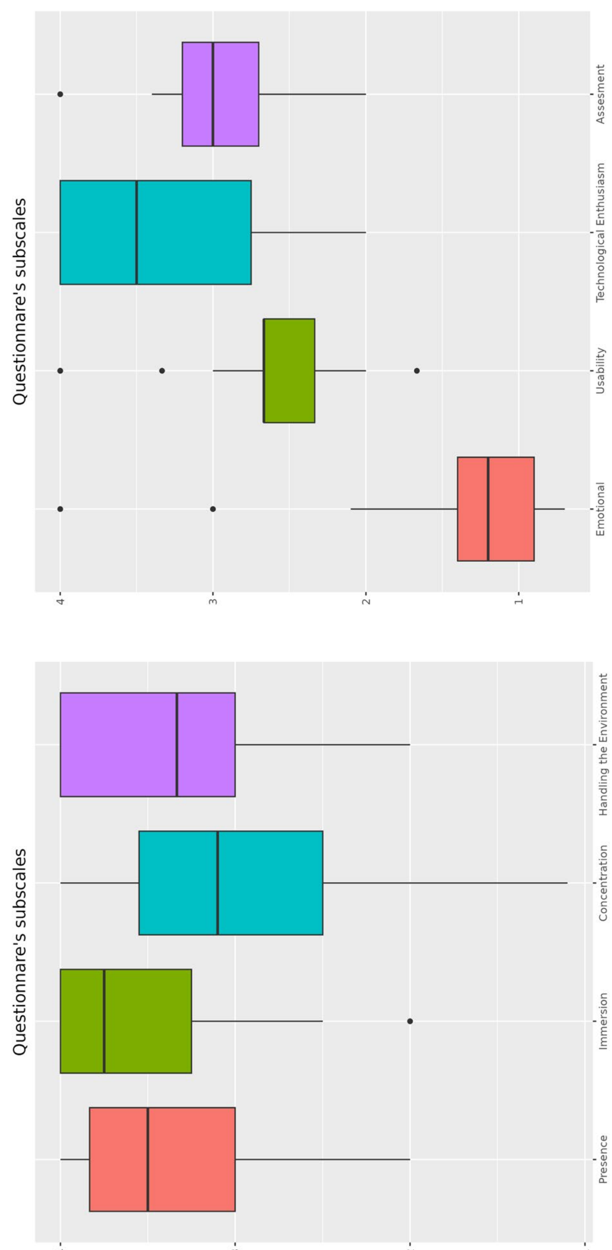

Fig. 2 Box plot of the mean values of the different subscales. Note that the score values are coded from 0 to 4 (see questionnaire Additional file 2 document) and that in the "emotional" block the lowest score gave the best evaluation

Table 6 shows the percentages of students who reply “no” to questions asked in the “adverse effects” section. A total of 48 students (60.70%) answered “no” to all the questions in this section.

Finally, 3 questions were asked about the “familiarity” with the immersive VR technology. In them, 63.30% said they had not had any previous experience with an immersive virtual environment. Moreover, 98.70% stated that they were not regular users of this type of technology. And 97.50% do not have this type of device.

4 Discussion

This paper proposes using the metaverse as a teaching resource in health sciences, and specifically in medicine. The purpose of this paper is to find out whether this resource, as such, is useful for educating students and to see whether it can be used as an additional complementary tool for training doctors. The capacity of the technology not only allows access to scarce or non-existent resources (e.g. the cadaver), but it also allows for objective measurements of the actions performed by students in the metaverse, which makes it a very useful assessment tool.

Moreover, the metaverse is compatible with the use of other types of teaching, being complementary to the physical resource that it models (e.g. the cadaver).

From our results, it can be deduced that, following the implementation features that we propose in this paper, the times for handling, identification, positioning and collaborative interaction within the metaverse (Tables 3 and 4) are in the order of seconds, and the ease of positioning, with distances travelled in the scenario within the metaverse are in the order of centimetres. There is an expected difference between the students who, without any prior information or instructions, are first to use the environment within the metaverse and the rest of the students participating in the experience in each group’s practical session.

However, this difference is very small in the case of positioning in the metaverse (see Table 3) and is reduced to practically half (see the times in Table 4) in the interaction activities within the metaverse.

These results indicate to us that the adaptation of technology through the features proposed in our paper is effective and minimizes the adaptation curve to the use of technology in the proposed metaverse scenario. That is, technology is not a barrier that prevents students from positioning themselves or performing activities within the metaverse and, therefore, it does not influence the teaching objective that can be pursued in medicine.

Table 6 Percentage of students who have no adverse effects

Issues	Number of Students Answering NO (%)
I felt sick while I was using the VR application	68 (86.10%)
I suffered a headache while I was using the VR application	75 (94.90%)
I suffered from eye strain while I was using the VR application	66 (83.50%)
I found I was sweating more than normal while I was using the VR application	63 (79.70%)
I suffered from vertigo while I was using the VR application	77 (97.50%)

Moreover, this is reinforced by the results (Fig. 2 and Table 6) obtained through the questionnaire attached to this article as an Additional file 2, where the responses are highly positive in terms of the use of technology itself. The adverse effects are anecdotal, which also supports our argument regarding the medical students' "familiarity" with this type of technology and that their interest in it is imperceptible. In other words, they are not especially enthusiastic about the technology as such, and yet our experience does not cause them any obstacles that would prevent them using it within the context of medical education. This is a line of research that, although not contemplated in this paper, is raised in the next section of the article as future work with actual clinical subjects. If the technology does not limit or influence the teaching objective to be achieved in the metaverse, it may help in the objective assessment of the academic content.

This conclusion is also backed up by the frequency results, the change in colour of the virtual hand (red, yellow and green), shown in Table 5. As can be seen, there is no statistical significance between the students who enter the experience first and the rest, which means that their prior knowledge of anatomy (remember that the colour of the hand indicated proximity to the anatomical position of the handled parts) is not being adulterated by the handling and use of technology. Furthermore, if we look at the results of the "status of the sequence" parameter in Table 4, this idea is reinforced, as the students who knew a lot about anatomy could, having been selected at random, be included in the initial users (the first ones) or the rest of the whole group.

On the other hand, if we consider the group of students who, according to the "status of the sequence" parameter (Table 4), completely finished the task, for both anatomical parts proposed to them, and the frequency of red hands is null, this will give us an idea of the number of students with a better mastery of anatomy. Moreover, as the name of each user is recorded in each application use session, these students could be identified. This opens the door for us to a feature that is also included in our design proposal, which is the measurement of objective assessments of medical knowledge.

In the questionnaire, shown in the Additional file 2 to this article, we can see several sections related to the perception the medical students have of their experience in the metaverse. From Table 5 it can be concluded, by means of Cronbach's alpha values, that the results collected are consistent and only in the case of the "usability" and "technological enthusiasm" sections is the value in the lower, albeit valid, ranges of consistency. If we look at the questions asked in these sections in particular, a redundancy can be seen in questions 1 and 3 in the "usability" section and in 2 and 3 in the "technological enthusiasm" section. So, although the Cronbach's alpha value validates both sections of the questionnaire, this would improve if we were to eliminate this redundancy in the questioning and, perhaps, add some more questions.

The results in Fig. 2 show a very good rating in all the experience sections presented, with a very positive assessment in the "concentration" Sect. (53.20% with the highest score in the subscale and 36.70% with the second highest) that the use of this type of experience allows us to learn academic health content. This confirms our initial premise that the multi-user IVR technology implemented in the metaverse scenario, adapted to match the student profile we are dealing with, as we have specified in this paper, adds value to the teaching and does not represent a barrier for medical students that distracts them from the academic content itself. In fact, in all the questions regarding the use and handling of the VR tools used, which would measure the naturalization characteristic that we defined in previous sections, it is evaluated with a high score. Similar results were found in reference to the identification and positioning.

At all times during the experiences, the teachers maintained perfect control of the metaverse area and carried out the practical session just like any other within the dynamics of the academic course. This points positively to the control, measurement and collaboration proposed as characteristics of this type of environment in the medical field.

As for the "adverse effects", Table 6 shows that the majority of medical students showed that a high percentage of them were not affected by them and, given the intensity of those who responded affirmatively, this was anecdotal for each adverse effect raised. Once again, the results indicate that the fact that we proposed a user experience designed for medical education has positive results in this aspect too.

5 Conclusions and next steps

In recent scientific literature, the metaverse has been presented as an amazing educational tool in health sciences. It offers the possibility of interactive learning contents, immersive navigation in clinical synthetic scenarios, real time collaboration among students, simulation of any clinical event and bringing the patient closer to the students. Although it is an ongoing idea in health sciences, encouraging results have been reached.

However, in the literature, we have found that the authors do not comment on how their health sciences students handle the technology, how long it took them to prepare the experiences in the classroom and how many times they had problems because the students did not get used to handling the immersive technology. In our experience, when one of these immersive applications in the metaverse is used in medicine, there are many practical problems that emerge in the classroom. Most of them are due to the technical limitations of the medical students to handle the technology (head-mounted displays, hands controllers, interaction with other students, spatial location in a virtual scene, etc.) that results in spending much of the learning time adapting themselves to manage and use the technology itself, and not in practising the medical academic content.

In this paper, we address this problem and we propose a new way for designing, implementing and using the technology in the metaverse as a teaching resource for medical education. Our work offers to other researchers, teachers and developers the guidelines and features that their immersive applications in the metaverse could include in order to minimize the effect of the use of this type of high profile technology in the health sciences learning process.

To this end, we propose to adapt the multi-user IVR technology, following our proposal of basic characteristics (naturalization, positioning, identification, measurement, control and collaboration), so that a metaverse environment is effective in medical education and does not pose a barrier to learning.

The results obtained, after carrying out several experiments described in this work, with sixth-year medical students, indicate that metaverse environments, designed with certain guidelines and features proposed, can be used effectively with medical students to catalyze, improve, complement, increase and promote student learning. Moreover, given the capacity offered by technology, it would allow the teacher and students to be measured, guided and helped, enabling objective evaluations of the contents received to be obtained.

In addition, the students' perception, apart from the usually positive view of this type of application given the wow effect of technology, indicates that the environment is not influencing their academic interaction and technology becomes a vehicle that guides them to carry out a series of teaching contents. They do not see the technology as a barrier that hinders their access to medical knowledge, due to the potential complexity of the use of this technology.

However, although our work is contributing to the state-of-the-art, is addressing a less explored aspect of the metaverse for education in medicine and proposes a guidelines and features to use successfully an immersive application for learning medicine, it would be more accuracy if we had had a higher sample of medical students and from several courses in the medical degree. Also, it could be interesting, and we are working on this line, to have a comparison between using a medical learning application in the metaverse and the classical methodology using cadavers.

Along these lines, taking advantage of the capacity that technology gives us and the dissection scenario created in the metaverse, we are currently working on specific academic content for clinical subjects in the medical degree. More specifically, on head, thorax and abdominal dissection procedures. In our next papers, once it has been proven that the technology does not limit the medical students' learning, we shall present our results using this environment to assess the students. We are planning to design a randomized study to evaluate the contribution of the metaverse in this aspect; a synthetic space where the students can learn and the teachers can assess the clinical activities of each student.

Similarly, we are working on extending the use of the metaverse for learning clinical techniques or procedures, with the idea of being able to apply this type of methodology with first or second year residents. Specifically, we are working on techniques for puncture with tactile sensation.

In summary, we are convinced that the concept of the metaverse has great potential for use in medical education and it will change the way of learning medicine. One of the clues for learning medicine is to be close to patients and this technology can create virtual patients, modelled with several characteristics, for training students and residents. Our experience with the use of technology for medical education made us intuitively aware of this but the experiments carried out with this work show us that, if we follow the recommendations indicated, to design and implement the experiences, the metaverse can markedly change medical education and facilitate medical students' access to patients without an actual patient being present, catalyzing their subsequent incorporation into residency programmes and optimizing the clinical practice processes in medical schools. Of course, all this is an optional resource and, if desired, complementary to those currently used to teach medicine.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions
All the authors have contributed to develop this research paper. The first author (MARF) has been the leader and promoter of this research work, conceptioning a designing the idea of this research, and cooperating with the fourth author (CNHF) for doing the statistical design and analysis. Second (JJR) and third (AM) authors coded and implemented the software application according to the directives of the first author (MARF) and they studied the capabilities of the technology in the framework of our research. The fifth (JRA) and sixth (MM) authors have been working with the first author (MARF) for many years and they have contributed in the conception of this work in the context of the projects mentioned at the acknowledgments section and the teaching experiences carried out at our University's Medical School. This lets us develop experiments and research in a practical studying environment. Of course, all the authors have contributed in this research paper following the ICMJE recommendations: Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; drafting the work or reviewing it critically for important intellectual content; final approval of the version to be published; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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