Learning Anatomy through Shared Virtual Reality

José Juan Reyes-Cabrera[1], José Miguel Santana-Núñez[1], Agustín Trujillo-Pino[1], Manuel Maynar[2] and Miguel Angel Rodriguez-Florido[2]

[1]Imaging Technology Center (CTIM), University of Las Palmas de Gran Canaria, Spain
[2]Chair of Medical Technology (CTM), University of Las Palmas de Gran Canaria, Spain

Abstract

Virtual reality (VR) is a powerful tool for educational purposes. In this work, we present a VR application for learning anatomy, focusing on the cardiac system in this early stage. Our application proposes that medical students put together parts of the human anatomy and check their performance at this task. The system also features a shared-VR mode, in which two or more students can work together, or can even be joined by a medical professor. In this paper, we briefly describe our new approach to medicine teaching and show promising results for further development. In addition, we have tested our application with students at the Medical School, and we are confident that this application will improve their training.

CCS Concepts
• Applied computing → Interactive learning environments; • Human-centered computing → Visualization;

1. Introduction

This work presents the early stages of the NEPO [dTec19](*"no podemos enseñar para olvidar", "we can not teach to forget"*). The main idea of this project is to use models of the human anatomy as an index and workflow for medical students, and later, in their residency and professional life. This project is part of a medical education program based on the study of anatomy, which serves as a scaffold for further knowledge. The focus of this project has been the cardiac system. In addition, other anatomical systems compatible with this application have been tested (such as vertebrae and ribs).

Virtual reality (VR) technology has achieved a high degree of visual fidelity and performance, enabling users to have different types of new immersive experiences using lightweight VR-headsets. In these environments, users can live experiences more immersive than using just a screen with a keyboard or mouse. It offers many benefits such as more intuitive interactions, an easier inspection of 3D models, and, in our use-case, an improved overall perspective of the whole body and the connections between different elements.

In this paper, we use VR to allow medical students to interconnect parts of the cardiac system to improve their learning experience. This type of immersive experience is a new option for learning anatomy, and in addition to a collaborative mode, using the application can be a supplement to some classes at our University in the future. In this environment, students and teachers can interact with each other. The system checks whether the student is doing his task well or not, giving positive and negative feedback, and driving him interactively to complete the task correctly.

2. Related work

In recent years, several studies have been carried out about the use of VR in medical education. Saalfeld et al. [SSD*20] propose a one-on-one tutoring system for anatomy education, focusing on the skull, using a shared VR scene. Falah et al. [FCK*14] have developed a real-time 3D representation of the heart in an interactive VR environment that provides self-directed learning and assessment tools, using stereo 3D glasses. Maresky et al. [MOA*19] have tested the viability and the assess efficacy of VR modes in commercial software for the purpose of teaching cardiac anatomy. Some education experiments have been carried out in several universities, to teach anatomy using VR technology, instead of reading traditional texts or interacting with a 3D module on a flat computer screen [ZKS*20], [ERM19], [IMP17].

Nowadays, there are many applications oriented to learn medicine, but a few focus on VR. Some commercial examples are 3D Organon VR Anatomy [Org16] and Educate and Explore Human Anatomy [Hol22]. In [PS18], Preim and Saalfeld present a large survey of virtual human anatomy education systems.

Regarding the use of collaborative learning, several studies have carried out this type of learning, such as that of the University of Ankara[AM10]. This study has evaluated a comparison between traditional learning and cooperative learning. The authors have compared the results using these techniques throughout classes. As it shows, the evaluations improve in the activities that are not carried out individually. In addition, other research attributes this type of teaching to some improvements in student motivation[FSFS17]. More recently, Chheang et al. [CSJ*21] have presented the use of a collaborative VR environment for liver surgery planning.
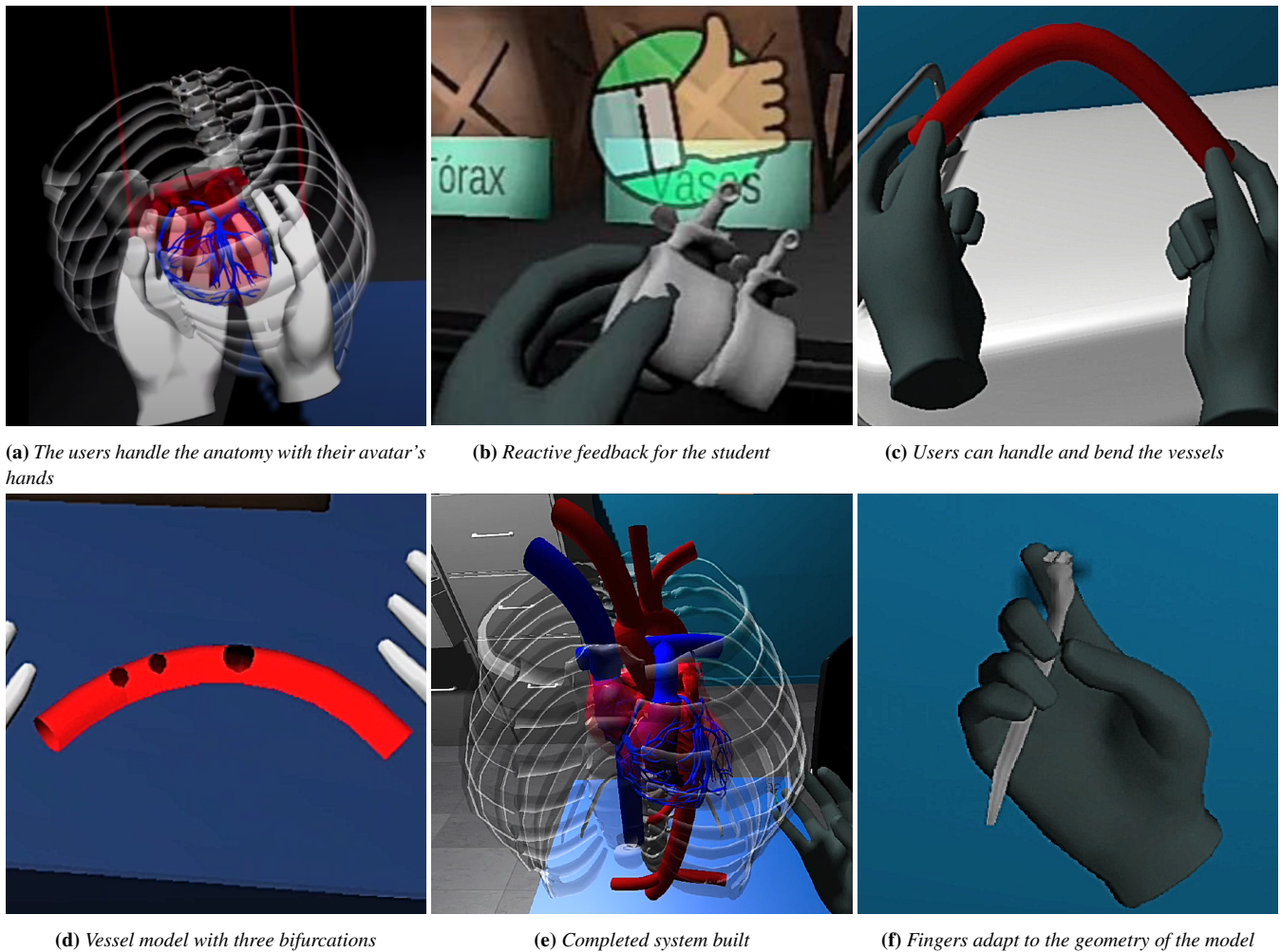
(a) *The users handle the anatomy with their avatar's hands*

(b) *Reactive feedback for the student*

(c) *Users can handle and bend the vessels*

(d) *Vessel model with three bifurcations*

(e) *Completed system built*

(f) *Fingers adapt to the geometry of the model*

Figure 1: *System functionalities*

3. Materials and methods

Our system allows the students to learn while building their own anatomical model, piece by piece, using their own hands. Besides, it allows the teacher to give instructions, and evaluate the students at their tasks. Traditional learning techniques are based solely on the vision and memory of students. In our system, users can also use their hands, 3D vision, and coordination (see Figure 1a). As a more immersive and contextual experience, it improves learning and memorization.

For the first user experience with the headset, a tutorial has been created that explains step by step how to use the controllers, how to grab, bend and release pieces, how to connect them in the correct place, how to obtain information of each part, and how to assemble the entire system in its final place. In this way, getting used to the virtual environment is a prior objective before proceeding with the actual experience of learning anatomy.

The students can assemble and disassemble each of the pieces as many times as needed. This way, they can see what the whole anatomy looks like when all the pieces have been connected together, and learn how these elements are combined to form the complete anatomical system. A pre-built model is provided as a guide, so students can compare their results. When two pieces are in the correct relative position and rotation, there is an attractive force that fixes them in place, and a click sound indicates that the union was done correctly. Visual signals have been added to help the user through warnings when the pieces do not fit well with each other, or to confirm that the connection is right (see Figure 1b). The users can have different objectives during their sessions, such as following the guidance of a teacher or taking some time trying to build the system with other peers.

The chosen VR-Headset used for the development has been the *Oculus Quest 2*. Moreover, two different types of interaction controllers have been used: *Oculus Touch* Controllers and *Manus Prime X Haptic* gloves. We have developed the current application using the game engine *Unity* to implement the 3D visuals, interactions, and scenery. The 3D modelling software *Blender* was also used to model the anatomical pieces and their animations.

3.1. Anatomical elements

The initial focus of the application is on the vessels around the heart, although the entire human body may be added in the future. With this idea, different components were added to represent these regions (with great importance in the area of the aorta). Other non-interactive elements have also been added with the advice of anatomy experts. This way, the user can find an interaction between the vessels and these objects, or use them as a visual reference.

On the one hand, users can interact with all kind of elements, and even closely inspect any of them. On the other hand, students must look and learn how the items are connected to each other. The 3D models in the application were selected from different sources outside the project (such as sketchfab). Some of these models could be joined, fixing their relative position and rotation.

3.1.1. Circulatory system

In the early stage of the project, our focus is on the cardiac system centered around the heart. This application allows us to look at the heart beating, and also interact with its inner parts. Namely, these elements are atria, ventricles and valves (mitral, aortic, tricuspid and pulmonary). Furthermore, the thorax has been modelled as a reference frame to identify the position of other components.

The heart model is surrounded by some vessels like the superior vena cava. They can also be connected to different anchor points, such as with the heart, in a bifurcation, or to each other. The current version of the application represents the great vessels (superior vena cava, inferior vena cava, pulmonary artery and aorta) and four parts of the aorta (ascending aorta, aortic arch, descending thoracic aorta and abdominal aorta).

3.1.2. Vessel modelling

The 3D object that represents a vessel is not a static model, since vessels are bendable. Our application generates a specific mesh for each one of them, and allows different user-manipulation techniques to bend the shape in a realistic way. To represent vessel geometry, a Bezier curve expression is used. By implementing Equation 1, we allow the user to easily bend the ends of a vessel, so the curve remain centered (see Figure 1c).

$$P(t) = \sum_{i=0}^{n} \binom{n}{i} (1-t)^{n-i} t^i P_i \tag{1}$$

In this equation, we use control points P_i to generate the Bezier curve with four invisible control points (n=4), two of them at the ends of the vessel, and the other two in the middle of the initial position of the vessel. We do not need to add more points because each vessel piece consists only of one curve. Hence, the central curve of the vessel is formed by interpolating the parameter t between 0 and 1. At each central point the direction of the curve is computed, so a ring of perpendicular vertices can be laid out around them forming a cylindrical surface.

This algorithm should not be computationally intensive in order to recalculate it in real-time. In addition, we only compute this process when the vessel or a control point is moved. Once the vertices have been computed, the next step is to triangulate the mesh. In this process, the application creates all the triangles that represent the shape. This is only calculated when the dynamic mesh has been created.

Finally, many arteries and veins have bifurcations at some points, which is represented by two vessels that can be joined in that point with a particular direction. In these cases, additional central points are generated around the insertion point, and the vertices of the surface are ignored by the triangulation algorithm to represent the hole in the mesh. Thereby, shapes like the one shown in Figure 1d are formed.

3.1.3. Vessel assembling

The connections for objects with static meshes are simple. They can be attached to a specific anchor, relative to a parent object (i.e. the position of the pulmonary valve depends on the position of the right ventricle). In contrast with those, the mesh of a vessel changes when a connection is made. Blood vessels have different types of connections in our body. For example, the left atrium with the superior vena cava, or other connections in different parts of the aorta.

Two types of unions have been considered. On the one hand, when connecting with a static component or a bifurcation, the end of the vessel adapts its shape to the vertices that describe that connection. Moreover, when connecting two parts of the aorta, in order to represent a smooth transition between vessels, an additional control point near the joint point on the vessel is added. This spline avoids sharp connections.

The final system built by connecting all the anatomical parts of the scene is shown in Figure 1e. To achieve this state, the user must grab and place all the elements to learn their correct position. This process is intended to be simple and intuitive so that most users can interact naturally with the application.

3.2. Handling 3D models

A realistic and natural behaviour is essential for this type of application. For this reason, the virtual avatar features hand models that adapt to the grabbed object (see Figure 1f). This is possible thanks to a series of colliders, able to detect when the hands are touching an object. Unity's physics engine allows you to check if the hand is touching a part of the body (this works to grab and adapt to the objects). This allows the rotation and translation of objects in the virtual space (6 degrees of freedom), which enables the user to inspect them thoroughly. Moreover, for the vessels, technically, users don't interact with the model itself, rather, they can take one of the control points and move it. The position of the control points changes when the user grabs the two ends of the same vessel. In this case, the control points move following the hand movements. Besides, if the user only grabs one part of the vessel, every control point is moved at once (so the entire vessel moves and is not bent). And when the user drops them, the system checks if a connection was made.

As mentioned at the beginning of the section, we have implemented software drivers for different types of interactions. First of all, the *Oculus Touch* controller allows, using a button for the middle finger, to simulate the grip by closing and opening the hand.

This way is quite intuitive and simple to grab items. This grab motion has been simplified so that the hand can be animated by pressing a single button (animation interpolates between open and closed hand based on grab value).

Furthermore, the project supports the usage of Manus haptic gloves. The use of this technology aims to create behaviours that resemble reality. This is because the user sees his hands directly in the virtual scene, and can interact with it using hand gestures (without using buttons). An important advantage of this technology is the haptic feedback received due to certain vibrations in his fingers, which indicates whether a connection has been carried out correctly or not.

In addition, the latest versions of the *Oculus Quest* allow hand-tracking without any kind of controller. This makes possible to interact with the scene, as long as the own hands of the user are visible to the headset. In this way, the interaction is much more natural, although not always as precise.

Context menus have also been implemented for each of the hands, left and right. With the right one, there are specific actions to use with the element grabbed at that moment (return to their initial positions, name of the piece, etc). On the left one, there is a menu of general options (turn on the lights, activate the assistant mode, etc), which allows customizing the virtual scene.

4. Cooperative learning

The last features are complemented with the addition of a shared experience with other students. In this way, users are able to interact with their peers, trying to solve the task that the teacher provides. A multi-user mode has been implemented, enabling the users to share the learning process in a common virtual space (see Figure 2). This virtual space can also include other participants (professors, examiners or observers) that may want to participate in the learning experience. The activity could be supported with additional information, like pre-built models or embedded text and images.
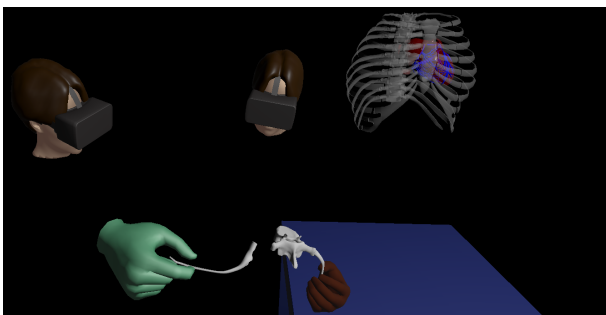

Figure 2: *Students working on a shared assignment*

The first steps implemented have been to carry out the correct synchronization of the position and rotation of the different elements of the scene, both the anatomical pieces and the head and hands of all the users with each other. Subsequently, the different events triggered by the users are taken into account, such as loading a new scene or making a connection between two elements.

The system has two different modes. The first one is the online

mode, where users are located in different physical places, and can communicate through voice synchronization. To implement this mode, a system based on *Photon networking* has been used, allowing the bidirectional real-time transfer of voice data recorded in the microphone of each headset. In addition, in this mode it is very important to be able to transfer an element that we have in our hands to a different user, so that the collaboration experience between the two be as realistic as possible. To be able to work with the same elements, there is only one user with the authority to handle a body part. If a person is going to grab an element, first it is necessary to ask the server for the authority of this object (so any movement of other clients will be dismissed).

The second mode is the local one, where people share the same physical room. In this case, the voice system is deactivated, since the participants can hear each other. In this case, it is preferred that the relative orientations of the participants in the real world match the virtual ones, so the voice sources are coherent. To achieve this, some marks were established on the real floor indicating the real position and orientation of the users when initializing the system.

A floating HTML web panel has also been created, which simulates a screen projection like those found in a classroom. In this way, a user acting as a teacher can show contextual information about a specific anatomical element, and talk to the students while showing images, text or even a video. The Figure 3 shows the room with the panel in the background with contextual information about an anatomical piece.
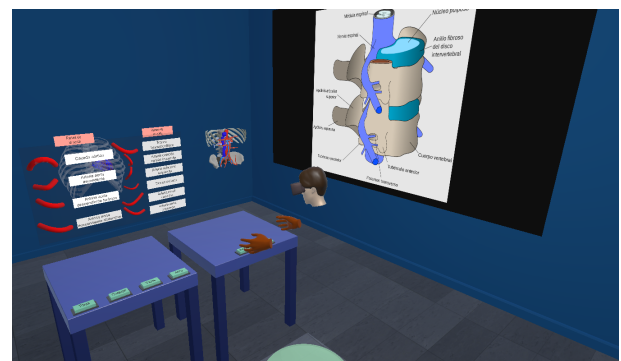

Figure 3: *Panel showing information about a vertebra*

There are some important differences between shared mode and individual mode. The virtual room should be more spacious and well illuminated, so we can see each other clearly and not get lost in the scene. Besides, each user must log into the system with their username and password. Once inside, each user's avatar has a characteristic colour to differentiate themselves, and also an individual profile and score for a possible evaluation by the teacher.

5. System evaluation

The system has been tested by some professors and former students with no VR experience. They have used the application with the *Oculus Touch* controller, although more experiments will be carried out in the future with the gloves and hand tracking options.

While using the application, they answered an informal questionnaire about the environment, their interaction and the task at hand.

The individual mode has been shown and tested by four medical professors. Everyone was asked to go through an initial tutorial on picking up and dropping items, using menus, etc., following the steps of the virtual assistant. This tutorial shows a visual signal each time the goals are achieved (see Figure 1b), which creates positive feedback for users to continue doing the class. Overall, all of them were quite satisfied with the system, even in its early prototype stage.

To test the collaborative mode, we enlisted the collaboration of two former medical degree students. To do the experiment, a more simplified scene was prepared. The virtual environment was gradually introduced to them until they got used to it. The goal was for them to learn how to use the controllers, orient themselves within the scene, pick up pieces and drop them again, etc. Once accustomed to the new environment, they were asked to follow the instructions to connect the different pieces correctly.

Their first impressions were positive. Both were able to identify how to move and interact with the scene after a brief explanation. These former students were curious about the different elements, and drew similarities between their fields of expertise and the elements of the application. Based on their own knowledge, and helping each other continually, they were able to identify the different parts and their possible connections (Figure 4 shows a screenshot taken during this experience). Both users deemed the system as a powerful tool for education. They also considered that if they had learned with this kind of tool previously, it might have been easier to acquire knowledge about the anatomical parts included. All participants show eager to repeat the experience and declared feeling very immersed in the virtual scene.
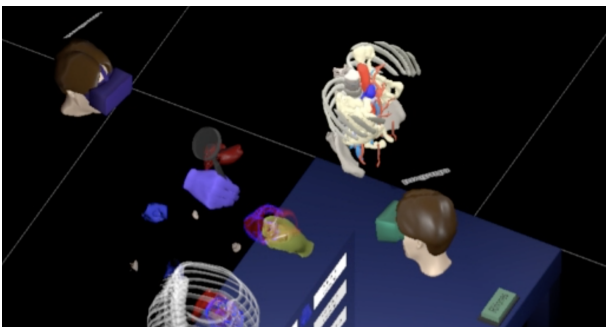

Figure 4: *Two students testing the collaborative mode*

6. Conclusions and future ideas

So far in this project, a VR application for anatomy teaching has been developed, focusing on some elements around the heart. This application implements an immersive way to study and comprehend human anatomy, using novel technologies and the immersive philosophy of the NEPO project.

Two working modes have been proposed. The individual mode allows to learn the anatomical elements of the circulatory system close to the heart and its connections, using a virtual assistant that guides the user. The collaborative mode allows two or more people to interact simultaneously to achieve the same goal.

Our team has focused on the interactions and the management of the different 3D anatomical models. The addition of new parts of the human body and other anatomical systems is a goal that will be considered in the near future. Lastly, our application will need to keep working with more expert validation and practical experiments with students. These two points will improve the features of the work presented in this paper.

7. Acknowledgements

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