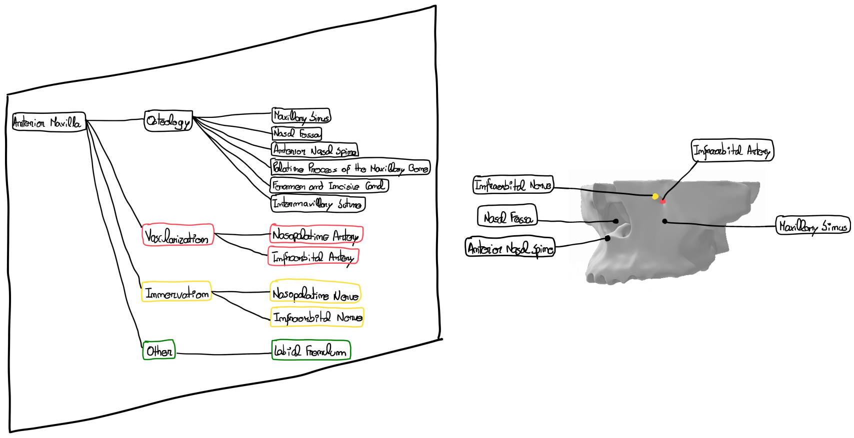

Anatomy Education Applied to Dental Surgery in Virtual Reality

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Thesis to obtain the Master of Science Degree in

Computer Science and Engineering

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Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Abstract

Dental anatomy is currently taught and studied using two methodologies: anatomical atlases and cadaveric material. The former is known to be quite laden with terms and concepts; the latter needs donations and unique storage conditions for its preservation. With the development of VR technology, these two paths can merge into one. Our work presents IMPLANTIGRAPH, a study and teaching tool that aims to explore the use of anatomical graphs and 3D labeling, containing anatomical information focused on Implantology, in an immersive environment, using virtual reality glasses and the respective controllers that allow the user to interact with any of the chosen information designs. We evaluated IMPLANTIGRAPH through anatomical questionnaires and subjective metrics with 30 Master's students in Dentistry and 3 anatomy teachers. The results showed that the use of anatomical graphs in an immersive environment, despite not being quite appealing, facilitates the process of learning and teaching anatomy applied to Implantology, thus benefiting the students' study and the teachers' teaching methodology, but only as a complementary tool to conventional methods. Hence, IMPLANTIGRAPH proved to be a promising tool for anatomy education applied to Implantology and a starting point for exploring the concept of anatomical graphs in virtual environments.

Keywords

Anatomy Education; Virtual Reality; Dental Implantology; Knowledge Representation.

Resumo

Anatomia dentária é correntemente ensinada e estudada usando duas metodologias: atlas anatómicos e material cadavérico. O primeiro é conhecido por ser bastante carregado em termos e conceitos; o segundo necessita de doações e condições únicas de armazenamento para a sua conservação. Com o desenvolvimento da tecnologia de realidade virtual, estas duas vertentes podem unir-se numa só. O nosso trabalho apresenta IMPLANTIGRAPH, uma ferramenta de estudo e ensino que visa explorar a utilização de grafos anatómicos e etiquetagem 3D, contendo informação anatómica focada em Implantologia, num ambiente imersivo, utilizando óculos de realidade virtual e os respetivos controladores que permitem ao utilizador interagir com qualquer um dos designs de informação escolhidos. Avaliamos a ferramenta IMPLANTIGRAPH através de questionários anatómicos e métricas subjetivas com 30 alunos de Mestrado em Medicina Dentária e 3 professores. Os resultados mostraram que o uso de grafos anatómicos num ambiente imersivo, apesar de esteticamente não ter sido apelativo, facilita o processo de aprendizagem e de ensino de anatomia aplicada à Implantologia, beneficiando assim o estudo dos alunos e a metodologia de ensino dos professores, mas apenas como ferramenta complementar aos métodos convencionais. IMPLANTIGRAPH mostrou-se, assim, uma ferramenta promissora para a educação de anatomia aplicada à Implantologia, e um ponto de partida para a exploração do conceito de grafos anatómicos em ambientes virtuais.

Palavras Chave

Ensino de Anatomia; Realidade Virtual; Implantologia Dentária; Representação de Conhecimento.

Contents

List of Figures

List of Tables

Acronyms

AAG Acyclic Anatomical Graph

CBCT Cone Beam Computed Tomography

HMD Head-Mounted Display

IPQ IGroup Presence Questionnaire

NASA-TLX NASA Task Load Index

SUS System Usability Scale

UI User Interface

VE Virtual Environment

VR Virtual Reality

Glossary

Kurtosis

Kurtosis is a measure of whether the data are heavy-tailed or light-tailed relative to a normal distribution [7] . . . . xiii, 49, 50

Skewness

Skewness is a measure of symmetry, or more precisely, the lack of symmetry of a distribution [7] xiii, 49, 50

Topographic Anatomy

Topographic Anatomy is an approach in studying anatomy wherein the body is studied based on regions and the relations of the structures contained in that region [8] 4

1

Introduction

Contents

The traditional methods for studying and teaching anatomy consist of the use of manuals with images, or real/plastic physical models. In recent years, new teaching methodologies have been tested, thanks to the advancement of the technological world. One of these options is an immersive environment, such as a Virtual Reality (VR) environment, as it provides us with infinite space, thus having immense potential to be explored as a new alternative to studying and teaching methods. Starting from this premise, this first chapter presents the motivation behind this work (Section 1.1), which research questions we intend to answer (Section 1.2), the hypotheses we will test (Section 1.3), the goals and contributions of our work (Section 1.4), as well as a short summary of the structure of this document (Section 1.5).

1.1 Motivation

Anatomy manuals and cadaverous materials are the key methods for studying and teaching anatomy. Commonly found in anatomical textbooks and flashcards, medical illustrations are populated with labels and arrows pointing to relevant landmarks [9–12]. Such visual and textual mapping is highly relevant when learning and teaching anatomy. However, it is very challenging to process the information (names, concepts, and relations) contained within such anatomical renderings due to a large amount of information, making it difficult for the student to memorize the information [1, 13]. Moreover, since conventional labeling only serves to pinpoint anatomical landmarks, the reader must perform the cognitive load to build the mind map, which connects related landmarks to each other [1, 14, 15].

As for the cadaverous material, despite the fact that it brings the advantage of spatial visualization and perception, it hides its high cost, continuous maintenance, appropriate storage conditions to avoid degradation, most-of-the-time-unrepeatable problem, and donations are quite rare. All of this makes the study of anatomy a great challenge for students [2, 9, 10, 16–18].

The textual information can be translated into knowledge representations (or knowledge maps) in the form of Acyclic Anatomical Graphs (AAGs), hence, creating an alternative method for learners to better retain the contents and concepts [15]. This method allows the building of mental models using ”general to particular” reasoning: starting with a main concept as the root of the map, it branches into several components, and these concepts can branch into even smaller concepts, and so forth. This generates a hierarchy that is easily readable, facilitating the perception of the topography of anatomical structures and their constituting elements [19]. In fact, this technique was widely studied by English author Tony Buzan, which he named *Mind Maps* [20]. According to Buzan, the use of mind maps can increase memory and facilitate the understanding of concepts and information, by using a visual map for a main idea that branches into related information pertaining to that main topic.

Several works and studies have explored the idea of using graphs as mental models or knowledge representations diagrams [15, 19, 21, 22]. However, these examples do not use AAGs, do not fully represent Buzan's technique, are not centered on dental implantology nor are fully dedicated to the study and teaching of anatomy in this area. Nonetheless, they demonstrate the power mental models have to facilitate understanding and retention.

With the increasing development of technologies, especially VR technologies, cadaverous material can be simulated in VR educational tools, which are more affordable, accessible, and immersive, turning the learning process more interesting and fashionable [16, 17, 23]. Several studies to understand the benefits and difficulties of using VR in anatomy have been developed, showcasing that the use of such technologies improves the anatomical learning effect on medical students and there has been an increase in adapting to digital modalities in anatomy education, therefore making this technology a great potential in the role of medical education in the near future [16, 24–26]. Focusing on dental anatomy, several studies to understand the benefits and difficulties of using VR in dental anatomy have also been performed, reaching the conclusion that dental students using VR technologies can learn motor skills more quickly compared to students using only phantom training [27], the use of VR technology is useful both in teaching as well as in the learning process [23, 28, 29], by giving students a better understanding of the subject being taught and a more effective knowledge transfer and retaining, both in short-term and long-term application [26, 30].

A variety of VR applications anatomy-related have been developed: some works explore general anatomy study [2, 17, 31]; other works are focused on dental medical procedures, however, they do not have a theoretical component [3, 32–34]. There is even one study that focuses on the reconstruction of dental cavities but uses Optical See-Through AR and not VR [25].

1.2 Research Questions

In this work, we want to evaluate the potential of anatomical graphs in immersive 3D environments, related to the learning and teaching of Topographic Anatomy applied to dental implantology, by adapting conventional teaching (labeling) to immersive environments complemented with graphs as mental maps of that same information. As such, the main research questions of this work are:

- RQ1 - Can knowledge representation as AAGs inside VR educational tools for oral surgery facilitate the learning and perception of anatomical structures and understanding of its topology relations?
- RQ2 - Can knowledge representation as AAGs inside VR educational tools benefit oral surgery education?
- RQ3 - Are AAGs inside VR educational tools a better approach to teach oral surgery, rather than current approaches such as visual textbooks?

1.3 Hypotheses

To help answer the former questions, we developed a VR prototype with different layouts representing dental anatomical concepts. We want to verify the following hypotheses:

- AAGs in VR environments help dental students to perceive mental models faster than current learning methods;
- AAGs in VR environments benefit the learning and teaching of dental surgical anatomy.

1.4 Goals and Contributions

In essence, the goals and contributions of our work are:

1. IMPLANTIGRAPH, a VR educational tool aimed to assist anatomy learning and teaching in dental surgery, focusing on the field of implantology. The design process brought together interviews with 2 dentistry teachers and 16 Master's students who have attended anatomy classes in the past, and co-design sessions with a dentist and dentistry teacher.
2. We report a comparative study between the use of the conventional training method applied to VR, and the use of AAGs together with the conventional layout, both implemented in IMPLANTIGRAPH. 30 students and 3 teachers were recruited to participate in the user study, where we measure the viability of the prototype through anatomical quizzes, system usability, workload measures, sense of presence, and user preferences.
3. Finally, we gathered more feedback through semi-structured interviews with all the participants regarding their experience with IMPLANTIGRAPH.

1.5 Document Outline

This document follows a specific structure that breaks down all our work in a simple and structured way. In chapter 2, we review the state of the art, analyzed in terms of the general use of Mind Maps or Graph-like diagrams and their application in the anatomy world, the use of VR technology in anatomy (and specifically in dental anatomy), we itemize literature limitations and gaps, and, from these, which ones our work will address to complement the work that has already been studied.

Then we move on to chapter 3, presenting our Requirements Elicitation, where we gathered the needs of our target users through Interview Sessions (with both teachers and dental students) and Co-Design Sessions (with medical professionals).

In the next chapter, chapter 4, we introduce our approach, IMPLANTIGRAPH, a VR tool to evaluate the power of using AAGs inside a VR environment.We start by explaining how we were able to obtain our jaw's 3D Models, followed by the hardware and software Apparatus involved in our entire process. Then we present the Architecture of the prototype and all the possible Interactions it allows users to perform.

Following is Chapter 5, revealing all the details of our User Study to evaluate our approach. Starts by presenting our participants, all the apparatus needed for the study sessions, and the variables of the study. Then, details the tasks we asked our participants to perform, the procedure of the sessions, the methods we used of assessing subjective measures, and how we statistically analyzed all data. All the results, statistical analysis, and discussion can be found in chapter 6.

Finally, we conclude the document by summarizing the main conclusions we draw from our study and what can be developed in future works in chapter 7.

2

Related Work

Contents

Chapter 2 provides examples of works that served as inspiration for our development: Section 2.1 explores the use of graph-like diagrams as a form of knowledge representation, while Section 2.2 explores this content specifically in the world of anatomy; Section 2.3 presents some VR applications dedicated to general anatomy, while Section 2.4 explores deeper into the world of dental anatomy; last but not least, Section 2.5 summarizes the literature limitations and gaps, and, from these, which ones our work addresses, and also how and why we divided this chapter into the specifics sections you will read bellow.

2.1 Mind Maps / Graphs

Daeijavad et al. [35] questioned how to display and organize 3D data information in multiple views inside an immersive environment, especially when the information might have connections in between, so they developed a taxonomy for multiple layouts inside this immersive environment by creating several layouts on a 3D space considering four design aspects: dimension, curvature, aspect ratio, and orientation. Although they did not test complex information, they conclude that the more data, the more difficult is to design the layouts. From this work, we followed a guideline on how to present and place a panel of static information in the user's Content Zone that can be tilted or rotated by the user.

Wen et al. [36] ask the same question because normally multiple display views of large amounts of data are normally presented on 2D visualization displays. They explored the design space of multiple-view representations in immersive environments by examining their effects on situated analytics. To do so, they divided situated analytics into perspectives of *situatedness* (spatial relationship between visual representations and physical referents) and *analytics* (data analysis, such as filtering), and explored different designs to achieve the best of both worlds (high situatedness and effective analytics) in an automatic layout adaptation prototype developed by the team. The resulting layouts facilitate the users on completing several tasks; however, they only considered spatial situatedness (other perspectives, like time, were not considered), and due to the limited FOV in their HDM they could only test up to six views; moreover, all views tested were static and had a fixed size. From here, we also followed a guideline on how to present and place the floating tags surrounding the 3D models.

Sun et al. [37] also explored design considerations to display cross-view data with multiple views. Based on data relationship characterization (schema, structure, weight, and size) and data relationships across multiple views (between visual elements, between views, and between visual elements and views), the authors made a series of considerations regarding context usage based on those values. In our case, considering that the structure and the size are the most relevant aspects, the best visual context usage is *space for visual elements*, allowing us to explore the 3D space VR can offer us.

The use of mind maps as knowledge representation in VR was explored by Flotyński et al. [22]. VR training is especially relevant in activities that are potentially dangerous or require advanced skills. However, training scenarios don't usually explore knowledge representation, making it hard for users without a programming background to create or modify their training systems. For that reason, the authors developed a framework to create semantic virtual training scenarios for electrical operators on high-voltage installations, where activities, mistakes, and equipment are represented using domain knowledge that the users understand. The results were very positive from non-technical users, facilitating the creation or modification of already-existing scenarios intuitively. The authors left for future work the extension of this framework to a "gamified mode" (an evaluation mode with scores), and extend the ontology with concepts of parallel activities for multi-user training, giving the example of firefighting.

As said in chapter 1, English author Tony Buzan widely studied the idea of graphs as a mind map. Based on his work, Figure 2.1 presents an example of a hand-drawn mind map of the Posterior Mandible.

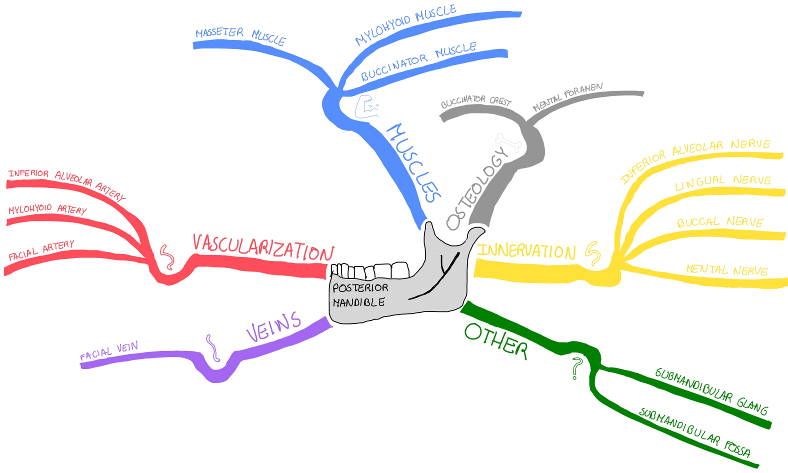


Figure 2.1: Example of a hand-drawn mind map, based on Tony Buzan's, within the context of this work.

2.2 Mind Maps / Graphs in Anatomy

The idea of using mind maps or graphs as knowledge representation in anatomy has been explored for a couple of years. One of the first digital knowledge representations concerning anatomy was developed by Schubert et al. [38] in the form of a semantic net. Combining computer graphics (which provides powerful tools for data visualization, especially concerning volume) with knowledge engineering (provides sophisticated data structures), a new approach for knowledge representation using a volume-based data structure was developed, using three-dimensional visualization of anatomical concepts, allowing for several domains of representations: *part of relations* - an object is part of a system, *is a relations* - groups anatomical objects to its categories, and *supplied by relations* - characterizes the blood supply for an object.

Another similar concept for knowledge representation was used in the Digital Anatomist Program, an anatomically based software framework for organizing, analyzing, visualizing, and utilizing biomedical information, developed by Brinkley et al. [39].

More recent work demonstrates that this technique continues to be explored today. Anatomical variations and their occurrence frequencies and similarities are essential to correctly diagnose and safely treat patients. Currently, this information is presented on textual information, requiring the reader to construct a mental model, which becomes more challenging with more complexity. Smit et al. [1] developed VarVis, an interactive visualization application for anatomical variations to compare and explore variations on branching structures interactively at a local or global level. VarVis uses illustrations of variations to create graphs that define nodes for every endpoint and junction, and encodes connectivity by placing edges between the nodes, resulting in a cycle-free tree. Every node has labels that indicate the endpoints they feed to facilitate the matching process. The application was received positively by the users, helping to provide insights into topological variations and identify similarities. Figure 2.2 shows the VarVis interface, where we can see a graph in the top right corner.

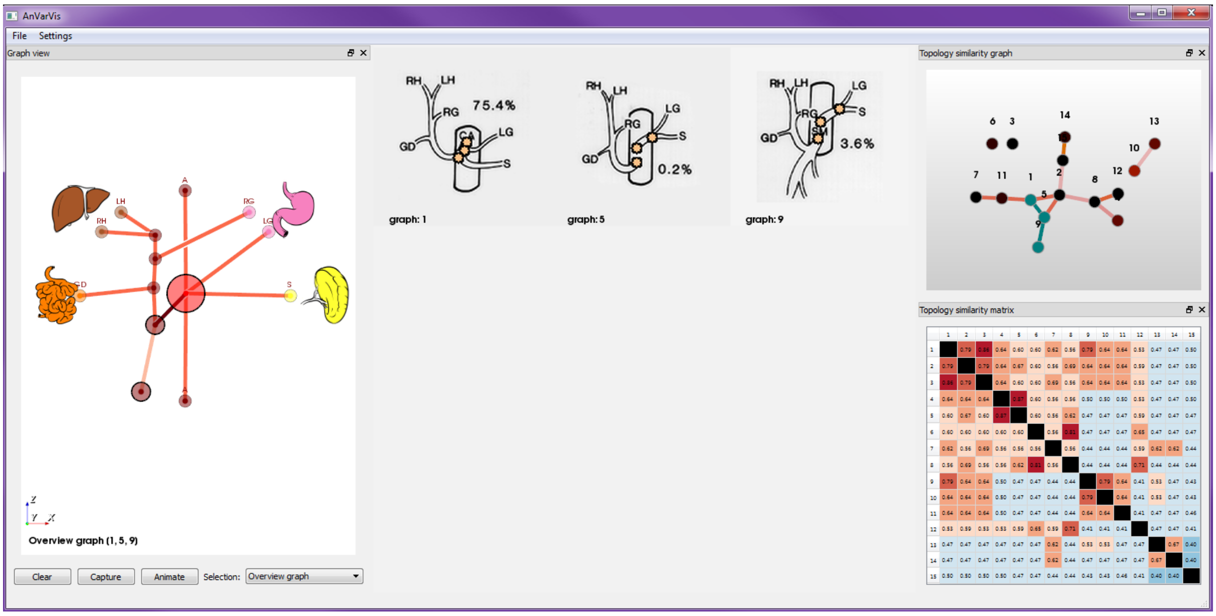


Figure 2.2: A look at the VarVis interface: left pane shows the entire summary tree; the center pane presents the selected variations, which are highlighted in green in the top right pane [1].

2.3 VR in Anatomy

VR is useful for medical education: not only increases physical interaction but aids in information recall. For anatomy courses, a VR educational tool could be effective in learning and retaining anatomy knowledge besides textbooks. Therefore, Gloy et al. [2] developed an immersive and interactive 3D anatomy atlas to freely explore anatomy structures of the human body through virtual dissection, to fasten the acquisition of new information, and improve the retention of knowledge. The atlas uses a Head-Mounted Display (HMD) and controllers to interact with the environment by grabbing surgery tools or changing features like transparency. Also, when the user grabs an organ, information about that organ appears to the side. The atlas was tested with non-medical students and results proved that, by using VR, acquiring unknown information is faster and memory retention is improved. Figure 2.3 presents a user, during the user testing, interacting with the immersive 3D anatomy atlas.

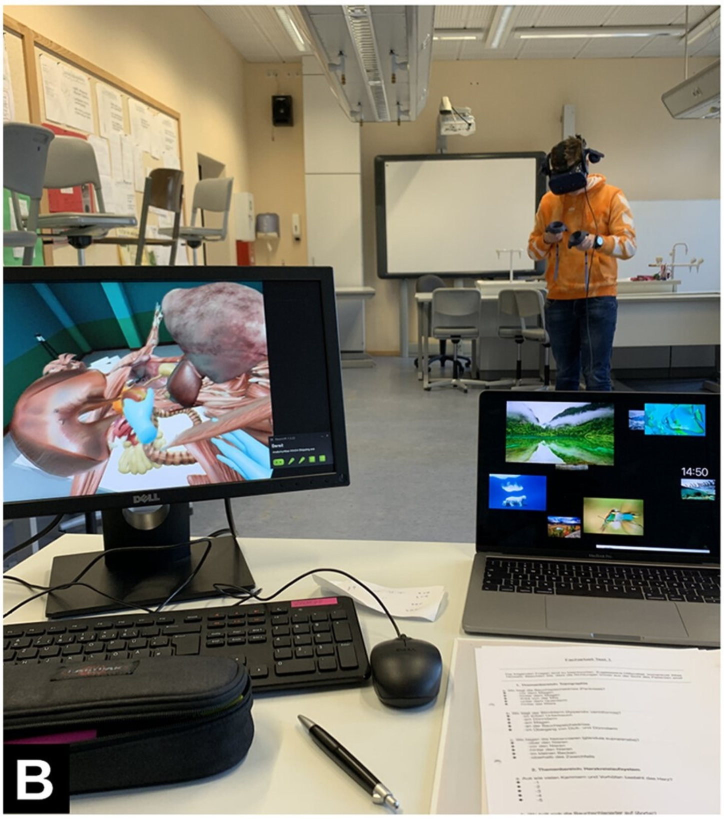


Figure 2.3: A student, wearing a head-mounted display, interacting with the 3D anatomy atlas, that can be seen in the monitor on the left [2].

Another work regarding VR in anatomy was tested by Yamazaki et at. [18]. In this case, VR was explored as a substitute to train surgical procedures on bones, since 2D computer screens and cadaver bone drilling (the current education methods) offer limited resources. Yamazaki created a 3D model of temporal bones to be used on a HMD to demonstrate the application of VR in pre-operative planning and usage through the intraoperative reference of a patient model. CT images were used to create the 3D models, and a session to first manipulate the bone and second to fill a questionnaire to assess its validity was conducted. Most participants were favorable about using the VR model, considering it superior to a 2D screen for both the training procedure as well as using it as an education tool.

2.4 VR in Dental Anatomy

VR is being explored specifically in dental anatomy. Grandhi et al. [32] developed a VR-based system to train dental anesthesia by giving users visual, auditory, and haptic feedback. As known, dental anesthesia is a challenging clinical procedure to master, so every dentist must be competent in doing it, and training on a plastic manikin head does not provide reliable feedback. The tool consists of a 3D head model from a real patient, virtual hands to interact with the environment, a control pad to perform real physical adjustments (e.g., inclination of the dental chair), sound and haptic feedback, two modes of usage (Practice and Assessment) and error counting. A user study was conducted, revealing the tool to be useful when integrated into the pre-clinical curriculum. For future work, the authors stated multi-point haptic feedback and multi-user ability.

Takano et al. [33] explored the training of drilling teeth because not only training in plastic teeth models can be expensive and limited within hospitals and universities, but consistent training deteriorates the materials. Therefore, a VR tooth drill training simulator was developed, allowing students to repeatedly perform drilling techniques. Using a HMD, controllers, a stylus, a 3D-printed tooth, and a smartphone, users can drill the model by pushing a button on the controller that starts vibrating once they touch the surface of the 3D model; inside the headset, users can see the model change its shape.

Another challenge for dental students is to master the procedure of dental implants. The shortage of this training affects their performance, resulting in a lack of precision and inadequate implant placement. Zorzal et al. [3] developed IMMPLANT, a VR educational tool to assist implant placement learning, helping students by manipulating 3D dental models with their dominant hand while operating a touchscreen device. By using a HMD, a small hand-tracking device, and a smartphone, the dominant hand is tracked to manipulate the 3D model and the virtual implant, while the non-dominant hand holds the smartphone that works as a controller. The system was tested and the results showed that the application constitutes a versatile and complementary tool to assist implant placement learning by promoting immersive visualization and spatial manipulation of 3D dental anatomy. Figure 2.4 shows a dental professional using IMMPLANT, by interacting with the 3D model using her dominant hand.

Zhang et al. [34] also studied the latter procedure by testing the effectiveness of a virtual simulation application to train dental implants on a pig's jaw. Users were divided into several groups that either operated on a real jaw, a virtual jaw, or both, and were later tested on a theoretical test. The results indicated that the combination of using a real jaw model with a virtual jaw model was effective in improving the user's scores on both the theoretical examination as well as mastering the implant procedure, proving VR technology to be a very reliable tool for students' training. The biggest limitation of this work was the use of a pig's jaw because although being similar to the human jaw, it is not the most suitable model to train real clinical cases.

Figure 2.4: A dental professional using IMMPLANT [3].

2.5 Limitations and Gaps

In the previous sections, we analyzed several studies regarding the use of graph-like diagrams, and VR in the world of anatomy (Table 2.1). During the analysis, we gathered some limitations and literature gaps that we mention below. In the end, we present which of these cases our work will address so we can add some contribution to what has already been studied.

	Interaction Paradigms				**Themes**				
	VR	**2D Graphs**	**3D Graphs**	**3D Models**	**Study**	**Education**	**Anatomy**	**Dental Education**	**Implantology**
[35]	X		X		X				
[36]	X	X			X				
[37]		X			X				
[22]	X	X			X				
[20]		X							
[38]			X	X	X		X		
[39]		X			X		X		
[1]		X			X	X	X		
[2]	X			X	X	X	X		
[18]	X			X	X	X	X		
[32]	X			X	X	X		X	
[33]	X			X		X		X	
[3]	X			X	X	X		X	X
[34]	X			X	X	X		X	X

Table 2.1: Classification of State-Of-The-Art Articles and Studies.

Regarding mind maps and graphs, Daeijavad et al. [35] do not test the design choices for layout performance on concrete examples; the system of Wen et al. [36] do not let users select views of interest or move the information, and the views are always static with a fixed size; Sun et al. [37] assumes data relationship as only relational data, knowing that not all data is relational or even discrete, and do not consider multiple views in a 3D or immersive environment; they also did not perform user studies to evaluate the design layouts; the system of Flotynski et al. [22] does not support collaborative creation by distribution users and multi-user training, and does not have a ”verification mode”, like a gamified feature with scores; Brinkley et al. [39] referred how time-consuming it is to segment CT medical images and lacks anatomical concepts; at last, the work of Smit et al. [1] lacks a larger study with medical students, since they only tested three participants.

Regarding the VR domain, Gloy et al. [2] referred that the questions used in the study were specifically created for the study ("a perfect fit"), and lacked a comparison between the VR application with other ways of learning anatomy; the system of Yamazaki et al. [18] does not offer real-time feedback on their application; the work of Grandhi et al. [32] does not have multi-point haptic feedback integration, no multi-user ability, and they did not perform a pilot test of the system; Zorzal et al. [3] warns that wearing a VR headset can force the users to continuously change their posture, therefore affecting their performance, and do not evaluate cognitive load; finally, Zhang et al. [34] concludes that although a pig's jaw has similarities to the human jaw, it is not the most suitable model to train.

From the previous limitations and gaps, our work addresses some of them, while others were already thought of as future work. Our system is divided into four activities, with each activity having its own content that is shown on two different layouts; therefore, we test the same content on different layouts per activity, the size of the layouts is not fixed (some activities have more concepts than others), and both layouts are movable in space (not static). Both layouts are tested on a 3D immersive environment with a generous number of medical students and teachers as participants. Our system was designed to be used while sitting down, therefore there is no need for rapid or prolonged movements that force participants to change their posture. At last, we use patient-specific models of human jaws. A gamified feature with scores, implementation of CT image segmentation to have different jaw models, and expanding the number of anatomic concepts and details were thought of as future work.

3

Requirements Elicitation

Contents

The present chapter reveals the Requirements Elicitation process, where we interviewed target users and gathered information about their needs and requirements. More precisely, Section 3.1 explains why we needed to interview our users, Subsections 3.1.1 and 3.1.2 summarize the answers of the teachers and students, respectively, and Section 3.2 details the co-design sessions with medical personnel for gathering anatomical information and content, and the early study for the low and mid-fidelity prototypes.

3.1 Interview Sessions

We handled sessions over two days, with 2 anatomy teachers, ages 58 and 61, with Ph.D. Degrees in Dentistry, and 16 students currently taking a Master Degree in Dentistry, aged between 21 and 29. Both teachers were male, and regarding the students, 6 of them were male and 10 were female. All participants have Dentistry as academic background. They were asked to fill in an Informed Consent form and Demographic Profile form at first, in order to participate in semi-structured interviews. These interviews were very helpful in gathering user requirements and needs, on the one hand, about the teacher's methodology in lecturing and evaluating the students, and on the other hand, the dental student's methodology in their own study and their feedback regarding anatomy classes. The interviews were audio recorded with all the participant's consent.

3.1.1 Teachers' Interviews

The teachers' interview was divided into four different groups of questions: *Conventional Teaching and Learning Tasks*, *"Out Of The Box" Tasks*, *Knowledge Assessment Methods*, and *Virtual Reality as a Learning and Education Method*.

Concernign *Conventional Teaching and Learning Tasks* and *"Out Of The Box" Tasks*, the teachers responded with the most common methods, such as PowerPoint presentations, diagrams, videos, and physical models to teach anatomy and practical content, but both answered that do not use "out of the box" methods to teach. In fact, one teacher manifested curiosity in using new technology, "especially 3D technology", to improve the learning tradition. Regarding *Knowledge Assessment Methods*, the evaluation of the students is conducted by using oral and written assessments. For the last group of questions, both teachers expressed their motivation to use VR tools in the teaching and learning process, yet none of them ever used such technology.

3.1.2 Students' Interviews

The students' interview was divided into two groups: *Study and Learning Methods*, and *Lecturing Methods*. The first group gathered information regarding the student's study methods, like PowerPoints, textbooks, pictures, online material, and even hand-written or hand-drawn sketches (provided later by some of the students, as seen in Figure 3.1), as well as limitations and difficulties while studying anatomy, the most common being a vast number of concepts, making it difficult to memorize).

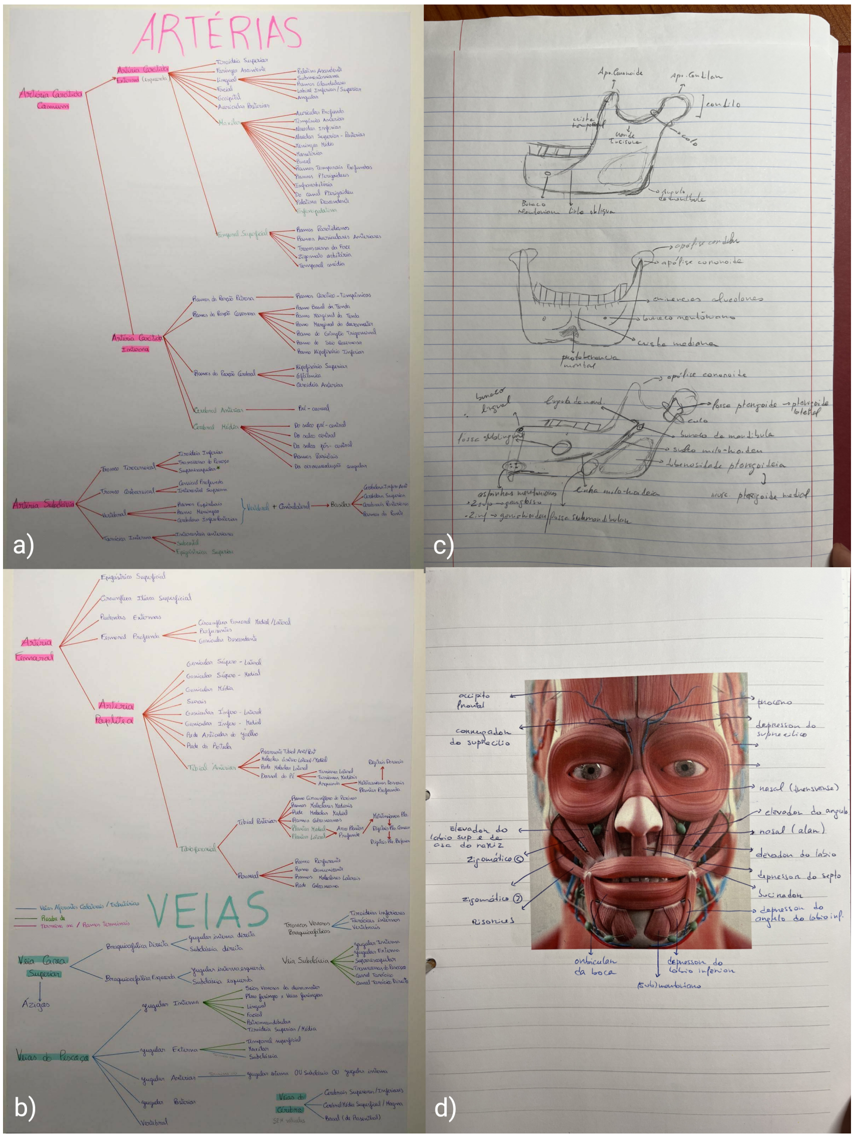


Figure 3.1: Some students' hand sketches from Anatomy classes: a) and b) schematize arteries and veins, c) schematizes the bones of the mandible, and d) labels the muscles of the face.

One student, in particular, mentioned the use of *mind maps* as a form of studying and memorizing. She started using this technique in "secondary school" to help her "internalize concepts faster and better understand hierarchies". She took "this method to university", using it extensively in "anatomy classes and study". She drew the "maps by hand, like a spider: the body (main node) was the main concept and the various legs (arcs) formed the 'first level of a hierarchy', which could in turn branch out into other legs, and so on". She used the technique to "memorize theoretical content" and as a "summary of her studies". Unfortunately, she does not have photographs or examples of maps made by herself because she "passed this study material on to other colleagues, who passed it on to others", from which we concluded that this method of study works well for anatomical study. The technique used by this student adapts to the theory of *mind maps* created by Tony Buzan, mentioned in chapter 1, thus strengthening the relevance of *mind maps* applied to the study of anatomy.

The last group gathered feedback from students attending anatomy lectures. The main problem with theoretical classes is PowerPoints with a lot of textual content instead of visual information leading to a lack of concentration; as for the practical classes, the main problem was, again, too much detail to memorize. Feedback for changes was also inquired: for the theoretical classes, students responded with applications with 3D models, more videos, and physical models; for practical classes, students wanted more videos and applications with 3D models.

3.2 Co-Design Sessions

Based on the observation sessions, several co-design sessions with a dentist and dentistry teacher were relevant to obtain some medical data to be included in the initial prototypes and to receive feedback on them. To begin with, we divided the maxilla and the mandible into six different regions, with anatomical concepts relevant to each region. From an open-access dataset of patient-specific human jaw models, the three most completed were chosen, as explained in section 4.1. The anatomic information was then hand-sketched by region on each of the jaw models to formulate the 3D conventional layout, resulting in three low-fidelity prototypes. A consensus was later made to elect the most complete and correct model to use on the final prototype. Figure 3.2 illustrates some of the first anatomical concepts of one region hand sketched on the chosen model.

Then it was time to design the other layout, an AAG, to the side, of the entire constitution of each region, suggesting a reading path of a hierarchy (from the main anatomical structure to its division into smaller constituents). Figure 3.3 shows the design of an entire view of one region.

A mid-fidelity prototype started to be developed on the Unity engine. This prototype consisted of the Premolar Mandibular region represented on a 3D model of the mandible by colored buttons over the surface of the model, that, when clicked, activated a floating tag with the name of the respective constituent (the conventional layout). Each button enables or disables one concept, and each color represents the different types of constituents: grey represents Osteology, blue represents Muscles, red represents Vascularization, purple represents Veins, yellow represents Innervation, and green represents relevant elements that do not fit into any of the classifications described before. This color scheme can be seen in both Figure 3.2 and Figure 3.3. Tony Buzan also used a color scheme for his *mind maps*, so we decided to create our own color scheme for each type of anatomical classification.

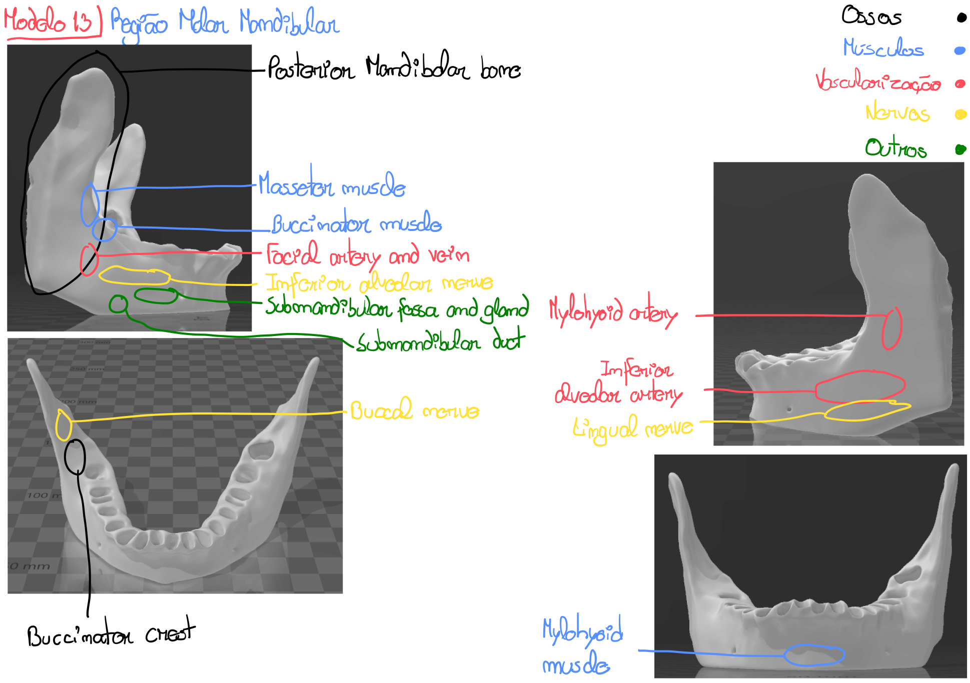


Figure 3.2: First anatomical concepts of the Posterior Mandible region hand sketched on the most complete model, with our color scheme for each type of anatomical classification in the upper right corner.

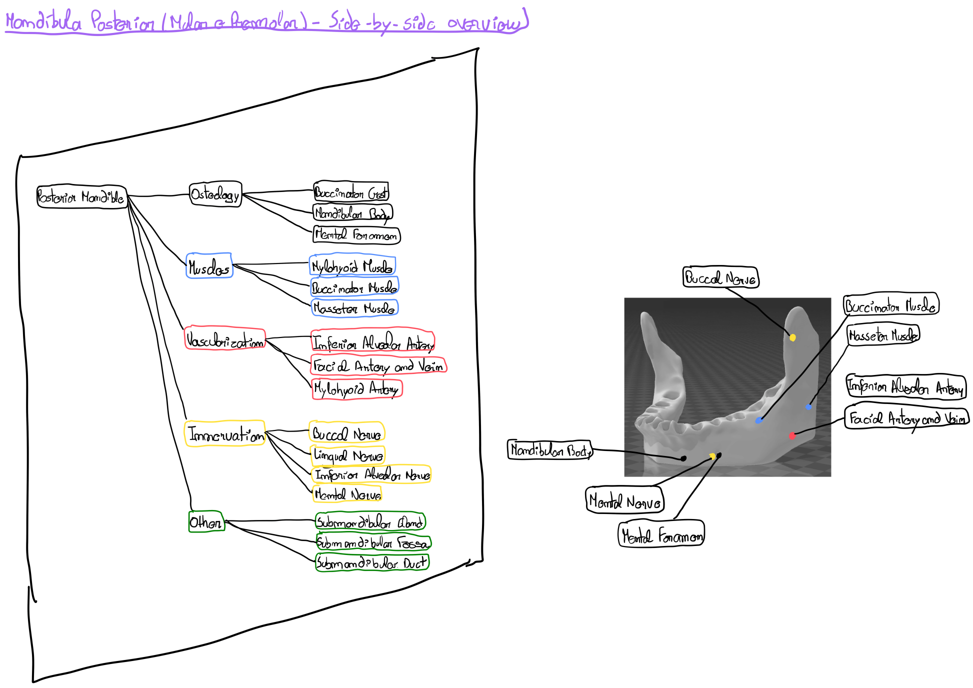


Figure 3.3: Hand sketch of the two layouts for the Posterior Mandible region: the *conventional layout* on the right and the *graph to the side* on the left.

Feedback from the co-design participant turned out positive. Regarding the virtual elements, the professional agreed that it was useful to have colors on the buttons because it helps to identify the type of elements being pointed out. One suggestion to be considered was the rotation and spatial movement of the 3D model so that the user could rotate it, being able to see the entire model and also decide on the distance to the camera (if it is too close or too far away).

The anatomic regions were discussed again and, for the sake of simplicity, were reduced to just four: anterior maxilla, posterior maxilla, anterior mandible, and posterior mandible.

4

IMPLANTIGRAPH

Contents

This chapter presents our workflow to develop the high-fidelity prototype called IMPLANTIGRAPH, which aims at addressing the benefits and limitations of AAGs in VR. In particular, Section 4.1 exposes the limitations we encountered during the acquisition of the 3D models used in the prototype and how we found a solution for the problem, Section 4.2 presents the software and hardware used during the development and validation phase, Section 4.3 introduces the architecture of our solution, and Section 4.4 explains in detail the immersive environment of our prototype and how the user can interact with its.

4.1 3D Models

To obtain a patient-specific model of an entire jaw, it was necessary to extract the 3D model from Cone Beam Computed Tomography (CBCT) images, preferably from a full-toothless jaw. Cooperativa de Ensino Superior Egas Moniz was able to find a CBCT on those conditions. The 3D reconstruction process followed the pipeline described by Paulo et al. [40]. However, the model resulting from the above procedure was considered invalid, as the patient in question did not have enough bone on the anterior maxilla and mandible, thus being an inadvisable model for anatomical study. This resulting model is shown in Figure 4.1.

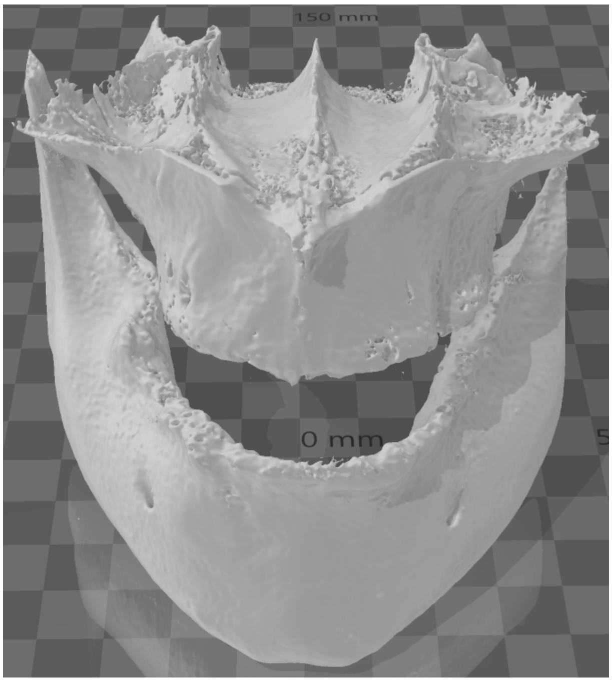


Figure 4.1: Invalid 3D reconstruction from the CBCT provided by Cooperativa de Ensino Superior Egas Moniz.

As further research was made to find a solution, a repository containing an open-access dataset of 17 patient-specific models of human jaws was found. Each of these models was inside a ZIP folder with STL files for the maxilla alone, the mandible alone, the upper teeth, and the lower teeth. As a full-toothless jaw was desired, only the STL files of the maxilla and the mandible were used. These STL files, however, were textureless. To add some realism to the models, a procedural bone texture was created using the Blender software (version 3.3.1 LTS). Adding to this, the origin point of both models was also corrected, as their pivot points were not centralized. Finally, both models were exported as an FBX file and imported into the Unity project.

4.2 Apparatus

Our prototype was developed in Unity3D (version 2021.3.8f1), a game engine with built-in support for VR development, particularly the Oculus Quest headset. Two HMD devices were used during the development and testing of the application: during development, the HMD in use was the Oculus Quest 2 (95º FOV, 1832 x 1920 pixels per eye, 72Hz refresh rate), and for the training with the users the Oculus Quest 1 (93º FOV, 1440 x 1600 pixels per eye, 72Hz refresh rate) was the chosen one.

4.3 Architecture

The architecture is schematized in Figure 4.2. The *User* interacts with the prototype through the Quest's *Controllers*, and the *HMD*, in return, visually provides the user with the 3D rendering of the prototype's content, rendered in the *Immersive Environment* module. This module has an independent submodule, called *Scene Configuration*, which allows the user to choose which region he wants to select, through a dropdown menu that uses the *DropdownStartMenu* class (Figure B.1). When entering one of the scenes, there are two main sub-modules: the *Floating Graph Click Detection* and the *Side Graph Click Detection*. The former is performed by the *ClickButtons* class in Figure B.2, which activates the floating label and changes the color of the box corresponding to the same constituent in the side graph. The latter is done through *ClickSideGraphLabel* class. Figure B.3 shows an excerpt from this class, indicating the activation and deactivation of the labels of both layouts. The user receives feedback from these interactions visually through the *HMD*.

4.4 Interaction

IMPLANTIGRAPH has five scenarios: an initial menu and four scenes that represent each of the anatomical divisions presented at the end of chapter 3. All interaction is done using the ray casts and buttons from the Oculus controllers on the virtual components of the prototype: the 3D models, the floating tags, and the AAG to the side (which from now on, for reasons of convenience and simplicity, we will call each the *floating graph* and the *side graph*, respectively).

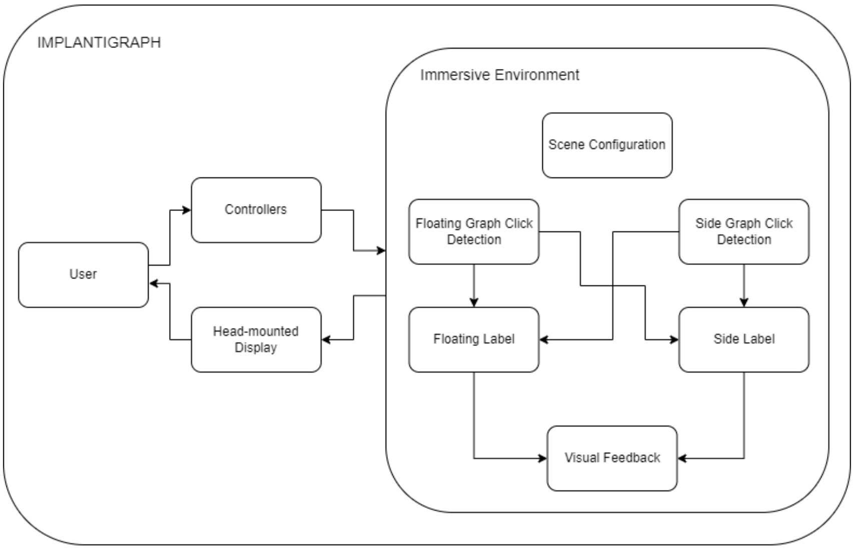


Figure 4.2: Architecture of IMPLANTIGRAPH.

Once the application is launched, the initial menu is the first scene that the user sees. In this scene, the user is presented with a dropdown menu where he can select one of the tasks by pointing the ray cast at the dropdown menu and using the trigger button of one of the Oculus controllers to click on one of the tasks. Once the task has been selected, the user must press the "Start Simulation" button, also using the trigger button. The flow described is shown in Figure 4.3. If you want to close the application, the user must press the "Close Application" button on that same menu.

After pressing the "Start Simulation" button, a new scenario is introduced to the user, corresponding to the task chosen. Here, a 3D model of the mandible or the maxilla, depending on the chosen task, is presented, as well as a very simple menu located on the right side of the user. For purposes of assistance and presentation in this document, the *Tutorial Task* is the one selected, representing the Posterior Mandible region, as seen in Figure 4.4. The *Tutorial Task* is the only scene that contains a menu of instructions, presented in Figure 4.5, that instructs and guides the user on how to interact with the model and the respective layouts.

To interact with the 3D model, the user must use the left and right thumbsticks on the Oculus controllers. The left thumbstick allows spatial movement (bringing the model closer or far away from the camera, as well as moving it to the left or the right). The right thumbstick allows the rotation of the model either horizontally (moving the thumbstick to the left or to the right) or vertically (upwards or downwards).

As for the right-side menu, it shows, at the top, the name of the task and the respective name of the anatomical region selected. In the middle, there are two checkboxes that activate or deactivate the two layouts - the "floating graph" and the "side graph". At the bottom, there are two buttons: a "Reset" button (as the name implies, it restarts the current scene in its entirety, returning to the initial state in which the user found it when exiting the initial menu) and a "Finish Exercise" button (exits the current scene and

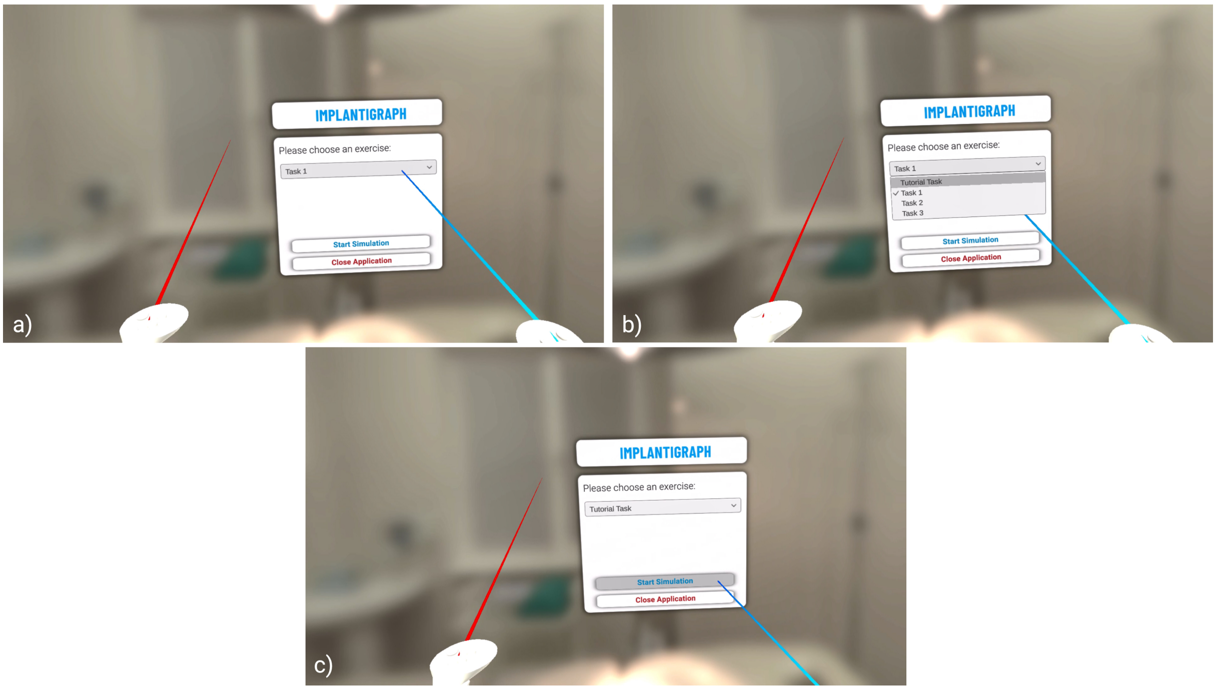


Figure 4.3: Steps of choosing a task in the Initial Menu: a) points at the dropdown menu; b) clicks on the dropdown menu to see the options; c) after clicking, the drop menu closes and user points at "Start Simulation" button.

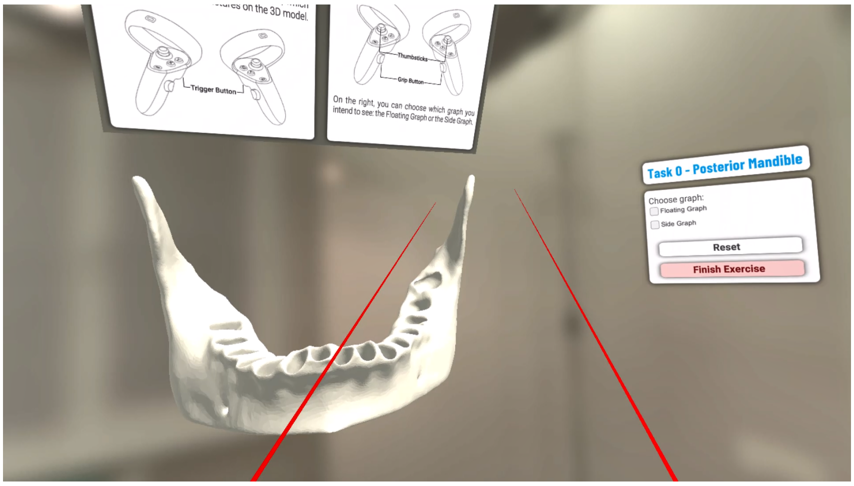


Figure 4.4: Initial view when a task is selected and the user enters the scene.

returns to the main menu scene). All interaction in this menu, which is fixed (it can't be moved), is done using the ray cast and the trigger button of any of the controllers. When activating the two checkboxes, the two layouts are activated and stay visible, as seen in Figure 4.6.

The **floating graph** consists of clickable buttons located on the surface of the model, having different colors and shapes. Each color represents a different type of constituent, as stated in chapter 3. The majority of the buttons are circular; however, there are two variations: some muscles are more

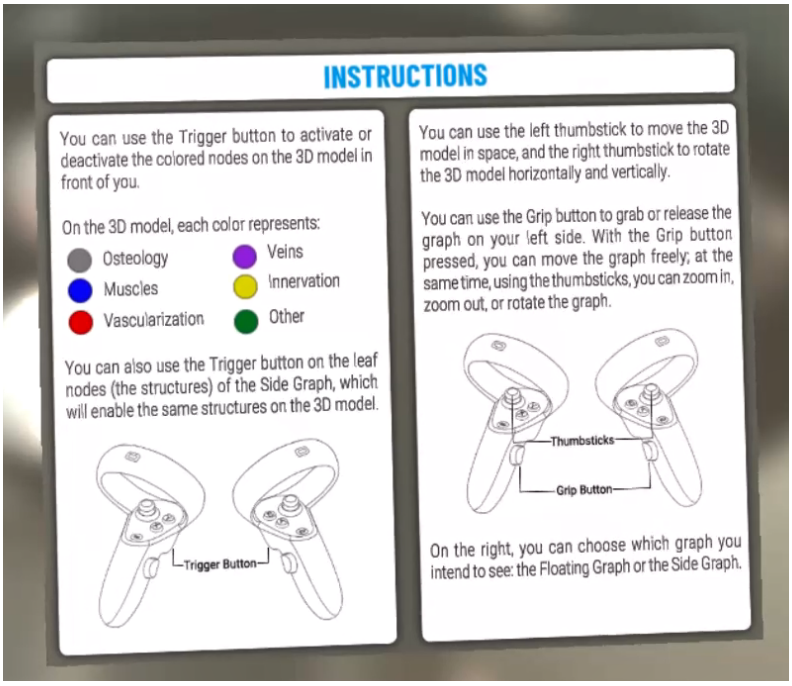


Figure 4.5: Instruction menu explaining all the possible interactions.

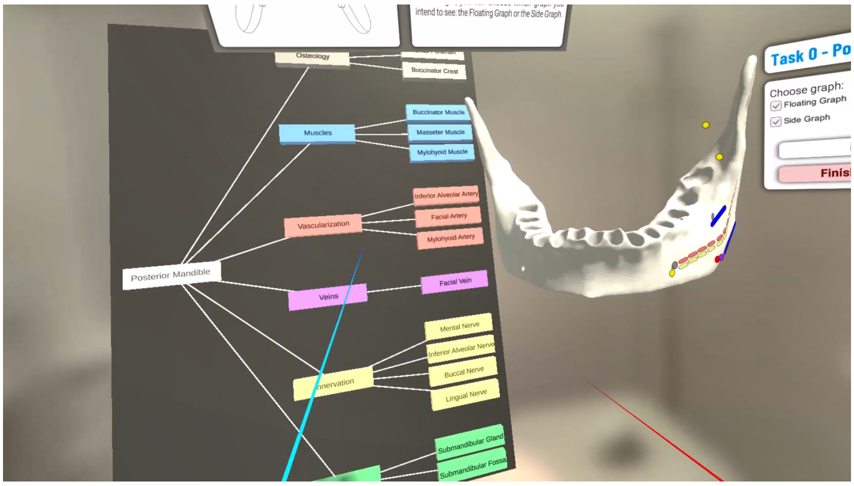


Figure 4.6: When the two checkboxes in the right-side menu are ticked, both layouts are activated.

rectangular in shape (follow the length of the muscle) and have an angulation (follow the direction of the fibers of the muscles themselves); in the Posterior Mandible region, the Inferior Alveolar Nerve and the Inferior Alveolar Artery are represented by a dashed line along the mandible because they are intraosseous, therefore not visible like the other constituents. The buttons of the floating graph, as well as both previous variations, can be seen in Figure 4.7.

To interact with the floating graph, the user must use the trigger buttons of the controllers. By pointing the ray cast at the button, the button highlights to a lighter color tone (Figure 4.8(a) and Figure 4.8(b)).

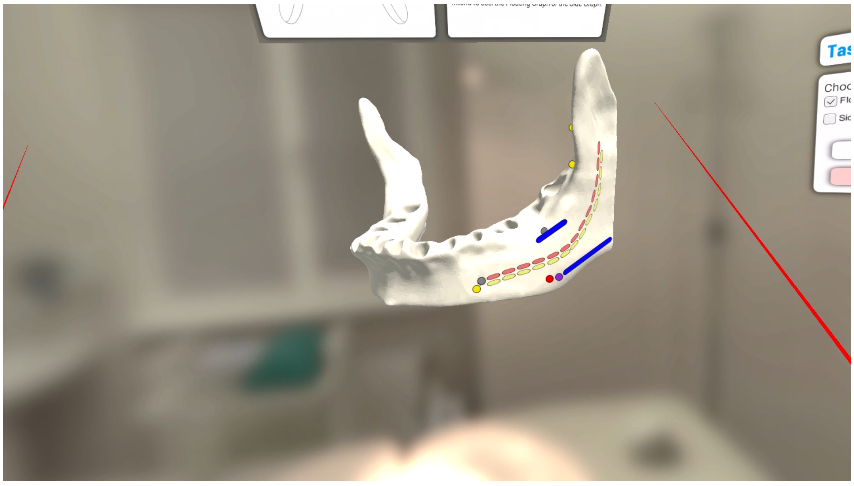
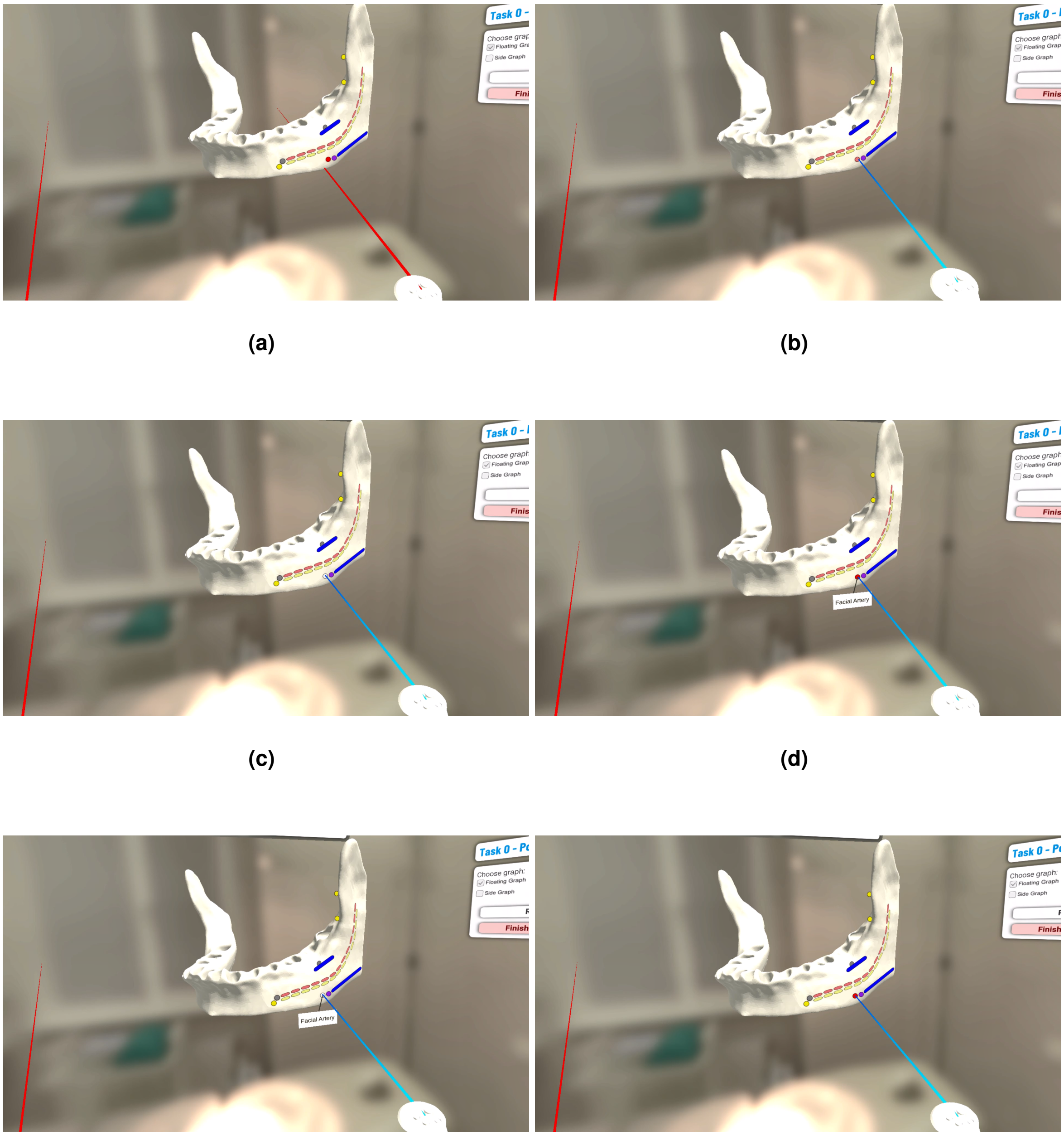


Figure 4.7: Colored buttons of the floating graph, as well as muscles and intraosseous variations.

Whenever the button is clicked it changes its color to white (Figure 4.8(c)), and it can either be activated (a floating label appears next to it, connected to the button via a line, as Figure 4.8(d) shows) or deactivated (both the label and the line joining the button to the label disappear, as seen in Figure 4.8(e) and Figure 4.8(f)). The floating graph is connected to the 3D model, which means that whenever the model is moved or rotated, the floating graph follows its movement. Figure 4.9 shows the entire floating graph of the selected scene.

The **side graph** is a plane with a dark background (to contrast with the prototype skybox) with multiple boxes organized to create a visual hierarchy. Starting at the main structure (always a white box on the left side), it branches into the main divisions (Osteology, Muscles, etc), and the latter are subdivided into the different anatomical constituents to be studied. Both the main divisions and their constituents are colored according to the color division stated in chapter 3. The side graph for the selected scene is presented in Figure 4.10.

The side graph is grabbable, so the user can move it freely around the scene and place it where they find it most pertinent and convenient, by using one of the grab buttons on the Oculus controllers. While grabbing the side graph, the trigger button can also activate or deactivate the link between this graph (the leaf nodes - any anatomical constituent) and the floating graph. By pointing the ray cast at the constituent in the side graph the user wants to select (Figure 4.11(a)), the user must click using the trigger button: this produces a highlighted effect both on the box and on the floating tag that appears next to the model (Figure 4.11(b)). After one second, the floating tag is no longer highlighted (Figure 4.11(c)). To deactivate, the user must point at the box and click using the trigger button: the floating tag gets deactivated and the box in the side graph stops being highlighted (Figure 4.11(d)). Finally, while grabbing the side graph, the user can also rotate it using the thumbsticks on the controllers, for better placement of the graph.



(a) (b) (c) (d) (e) (f)

Figure 4.8: Interaction with the Floating Graph. (a) Before pointing at the button. (b) Pointing at the button. (c) When clicking on the button to activate, the button changes to white. (d) The button returns to the original color and the label appears. (e) When clicking on the button to deactivate, the color also changes to white. (f) After clicking, the button returns to the original color and the label disappears.

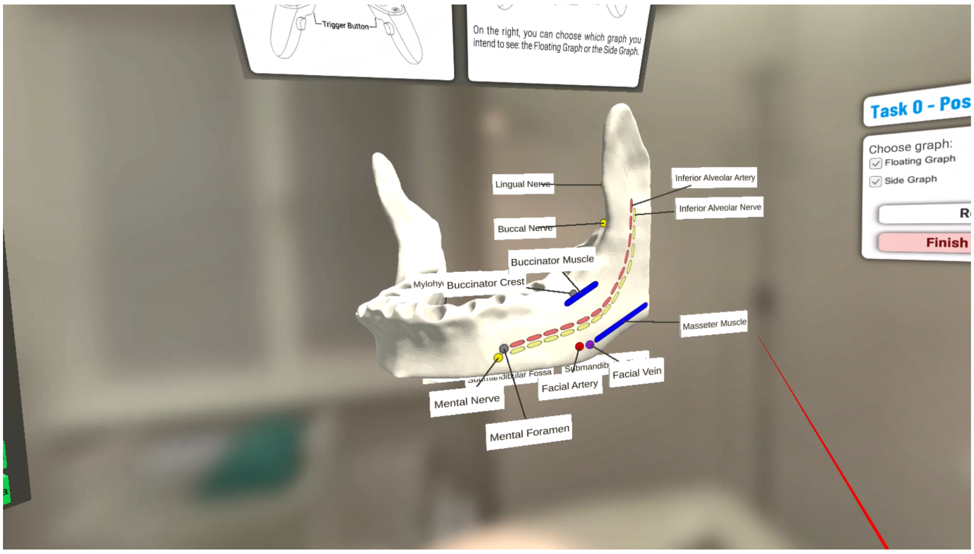


Figure 4.9: The floating graph of the selected task with all the buttons clicked and labels visible.

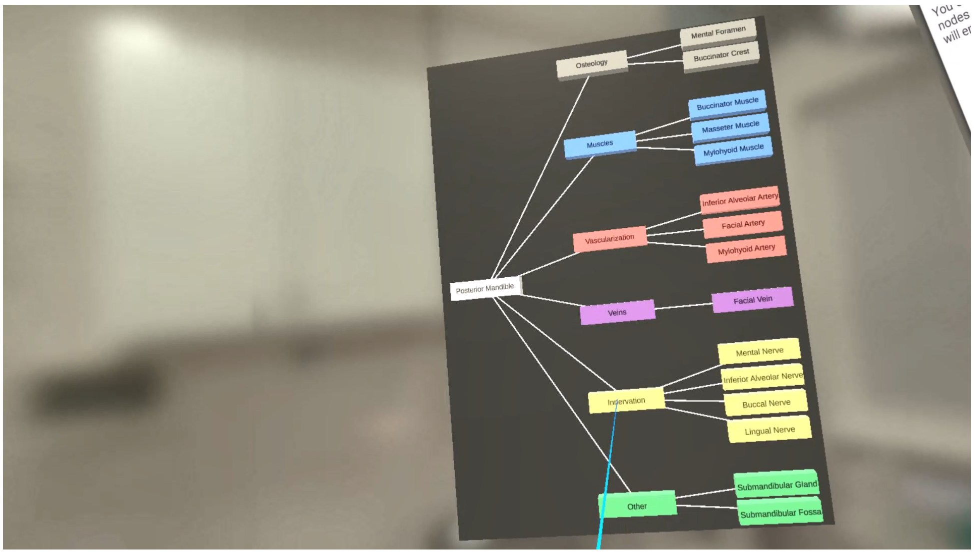
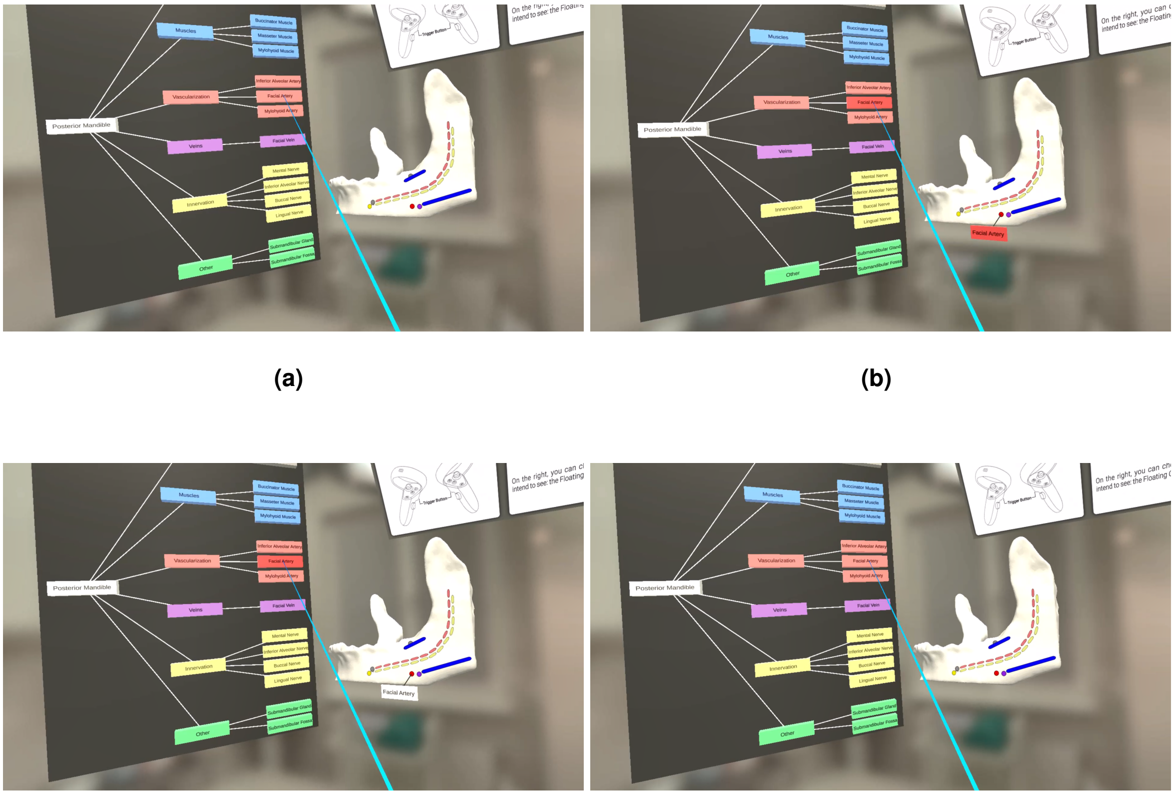


Figure 4.10: The entire side graph of the selected task.



(a) (b) (c) (d)

Figure 4.11: Interaction with the Side Graph. (a) Pointing at the constituent with the ray cast. (b) Clicking on the constituent: the box highlights to a darker color and the floating tag appears highlighted. (c) The box continues highlighted and the floating tag stops being highlighted (1s difference from Image 4.11(b). (d) Pointing at the box and clicking using the trigger button to deactivate.

5

User Study

Contents

Chapter 5 explains in detail the User Study sessions performed to evaluate IMPLANTIGRAPH. It begins by presenting the demographic information of the participants in Section 5.1, followed by all the apparatus used during the sessions in Section 5.2; Section 5.3 divides the variables of the study in Independent Variables (Subsection 5.3.1) and Dependent Variables (Subsection 5.3.2). The structure of the tasks is presented in Section 5.4, and the flow of an entire session is exposed in Section 5.5. At the end of a session, the subjective measures are assessed as explained in Section 5.6, and how we statistically analyze the final results is detailed in Section 5.7.

5.1 Participants

A total of 33 participants were invited to take part in our user study: 30 Master's students in Dentistry, and 3 teachers. The students, 20 female and 10 male, with ages ranging from 21 to 31 (Mean = 23,5, Standard Deviation (SD) = 2,7), were all perceiving a Master Degree in Dentistry, with one of them being employed as an Oral Hygienist for 5 years. Of the 30 students, 9 of them referred that they never dealt with VR technology. Figure 5.1 shows an alluvial diagram that highlights important students' characteristics gathered from the Demographic Profile Form.

As for the 3 teachers, all male, with ages ranging from 25 to 51 (Mean = 34,7, SD = 11,6), two have a Post-Graduate Degree in Dentistry and one a Ph.D. Degree in Dentistry. They are all employed with specialties in *Implantology*, *Oral Rehabilitation and Implantology*, and *Oral Pathology and Surgery (with a subspecialty in Oral Cancer)*, and the years of experience range between 2 and 25 (Mean = 10,7, SD = 10,2). One of the professors never dealt with VR technology.

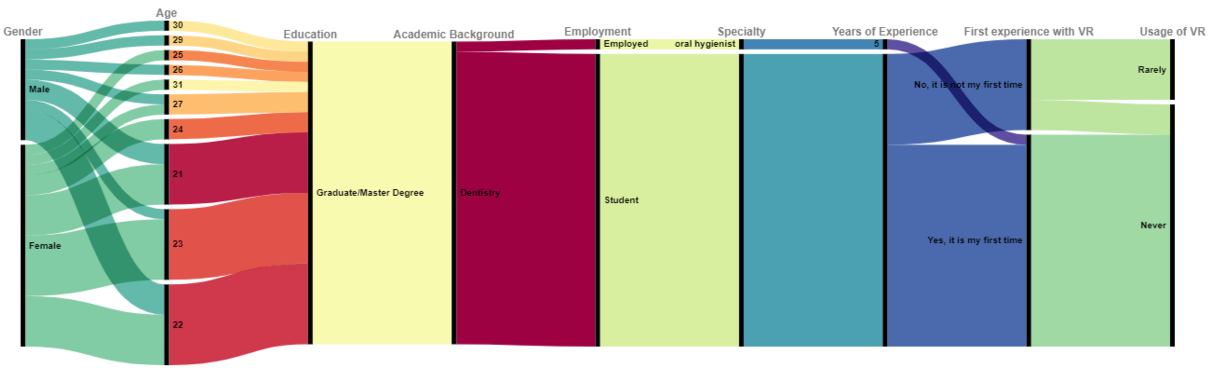


Figure 5.1: Alluvial diagram showing the demographic data from the students. In the diagram, the information is categorized in each column and the ratios of the categories are presented: the bigger the height of the flows, the bigger the values.

5.2 Apparatus

The user study took place at Cooperativa de Ensino Superior Egas Moniz. The setup consisted of the Oculus Quest 1 headset (93º FOV, 1440 x 1600 pixels per eye, 72Hz refresh rate), the IMPLANTIGRAPH prototype loaded on the headset, and two portable computers: the first to support the prototype casting of the Oculus and the second to fill in the questionnaires and answer the quizzes.

5.3 Variables

5.3.1 Independent Variables

One independent variable was chosen to evaluate the labeling method to represent the anatomic information, and its values are ”conventional labeling” (a 3D model of the maxilla and the mandible with colored buttons associated with floating labels, a transpose from textual labeling to the 3D virtual world - *floating graph*), and ”side-by-side labeling” (an anatomic graph separating the different type of structures of each region, with each structure having an associated color - *side graph*).

5.3.2 Dependent Variables

As for the dependent variables, these were branched between objective measures and subjective measures. Objective measures focus on educational performance, namely the time of each quiz, the accuracy of each exercise, and the number of concepts (regarding Master's students). The subjective measures express the participants' satisfaction and preferences, the usability of the system, the necessary workload, and the sense of presence, followed by semi-structured interviews to collect informal feedback from both the students and the teachers.

5.4 Tasks

The evaluation method for the Master's students used the between-group design. Students were divided into two groups: **Group A** used only the conventional layout (floating graph), and **Group B** used both the conventional and the side-by-side layout.

After a quick demonstration of the prototype by the examiner, both students' groups had a 5-minute habituation task, indicated in the prototype as *Tutorial Task*, so they could read the instructions panel (Figure 4.5) and better understand how to interact with the prototype. Then, they were asked to complete a total of 3 different tasks, one for each region, with an evaluation quiz at the end of each task (Quiz 1, Quiz 2 and Quiz 3 are available in appendix A).

A task is divided into two phases. The first one is a 5-minute studying phase, where the students explore the assigned region; the second one is the evaluation quiz about the content just studied. Each task had a different difficulty level, based on the number of concepts: task 1 had 14 concepts, the easier one; task 2 had 18 concepts, standing in the middle; task 3 had 24 concepts, being the hardest one. All evaluation quizzes had exactly 3 questions.

As for the teachers, they were not submitted to any sort of evaluation, but rather a free-hands session to explore the prototype and give their feedback as using IMPLANTIGRAPH as a lecturing tool.

5.5 Procedure

At the beginning of each session, each participant was asked to fill in an informed consent form (both the students and the teachers) to explain the key elements of the study and what their participation will involve, as well as a demographic profile form regarding their gender, education, employment (if applies), and previous VR experience, followed by an explanation of the structure of the session and a quick demonstration on how the prototype works.

The students were first asked to train in a habituation task. Following this, they were given a sequence of tasks that was randomized for each student using the Latin Squares method. All students were given 3 tasks with a maximum of 5 minutes per studying phase of each task. At the end of each one, they had to complete an assessment test. The time required for finishing each assessment was measured. Figure 5.2 shows students and teachers using the prototype during the user study sessions.

Figure 5.2: Students (above) and Teachers (bellow) participating in the User Study sessions.

As for the teachers, the examiner first gave a practical example of how the prototype works and what interactions are possible, and then they had free hands to use the prototype and explore deeper into the interactions and anatomic concepts presented there, for a maximum time of 10 minutes.

5.6 Assessing Subjective Measures

After the experimentation phase, each participant was asked to complete several questionnaires: a User Satisfaction Questionnaire (one for Group A and another one for Group B and the Teachers, since they were evaluated on two different independent variables) to receive feedback on the layouts and the user's preferences, a System Usability Scale (SUS) questionnaire to measure the usability of the prototype, a NASA Task Load Index (NASA-TLX) questionnaire to assess the task's workload, and an IGroup Presence Questionnaire (IPQ) questionnaire to measure the sense of presence experienced in the Virtual Environment (VE). Last but not least, the participants were submitted to a semi-structured interview regarding the use of anatomical graphs in VR, the advantages and disadvantages of using this prototype, and what changes they would suggest to improve the application. These interviews are presented at the beginning of appendix A. A full session with the students lasted between 40 to 50 minutes and with the teachers 20 to 30 minutes.

5.7 Interpretation of Subjective Measures and Statistical Analysis

5.7.1 User Satisfaction Questionnaire

All participants were asked to fill out a preference questionnaire (one for Group A and another one for Group B and Teachers) after all tasks were completed. Group A responded only to questions regarding the floating graph since it was the only layout they used; Group B and Teachers responded to questions regarding the floating graph, the side graph, and preference between the two. A 6-point Likert scale was used in the questions regarding both layouts, with 3,5 being the central value of the scale.

5.7.2 System Usability Scale

The SUS (System Usability Scale) questionnaire is a measuring tool to assess the usability of a system through 10 5-point Likert-scale items that alternate between positive and negative tones [41], resulting in a final number from a composite measure. The 10 items are presented in Table 5.1.

The results of the 10 5-point items give us the *raw scores*. To calculate the *final raw score*, from the odd-numbered questions, we subtracted 1 from each raw score, and from the even-numbered questions, we subtracted the raw scores from 5, and we added the values. To calculate the *final score*, we needed

SUS Questions	
1.	I think that I would like to use this system frequently.
2.	I found the system unnecessarily complex.
3.	I thought the system was easy to use.
4.	I think that I would need the support of a technical person to be able to use this system.
5.	I found the various functions in this system were well integrated.
6.	I thought there was too much inconsistency in this system.
7.	I would imagine that most people would learn to use this system very quickly.
8.	I found the system very cumbersome to use.
9.	I felt very confident using the system.
10.	I needed to learn a lot of things before I could get going with this system.

Table 5.1: SUS questions.

to convert the previous result to a range from 0 to 100 by multiplying the sum by 2,5. Equation 5.1 shows the entire computation described above to calculate the *final score*.

$$\begin{aligned} SUS = 2,5(20 + SUM(SUS01, SUS03, SUS05, SUS07, SUS09) - \\ SUM(SUS02, SUS04, SUS06, SUS08, SUS10)) \end{aligned} \tag{5.1}$$

To interpret the SUS questionnaire, a *final score* above 68 is considered above average, and below 68 is considered below average [42].

5.7.3 NASA Task Load Index

The NASA-TLX (NASA Task Load Index) is a rating procedure to assess the workload score through 6 20-point Likert-scale items, represented in Table 5.2. These 6 items are divided into six subscales: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Performance (PO), Effort (EF), and Frustration (FR) [43].

NASA-TLX Questions	
1.	How mentally demanding were the tasks?
2.	How physically demanding were the tasks?
3.	How hurried or rushed was the pace of the tasks?
4.	How successful were you in accomplishing what you were asked to do?
5.	How hard did you have to work to accomplish your level of performance?
6.	How insecure, discouraged, irritated, stressed and annoyed were you?

Table 5.2: NASA-TLX questions.

The score consists of a unique number that ranges between 0 and 100. To compute the score, we calculated the unweighted scores by summing them, multiplying the sum by 5 (to match the 0-100 interval), and calculating the mean. Equation 5.2 shows the computation described above.

$$NASA - TLX = \frac{5(MD + PD + TD + PO + EF + FR)}{6} \tag{5.2}$$

The result is then assigned to a specific workload classification scale presented in Table 5.3.

Workload	Value
Very Low	0 - 20
Low	21 - 40
Moderate	41 - 60
High	61 - 80
Very High	81 - 100

Table 5.3: NASA-TLX classification scale [4].

5.7.4 IGroup Presence Questionnaire

Participants were asked to fill in an Igroup Presence Questionnaire (IPQ) to measure the sense of being present in a VE, in this case, a VR environment. The questionnaire consists of 14 5-point Likert scale questions divided into four variables, expressed in Table 5.4 and Table 5.5, respectively.

IPQ Questions	
1.	In the computer generated world, I had a sense of "being there".
2.	Somehow I felt that the virtual world surrounded me.
3.	I felt like I was just perceiving pictures.
4.	I did not feel present in the virtual space.
5.	I had a sense of acting in the virtual space, rather than operating something from outside.
6.	I felt present in the virtual space.
7.	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?
8.	I was not aware of my real environment.
9.	I still paid attention to the real environment.
10.	I was completely captivated by the virtual world.
11.	How real did the virtual world seem to you?
12.	How much did your experience in the virtual environment seem consistent with your real world experience?
13.	How real did the virtual world seem to you?
14.	The virtual world seemed more realistic than the real world.

Table 5.4: IPQ questions.

Variable	Meaning	Questions
General (G)	General "sense of being there".	1
Spatial Presence (SP)	Sense of being physically present in the VE.	2 - 6
Involvement (INV)	Measures the attention devoted to the VE and the involvement experienced.	7 - 10
Experienced Realism (REAL)	Measures the subjective experience of realism in the VE.	11 - 14

Table 5.5: Structure of the IPQ [5].

One way to interpret its result is by its means, as Table 5.6 shows [6].

Sense of Presence	Value
Very Bad	1,00 - 1,80
Bad	1,81 - 2,60
Moderate	2,61 - 3,40
Good	3,41 - 4,20
Very Good	4,21 - 5,00

Table 5.6: IPQ classification scale [6].

5.7.5 Semi-Structured Interviews

More subjective and informal data was gathered from semi-structured interviews with each participant, students and teachers. The structures of both interviews are exposed in appendix A. After joining all the answers per question, a thematic analysis method was performed to gather relevant information and feedback regarding common themes participants expressed about.

5.7.6 Statistical Analysis

Several methods for statistical analyses were performed: Descriptive Statistics, Shapiro-Wilk Test, Independent Samples t-Test, Chi-square Test, One-Sample Wilcoxon Signed Tank test, and Mann-Whitney U Test, all carried out using IBM SPSS Statistics 26 [44] for Windows. For all tests, a p-value of less than *alpha* = 0,05 was considered statistically significant. Apart from the time to answer each quiz (that could possibly be dependent), all our samples are independent, so we did not need to test the assumptions for normality, we simply used non-parametric tests.

It must be referred that, for the Teachers, our sample consisted only of 3 participants, so we did not perform any statistical analysis on the Teachers' answers, since the sample size is insignificant for consistent and accurate results of an entire population.

6

Results & Discussion

Contents

All data collected during the User Study referred in chapter 5 includes performance metrics and subjective metrics. Performance metrics were measured using IMPLANTIGRAPH, consisting of task completion time (Section 6.1), the number of wrong answers from the anatomical quizzes (Section 6.2), and the number of concepts in each task (Section 6.3). As for subjective metrics, they were measured using user preference questionnaires (Section 6.4), system usability questionnaires (Section 6.5), task workload (Section 6.6), and sense of presence (Section 6.7), together with comments and suggestions obtained through semi-structured interviews with each participant (Section 6.8).

We divided the 30 students into two groups of 15: **Group A** was tested using only the floating graph, and **Group B** was tested using the floating graph and side graph. Teachers also tested both layouts.

6.1 Task Completion Time

The time students needed to complete the anatomical quizzes gave us some insights into the use of anatomical graphs in an immersive 3D environment. The comparison, between both groups, of the average time to complete each quiz is represented in Figure 6.1.

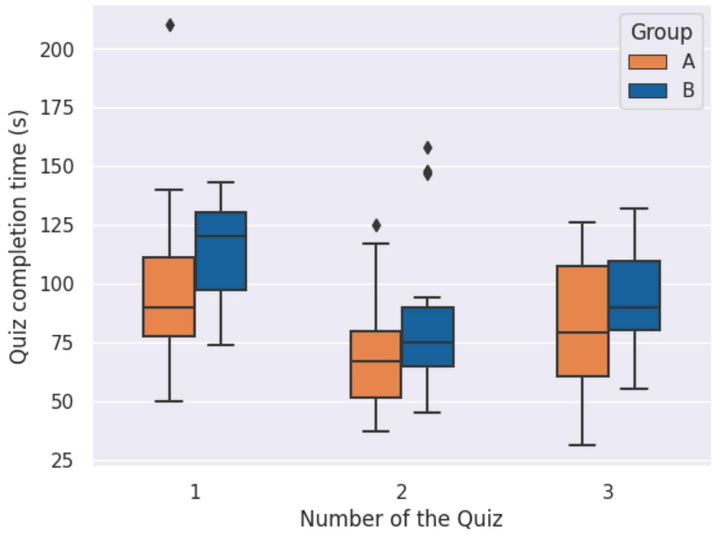


Figure 6.1: Comparison of quiz completion time (in seconds) for each quiz between each group.

The distributions of the response times for both groups were tested for normal distribution using the Shapiro-Wilk Test. For a value of *alpha* = 0,05, we had two out of six p-values less than *alpha*, so the assumption of normality was violated; however, by performing descriptive analysis, we can verify that the characteristics of the data (considering the Skewness and Kurtosis values [45]) allow us to use parametric tests, so the comparative analysis can be carried out using the t-Student test, more specifically an Independent Samples t-Test, with the null hypothesis (H0) defined as ”The means of the quizzes completion times by using one layout or two layouts are identical". The p-values from the Shapiro-Wilk test, the Skewness, and Kurtosis are represented in Table 6.1, while the means, standard deviations (SD), and the p-values from the Independent Samples t-Test are represented in Table 6.2.

Quiz	Group	p-value	Skewness	Kurtosis
Q1	A	0,020	1,675	3,607
	B	0,219	-0,511	-0,882
Q2	A	0,158	0,982	0,507
	B	0,007	1,201	0,246
Q3	A	0,842	-0,021	-1,153
	B	0,558	0,066	-0,759

Table 6.1: Results of the Shapiro-Wilk test, and the Skewness and Kurtosis values from the descriptive analysis of the time to complete the quizzes.

Quiz	Group	Mean	SD	p-value
Q1	A	98,13	39,916	0,214
	B	113,20	22,729	
Q2	A	70,27	25,381	0,157
	B	86,67	35,582	
Q3	A	82,73	29,906	0,292
	B	93,20	22,976	

Table 6.2: Mean and standard deviation (SD) of the quizzes completion time (in seconds) from each group, and p-values of the Independent Samples t-Test.

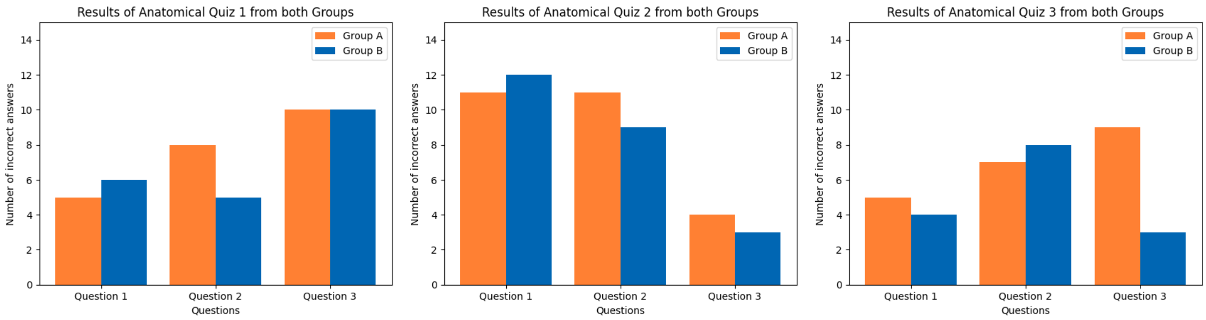
Figure 6.1 shows that the quiz completion time for both layouts is slightly higher than just for the conventional layout (the black rhombus are outliers, not to be considered). This result can be justified by a longer interval of time to revive the concepts in both layouts, as the students had two alternative ways of reaching the same information, leading to a more time-consuming mental organization of that information; the construction of mental maps can also be a justification for this result, as students can think of the two formats of obtaining the information they have just studied and try to build a mental model from those two to try to answer correctly.

The statistics in Table 6.2 show that, regarding the means, Group A took less time answering the quizzes, which goes along with Figure 6.1. However, all p-values from the t-Test are above the *alpha* value, so we can not consider this a significant result (the differences in times between both groups are not substantially large to be statistically relevant).

Summarizing, we can conclude that students with both layouts took more time responding to the quizzes, but the time factor does not let us conclude the influence of using one or two layouts.

6.2 Number of Errors

The results of the anatomical quizzes allowed us to assess whether the use of anatomical graphs in an immersive 3D environment have the potential to be a study tool as it helps students to get better results. To test this, we compared the number of incorrect answers for each question of each quiz by each group, represented in Figure 6.2, and we compared the percentage of incorrect answers per quiz between groups, summarized into one variable that represented the percentage of incorrectly answered questions, presented in Figure 6.3.



(a) Quiz 1 **(b)** Quiz 2 **(c)** Quiz 3

Figure 6.2: Comparison of the number of incorrect answers for each question of each quiz, by each group.

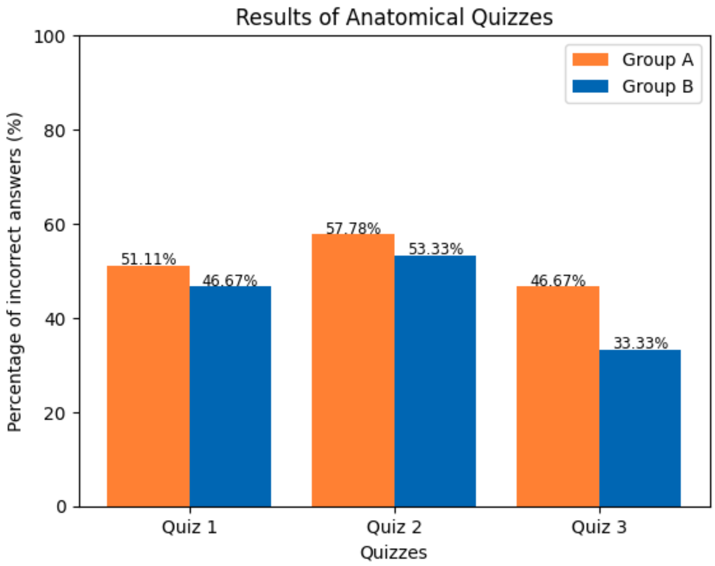


Figure 6.3: Comparison of the percentage of incorrect answers per quiz between groups.

Since our samples are independent and this data is categorical, there was no need to test the assumptions of normality: we used a non-parametric, distribution-free test to statistically analyze our samples [46]. In this case, we used the Chi-square Test, with the null hypothesis (H0) defined as ”There is no relationship between the answers of both groups, for each question”. The results of the Chi-square Test are presented in Table 6.3.

Quiz	Question	p-value
Q1	1.1	0,705
	1.2	0,269
	1.3	1,000
Q2	2.1	0,666
	2.2	0,439
	2.3	0,666
Q3	3.1	0,690
	3.2	0,715
	3.3	0,025

Table 6.3: p-values from the Chi-square test to compare the frequencies of the answers of each quiz question.

Figure 6.2 shows that, out of the 9 questions, in 5 of them students from Group A have more incorrect answers than students from Group B, and in 3 of them students from Group B have more incorrect answers than students from Group A, indicating a minor number of incorrect answers from Group B. Since Group B used both layouts, we inferred that anatomical graphs benefited the learning process.

Figure 6.3 indicates that, overall, Group B had the best results, since their percentage of incorrect answers is smaller on all three quizzes. This conclusion goes along with the inference stated above, strengthening the premise that anatomical graphs benefited the learning process.

The statistics in Table 6.3 show that only question 3.3 is statistically significant, as its p-value is less than *alpha*; this represents less than 20% of the questions. Therefore, the results do not allow us to conclude anything about the use of anatomical graphs in an immersive 3D environment as a study tool via the number of errors, since there are no significant differences in the performance of the two groups.

All things considered, we can conclude that, in general terms, using the side graph lead to better results (fewer incorrect answers), although the number of incorrect answers does not let us conclude the influence of using one or two layouts.

6.3 Number of Concepts

According to section 5.4, the tasks follow a specific level of difficulty based on the number of concepts. From Figure 6.3, we can see that the percentage difference from each group between each quiz is, respectively, 4,44%, 4,45%, and 13,34%. Taking into account that the difficulty increases with the quiz (quiz 1 is the easiest and quiz 3 is the most difficult) and that the percentage differences increase as well, we can conclude that Group B answered fewer incorrect answers and, therefore, the anatomical graphs benefited the learning process.

6.4 User Satisfaction

The User Satisfaction questionnaire was relevant to understand how the participants dealt with each layout they experimented. To test the significance of the responses, we performed two tests: for the questions regarding satisfaction, we performed the non-parametric One-Sample Wilcoxon Signed Rank test with the null hypothesis (H0) defined as "The median of each Likert item equals the hypothesized median (3,5)"; for the preference questions, we used frequency tables from descriptive statistics. The medians of the responses from all groups for the **floating graph** and their respective Wilcoxon p-values are summarized in Table 6.4, the medians of the responses from Group B and Teachers for the **side graph** and their respective Wilcoxon p-values are summarized in Table 6.5, and the frequencies from the preference questions are presented in Table 6.6.

Statements	Group A		Group B		Teachers
	Mdn (IQR)	p-value	Mdn (IQR)	p-value	Mdn (IQR)
01 - Floating labels help locating elements anatomically.	6 (1)	0,002	6 (1)	0,000	6 (0)
02 - Floating labels help identify different types of constituents.	6 (0)	0,001	5 (1)	0,001	6 (0)
03 - Floating labels help memorize the constitution of the region.	5 (1)	0,002	6 (1)	0,000	6 (0)
04 - Floating labels help perceive the anatomy of the region.	6 (1)	0,003	6 (1)	0,001	6 (0)
05 - Floating labels are useful.	6 (0)	0,001	6 (1)	0,000	6 (0)
06 - Floating labels are easy to use.	5 (1)	0,005	6 (1)	0,001	6 (0)
07 - Floating labels help fast learning.	6 (1)	0,004	6 (1)	0,001	6 (0)
08 - Floating labels are useful to study anatomy related to implantology.	6 (1)	0,002	6 (1)	0,001	6 (0)
09 - Floating labels interactivity promotes focus and learning.	6 (2)	0,004	6 (1)	0,002	6 (0)
10 - Being able to move and rotate the 3D model is useful.	6 (0)	0,002	6 (0)	0,000	6 (0)

Table 6.4: Median (Mdn) and Interquartile Range (IQR) of the responses to the Likert items of the User Preference questionnaire related to the Floating Graph, and the p-values of the One-Sample Wilcoxon Signed Rank test comparing the medians of the students with the hypothesized median (3,5).

Statements	Group B		Teachers
	Mdn (IQR)	p-value	Mdn (IQR)
01 - Side graph helps locating elements anatomically.	6 (3)	0,013	6 (0)
02 - Side graph helps identify the different types of constituents.	6 (2)	0,005	6 (0)
03 - Side graph helps memorize the constitution of the region.	5 (3)	0,030	6 (0)
04 - Side graph helps perceive the anatomy of the region.	6 (3)	0,014	5 (0)
05 - Side graph is useful.	6 (2)	0,003	6 (0)
06 - Side graph is easy to use.	6 (1)	0,000	6 (0)
07 - Side graph helps fast learning.	5 (1)	0,006	6 (0)
08 - Side graph is useful to study anatomy related to implantology.	5 (3)	0,019	6 (0)
09 - Side graph interactivity promotes focus and learning.	5 (3)	0,019	6 (0)
10 - Interaction of both layouts helps anatomical study of the region.	6 (1)	0,008	6 (0)
11 - Being able to grab and move the side graph is useful.	6 (1)	0,005	6 (0)

Table 6.5: Median (Mdn) and Interquartile Range (IQR) of the responses to the Likert items of the User Preference questionnaire related to the Side Graph, and the p-values of the One-Sample Wilcoxon Signed Rank test comparing the medians from Group B with the hypothesized median (3,5).

Table 6.4 shows that the median of all responses from all participants for the floating graph was higher than the hypothesized median (3,5) and the values of dispersion were low (between 0 and 2), which confirms that participants positively evaluated the floating graph in terms of usability and found it very useful as a study method. Besides, the Wilcoxon test proved that the results are all statistically significant (all p-values are less than 0,05), which emphasizes their level of confidence.

Preference Question	Group B		Teachers	
	Floating Graph	Side Graph	Floating Graph	Side Graph
Which layout do you prefer?	13	2	2	1
Which layout was the most appealing?	11	4	3	0
Rank the layouts (Most Preferred Layout)	13	2	2	1
Rank the layouts (Less Preferred Layout)	2	13	1	2

Table 6.6: Answers from the Preference Questions between layouts for Group B and Teachers.

Table 6.5 shows that the median of all responses from Group B and Teachers for the side graph was higher than the hypothesized median (3,5) and the values of dispersion, although low (between 0 and 3), are a bit higher than those for the floating graph, which indicates more dispersion on the data. The Wilcoxon test results proved that the results are all statistically significant (all p-values, although a bit higher than the ones for the floating graph, are all still below *alpha*). From this information, we can conclude that the participants also evaluated positively the side graph in terms of usability and found it useful as a study method, but not as much as the floating graph.

Table 6.6 shows that, in regard to the students' preference between both layouts, 13 students preferred the floating graph and 11 students found the floating graph the most appealing one. When asked to rank both layouts, 13 students ranked the floating graph first. From this information, we can conclude that, overall, students who experimented both layouts elected the floating graph as the most useful one. As for the teachers, two chose the floating graph as their preferred layout but all three found the floating graph the most appealing one. When asked to rank both layouts, two of them ranked the floating graph first. We can conclude that teachers also elected the floating graph as the most useful one.

All things considered, we can conclude that participants evaluated positively both layouts (the floating graph more than the side graph), and the floating graph was, generally, the favorite layout in terms of preference. All these results are statistically significant, as proven by the Wilcoxon tests.

6.5 System Usability

The System Usability Scale (SUS) questionnaire was essential to assess the usability of IMPLANTIGRAPH and, to a certain degree, the user experience between using one or two layouts. Since the groups are independent, we used a Mann-Whitney U Test with the null hypothesis (H0) defined as ”The difference between the mean of the SUS score and the average score (68) is zero”. Table 6.7 presents the means and standard deviations for the raw and final scores of the SUS for each group, and Table 6.8 shows the p-values and Z-scores obtained from the Mann-Whitney U test.

From Table 6.7, we can see that, for group A, the mean of the final score was 87,50 (SD = 8,06); for group B, the mean score was 87,83 (SD = 6,94); for the teachers, the mean score was 90,00 (SD = 7,36). As stated in section 5.7.2, a result above 68 is considered above average. Since the three means

SUS Score	Group A		Group B		Teachers	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Raw	35,00	3,26	35,13	2,78	36,00	2,94
Final	87,50	8,06	87,83	6,94	90,00	7,36

Table 6.7: Mean and standard deviation (SD) for each group's raw and final SUS questionnaire scores.

SUS Question	SUS1	SUS2	SUS3	SUS4	SUS5	SUS6	SUS7	SUS8	SUS9	SUS10
p-value	0,118	0,499	0,616	0,170	0,179	0,239	0,583	0,501	0,668	0,857
Z-value	-1,562	-0,676	-0,501	-1,373	-1,343	-1,177	-0,549	-0,673	-0,429	-0,180

Table 6.8: p-values and Z-scores obtain from the Mann-Whitney U test applied to the SUS questionnaire.

are above the average, we can conclude that participants considered IMPLANTIGRAPH to have a very good User Interface (UI) and good usability.

Table 6.8 has two variables: the Z-score and the p-value. All values of Z are negative, which indicates that Group B has greater values than Group A (which goes along with the result above); however, all p-values are bigger than the considered *alpha*, so the results are not statistically significant.

All in all, we can conclude that both the Students and Teachers considered IMPLANTIGRAPH to have an excellent UI and usability, although the answers from the students do not let us conclude if the user experience changes with the use of one or two layouts.

6.6 Perceived Workload

The NASA Task Load Index (NASA-TLX) questionnaire was indispensable to assess the task's workload, especially between the use of one or two layouts. We used a Mann-Whitney U Test with the null hypothesis (H0) defined as "The probability distribution of one group is the same as the probability distribution of the other group". The mean score and SD of each parameter, as well as the final score, are presented in Table 6.9, while the p-values and Z-scores obtained from the Mann-Whitney U test are presented in Table 6.10.

NASA Parameters	Group A		Group B		Teachers	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Mental Demand (MD)	20.33	22.02	32.00	28.74	15.00	7.07
Physical Demand (PD)	14.00	12.14	18.00	21.74	11.67	6.24
Temporal Demand (TD)	24.33	23.08	34.00	32.62	13.33	8.50
Performance (PO)	16.00	22.08	15.67	24.28	28.33	33.25
Effort (EF)	19.67	18.48	30.00	31.30	21.67	16.50
Frustration (FR)	14.33	14.81	23.33	29.19	8.33	2.36
Final Score	18.11	18.78	25.50	27.98	16.39	12.32

Table 6.9: Means and Standard Deviation (SD) of each NASA-TLX parameter, as well as the final NASA-TLX score, for each group.

NASA Parameter	p-value	Z-value
MD	0,290	-1,057
PD	0,896	-0,130
TD	0,768	-0,295
PO	0,983	-0,021
EF	0,486	-0,697
FR	0,582	-0,551

Table 6.10: p-values and Z-scores obtain from the Mann-Whitney U test applied to the NASA-TLX questionnaire.

The results from Table 6.9 were analyzed according to the workload classification scale in 5.3. For Group A, four out of six parameters are in the ”Very Low” range, with only *Mental Demand* and *Temporal Demand* entering the ”Low” values. This could be due to the amount of information to study in under 5 minutes, as well as reviving the concepts while studying and answering the anatomical quizzes.

Group B presents higher values, with four out of six parameters in the ”Low” range, with *Physical Demand* and *Performance* going back to the ”Very Low” values in the scale. Both these results are positive: Group B has more parameters in the ”Low” range because, although they had to study the same information as Group A, they had that same information in two different representations, turning the study and user experience overwhelming, increasing the workload; moreover, both the *Physical Demand* and *Performance* parameters in the ”Very Low” range demonstrates that, by using two layouts, the user performance is not affected and there is no physical effort added while utilizing the prototype.

As for the Teachers, the majority are also in the ”Very Low” range, with only the *Performance* and *Effort* located in the ”Low” range of the scale. These results are quite different from the students. This could be due to teachers possibly having more difficulty in adapting to newer technology and having to make an extra effort to succeed.

The final scores of each group are situated between the ”Very Low” (two of them) and ”Low” range, which means that IMPLANTIGRAPH is not considered to have high demand levels, being an easy-to-use study and teaching tool.

The results from the Mann-Whitney U test, presented in Table 6.8, show that all Z-values are negative, which indicates that Group B has greater values than Group A (in fact, from the previous results, we do see that Group B has a higher final score than Group A), however, all p-values are bigger than *alpha*, so the results can not be considered statistically significant.

Summing up, we came to the conclusion that students and teachers perceived very low levels of cognitive workload while using IMPLANTIGRAPH, not reaching high demand levels or having many difficulties in its usage, although the answers from the students do not let us conclude if the cognitive workload difference is noticeable while using one or two layouts.

6.7 Immersive Presence

The IGroup Presence Questionnaire (IPQ) was crucial to measure the sense of being present in a VE, and if the use of two layouts changes that same sense. We used a Mann-Whitney U Test with the null hypothesis (H0) defined as ”The probability distribution of one group is the same as the probability distribution of the other group”. The mean score and SD of each parameter, as well as the final score, are presented in Table 6.11, while the p-values and Z-scores obtained from the Mann-Whitney U test are presented in Table 6.12.

IPQ Variables	Group A		Group B		Teachers	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
G	4,27	0,799	4,33	0,816	3,33	1,523
SP	4,27	0,704	4,27	0,961	3,80	1,474
INV	3,00	1,309	3,60	1,454	3,00	1,348
REAL	2,13	0,640	2,33	1,113	2,83	1,403

Table 6.11: Means and Standard Deviation (SD) of each IPQ parameter for each group.

IPQ Question	p-value	Z-value
IPQ1	0,768	-0,295
IPQ2	0,735	-0,338
IPQ3	0,191	-1,307
IPQ4	0,531	-0,626
IPQ5	0,145	-1,457
IPQ6	0,394	-0,852
IPQ7	0,163	-1,395
IPQ8	0,983	-0,021
IPQ9	0,395	-0,851
IPQ10	0,358	-0,919
IPQ11	0,723	-0,354
IPQ12	0,595	-0,532
IPQ13	0,364	-0,907
IPQ14	0,432	-0,786

Table 6.12: p-values and Z-scores obtain from the Mann-Whitney U test applied to the IPQ.

The results from Table 6.11 were analyzed according to the four variables (defined in Table 5.5) and their means (defined in Table 5.6).

The G variable, for Groups A and B, is in the range of ”Very Good”, with Group B having a slightly higher value, but for the Teachers, the value is in the ”Moderate” level. This shows that Students had a higher sense of being in a VE than the Teachers. Reasons for these results could be, on the one hand, since it is thought of as a study tool for the students, there is no need for major movements and locations; on the other hand, teachers think of the application as a new teaching method, therefore the lack of major movements can affect the sense of being in a VE, or missing features that could really emphasize the 3D environment.

The SP variable has the same value on Group A and Group B (in the ”Very Good” range), but the Teachers’ value decreases to the ”Good” level. The students’ result indicates that, whether or not having the side graph, the sense of being physically present in the VE is high, but the same does not occur for the Teachers, as they do not feel physically present in the VE. This could be due to either the lack of major movements in the real world or even the level of detail of the application.

The INV variable has the ”Moderate” value in Group A and the Teachers, but Group B is one level above, in the ”Good” range. These results are a direct consequence of the location where the test sessions took place. The university clinic, being a work environment and, at the same time, a study environment for apprentices, becomes a noisy environment, not allowing a silent environment for maximum concentration and bringing up the awareness of the real world surrounding the participant. Nonetheless, the positive aspect of the situation is that the results do not fall into the negative levels of the scale, meaning that even with a noisy ambiance, it is still feasible to work with IMPLANTIGRAPH.

Last but not least, the REAL variable has the students’ values in the ”Bad” range and the teachers’ one in the ”Moderate” range, meaning that there is almost no realism in the VE. In fact, there is no parallel to compare with real life: when students are studying, they do not have an interactive side graph with them to study, and when they use physical models of the jaw, these do not contain indications like the floating graph, therefore not even existing a connection between the two, so the results, despite the fact that they are on the lower levels of the scale, are expected. Besides, the 3D models presented in the prototype, although being patient-specific models, may not look realistic enough for students and teachers to feel that they have a real model in front of them.

The results from the Mann-Whitney U test, presented in Table 6.12, show that all Z-values are negative, indicating that Group B has greater values than Group A (in fact, Table 6.11 shows that, besides the SP variable where both groups have the same result, Group B has higher values than Group A); however, all p-values are bigger than *alpha*, so the results can not be considered statistically significant.

All things considered, we can conclude that the students felt a higher sense of being present in a VE than the teachers, but the values are generally between ”Moderate” and ”Good”. The awareness of the real-world surroundings and the lack of realistic ambiance are the major downsides to IMPLANTIGRAPH. Note that the difference between having one or two layouts can not be fully answered since the statistical results do not firmly confirm such differences.

6.8 Verbal User’s Feedback

At the end of the sessions, participants were asked to attend semi-structured interviews to provide detailed feedback related to IMPLANTIGRAPH, the layouts, its advantages and disadvantages, and suggestions for further improvements. Many answers and comments were common to almost all participants, but we also had unique or unusual ideas. They are identified by participant(s) ID. An ID consists of a number followed by a letter. The number ranges from 1 to 15, and the letter corresponds to A, B, or T. In this identification, the letter A corresponds to Group A, who only tested the floating graph; the letter B corresponds to Group B, who tested both layouts; the letter T corresponds to Teachers. The feedback was summarized in the themes below.

6.8.1 Complement to Conventional Studying Methods

All students said that IMPLANTIGRAPH, overall, was a good complement to their studies. Group A stated that the information was ”easy to visualize” (5A, 14A) and, together with a ”3D perspective” (13A), makes it a ”more interactive way of learning” (1A, 5A). It feels like a great ”studying tool for beginners and non-beginners” (3A), as we can ”move the model” (5A, 8A, 9A, 10A).

Group B had the same opinion, but as for the two layouts, the side graph was ”less useful” than the floating graph (1B, 13B, 14B), but the ”interaction between the two” was positive (7B). ”It won't be a complete substitute, but it is really useful to study because it is 3D” (4B, 10B), and ”helps perceiving the exact locations” (5B). ”Having the information listed together with an interaction” is also positive (7B)

Teachers also agree that IMPLANTIGRAPH is a good complement, it is ”logical to have both layouts” (1T), ”one complements the other” (2T), and helps ”visualizing anatomical areas” (3T).

6.8.2 Interaction and Content Benefits

Overall, the floating graph was the elected feature of IMPLANTIGRAPH. Group A said that the ”3D perspective” (1A, 3A, 10A) of the floating graph was ”better than using books” (1A, 6A, 10A, 11A), as they could see up close the ”exact locations” (3A, 4A, 7A, 12A, 14A) by ”moving the model” (3A, 8A, 11A, 15A), and VR brought ”spatial visualization” (5A(to a new level, as they can almost be ”inside the model” (5A); it is ”easy to use and interact with”, as said before, making it a more ”interactive” and ”stimulating” way to learn (4A, 6A, 7A, 8A, 9A, 10A, 11A).

Group B said that the ”interaction between the two layouts” was a ”good” idea (1B, 6B, 10B), the ”color scheme was a major help” (7B, 14B), the prototype is ”good for memorization and revision” (3B, 4B, 5B), and overall ”easy to use, to interact with, and intuitive” (2B, 3B, 4B, 5B, 10B, 11B, 12B, 13B); one student said that ”having the mind map helps a lot in memorization” (10B) when talking about the side graph, a reference to Buzan's work. Teachers said that IMPLANTIGRAPH ”eases memorization” (1T) and is ”interactive and intuitive” (2T, 3T).

6.8.3 Limitations to the Prototype

When asked about limitations and difficulties, Group A and Group B said that ”some of the buttons” from the floating graph, ”when too close together, make it hard to reach and click” (3A, 8A, 9A, 15A, 6B, 9B, 14B), and using the prototype for ”an extended period of time can be tiresome” (5A, 11A, 2B, 9B). Some students also complained about the ”controllers’ sensibility” (2A, 7A, 8A, 13A, 12B) when trying to click on the buttons of the floating graph, and the fact that the ”trajectories of the arteries and nerves” are not represented (11B). One teacher complained that ”only the exterior was visible”, there was no way to see ”intersections or change transparency” (2T).

6.8.4 Proposals for New Features

Students from both groups gave really interesting ideas:

- adding the trajectories of arteries, veins, and nerves, instead of a single circular button (1A, 2A, 3A, 11A, 4B, 6B, 10B, 11B, 14B);
- a filter menu to see only a type of constituents (5A, 7A, 13A)
- adding surrounding ambient music to help concentrate (3A, 3B, 11B);
- a feature to add a CBCT image and train a real clinical case inside the application (4A, 6A, 8A);
- add more information to the constituents (more descriptive information regarding each bone, each artery...) (3A, 6A, 2B, 8B, 14B, 15B);
- being able to see several versions of the same model spread across the space (a bone model, a face model, the model with teeth...) (3B);
- trying to ”gamify” the prototype with interactive activities or follow-along tutorials (2A, 4A, 10B).

As for the teachers, here are some ideas they would like to see in our prototype:

- ”gamify” the prototype with a topographic quiz (1T);
- having the arteries and nerves’ trajectories (2T);
- a filter menu (2T, 3T);
- being able to see several versions of the same model spread across the virtual space (a bone model, a face model, the model with teeth...) (3T).

6.8.5 Future Acceptability

When asked if participants (both students and teachers) would use the prototype, all of them said ”yes”: to use it ”while studying anatomy”, to ”revive concepts before an exam”, to ”plan real surgeries”, and ”to teach” (this comment came from one of the teachers).

7

Conclusions & Future Work

Contents

After all the theoretical study, the implementation of the prototype and its testing, and the analysis of the results, we present the mains conclusions of our work (Section 7.1, as well as ideas for future work on our prototype (Section 7.2).

7.1 Conclusions

On the one hand, we learned that dentistry students, in particular, draw and use diagrams in the form of graphs to study hierarchies of the most varied subjects, be it arteries, nerves, or even more complex structures that encompass these two. In a way, they create a mind map of the information they have to study, adding some color filtering for different branches of the graphs. On the other hand, VR has been studied and tested recently in the medical field, whether for general anatomic 3D atlas or to train surgical procedures. With regard to dentistry, the focus of the exploration of VR has been on the training of procedures, like anesthesia or drilling.

The proposal of our work was to join these two different fields and study the use of anatomical graphs in immersive 3D environments, by developing a high-fidelity prototype that serves both as a learning and a teaching tool for topographic anatomy applied to dental implantology. IMPLANTIGRAPH is a VR prototype that runs on Oculus Quest (either Oculus Quest 1 or Oculus Quest 2), and it is divided into four different anatomical regions regarding implantology knowledge, with each region having a 3D model of the jaw and the most relevant anatomical concepts that dentists needed to know and locate to perform a dental implant placement. These anatomical concepts are presented in two different layouts: the ”floating graph” (a series of floating tags that involve the 3D model) and the ”side graph” (a hierarchy-like visualization of the same subjects, based on the students' diagrams).

In order to gather ideas for implementation, design, and content, interview sessions were held with dental students and anatomy teachers, as well as some co-design sessions with a dentist where we gathered the relevant anatomical structures and concepts to be included in the application, as well as discussing drafts, sketches, and low-fidelity prototypes to ensure that our idea was coherent and we could move towards a high-fidelity prototype.

With the high-fidelity prototype developed, we conducted a user study with 30 Master's students in Dentistry and three teachers with specialties in *Implantology*, *Oral Rehabilitation and Implantology*, and *Oral Pathology and Surgery (with a subspecialty in Oral Cancer*. The user study let us confirm that IMPLANTIGRAPH, as a whole, offers a reliable studying and teaching tool in dental implantology. However, we can identify three major limitations. One is regarding the floating graph: some anatomical concepts are too close to each other, making it difficult for the user to click exactly on the constituent he pretends to analyze. Another one is regarding the side graph: the vast majority of the participants did not find this feature as useful and appealing as the floating graph, and since this feature is the main idea of our project, further and intensive development must be performed to make this feature as attractive and useful as the floating graph. This is justified by analyzing all the results from chapter 6.

From Section 6.1, we infer that students who used both layouts took more time answering the anatomical quizzes, which is coherent since they have more displays of information to analyze. The number of errors, in Section 6.2, proved that, although there is no major significance in using one or two layouts, using both lead to fewer incorrect answers. Section 6.3 allowed us to conclude that the more concepts the participants had to study, the more relevant the help of using the side graph. The User Satisfaction (Section 6.4) revealed that participants evaluated positively both layouts, but preferred the floating graph. The SUS (Section 6.5) demonstrated how easy and intuitive our UI is: on a scale from 0 to 100, Group A rated the lowest value, 87,50, which is a very good result. The NASA-TLX (Section 6.6) proved that working with IMPLANTIGRAPH does not produce high levels of cognitive workload nor high demands levels. The IPQ (Section 6.7) revealed that students felt a higher sense of being in a VE and a higher sense of being physically present in a VE, than the teachers; all participants were affected by the noisy ambiance surrounding and agreed that there is almost no realism in the VE (it does not look entirely like the real world). As for the semi-structured interviews, the feedback received was positive, and the answers highlighted and helped us identify the limitations we described above.

By correlating the results, a major conclusion we take is that the use of side graphs is a positive feature: directly, the participants preferred the floating graph, probably due to its direct connection with the 3D model, but indirectly, the results were consistently better when using the side graph. This means we must further investigate how can we transform the side graph feature into an appealing, useful, and a more complete tool that enhances the studying and teaching of dental anatomy methodologies turning IMPLANTIGRAPH into a crucial and relevant application for implantology students and teachers.

Summing everything up, we can answer the research questions formulated in Section 1.2:

- **RQ1** - Can knowledge representation as AAGs inside VR educational tools for oral surgery facilitate the learning and perception of anatomical structures and understanding of its topology relations?

- A1 - Anatomy graphs facilitate the learning process: the results from the number of incorrect answers and some feedback from the semi-structured questions support this answer.

- **RQ2** - Can knowledge representation as AAGs inside VR educational tools benefit oral surgery education?

- A2 - The feedback received from both the students and the teachers was very positive, especially the answers from subection 6.8.5, where the majority of the participants would use our prototype.

- **RQ3** - Are AAGs inside VR educational tools a better approach to teach oral surgery, rather than current approaches such as visual textbooks?

- A3 - We do not have enough data that fully supports such a question; however, in subsection 6.8.1 participants stated that IMPLANTIGRAPH was a great complement to the current approaches. Therefore, we can not say that is a better approach.

We can also verify if our hypotheses from Section 1.3 are rejected or not:

- **H1** - AAGs in VR environments help dental students to perceive mental models faster than current learning methods.
- A1 - In Section 6.1, the results show that the quiz completion time for both layouts is slightly higher than just for the conventional layout, and this could be due to the construction of mental maps, as students can think of the two layouts of obtaining the information they have just studied and try to build a mental model from those two to try to answer correctly. So we can verify this first hypothesis.
- **H2** - AAGs in VR environments benefit the learning and teaching of dental surgical anatomy.
- A2 - All the feedback from the semi-structured interviews in Section 6.8 support this hypothesis, so we also verify it.

7.2 Future Work

Our work provided many positive insights and results that open many questions to be addressed in the future. From the feedback received from participants, as well as ideas that came up during the development, interesting and insightful features can be thought out in future work. One example is the use of another labeling layout, named **wrapping graph**, consisting of an extension of the conventional labeling, by adding the main structure and the different domains to the already existing floating tags (all the anatomic information that is on the side graph will be presented in floating tags, framing and wrapping the 3D model). It can be thought of as a *dome* involving the 3D model.

A menu of filters for both layouts was a feature the majority of the participants mentioned. Having the option to select, for example, only the domains we want to study: if the user wants to study only the Vascularization class, he could filter that domain, being able to see just the floating tags and a side graph dedicated to that domain.

Another interesting idea was given by a student to improve the side graph. Due to its size, the side graph could be either *collapsible*, in order to choose just the subjects that are going to be studied, or instead of having one large side graph, having *little graphs*, one for each domain, reminding the idea of *post-its*. Both these options go along with the filters just spoken before.

One teacher indicated that having several options to place the 3D model according to the different anatomic views would be very helpful. Just like anatomy books have several views (the front view, the right-side view, or the back view), we could have an extra option to place the model at that exact view, and not have to manually rotate it.

Regarding VR, taking advantage of the resources that it offers to us and focusing on interactivity, we could explore the *Gamification* of the application in several aspects:

- The Tutorial task we asked the participants to perform could be transformed into an interactive follow-through tutorial, where the instructions appear sequentially as the user follows them;
- The anatomy quizzes could be performed inside the application. As an example, a task where the user must place the labels on the corresponding slots that appear around the 3D model. This idea can be applied in sample tests for students to study, and also as part of the evaluation criteria, giving teachers the possibility to create their own anatomical questions;
- Having the option for students and teachers to create graphs from scratch could improve anatomy studying and lecturing by making it more interactive.

We wanted to study if anatomical graphs in immersive 3D environments benefit the learning and teaching process, so apart from all the prior ideas, the main focus for the future should be on improving the side graph, study more its possible applications, different designs, newer layouts, different color scheme, and what more to present and how to present the anatomical information. The results were promising, the potential exists: it is essential to continue the work done so far.

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A

User Study Support Material

Students' Semi-Structured Interview

1. In your opinion, do anatomical graphs in VR complement the learning of surgical anatomy applied to implantology?
2. What advantages/benefits/improvements do you derive from using graphs for learning surgical anatomy to implantology? Explain in as much detail as possible.
3. What are the disadvantages/limitations/difficulties that you draw from the application of graphs for learning surgical anatomy applied to implantology? Explain in as much detail as possible.
4. Taking into account the general concepts of the application, what changes would you make to the tool (new ideas, proposals, new interaction paradigms) to make the tool and the learning process more natural and beneficial?
5. Would you use the anatomical graphs in VR, and, if yes, how?

Teachers' Semi-Structured Interview

1. In your opinion, do anatomical graphs in VR complement the teaching of surgical anatomy applied to implantology?
2. What advantages/benefits/improvements do you derive from the application of graphs for teaching surgical anatomy applied to implantology? Explain in as much detail as possible.
3. What are the disadvantages/limitations/difficulties that you draw from the application of graphs for teaching surgical anatomy applied to implantology? Explain in as much detail as possible.
4. Taking into account the general concept of the application, what changes would you make to the tool (new ideas, proposals for use, new interaction paradigms) to make the tool and the teaching process more natural and beneficial?
5. Would you use the anatomical graphs in VR, and, if yes, how?

Informed Consent Form

Dear Participant, we are conducting a study about the potential of using a Virtual Reality tool to teach and learn anatomy. Therefore, we require your participation to contribute to our work!

To take part in this study, you will participate in a session in which you will be asked to perform some tasks on our prototype, in order for us to gather your feedback and analyse the power of our idea!

At the beginning of the session, you will be asked to fill a Demographic Profile form. Then we pass onto the test session, where we will be collecting data via photographies, videos, and screen recordings of your performance, if you allow it!

All information obtained will be treated confidentially and may not be revealed to anyone. However, it may be used for statistical analysis and for scientific purposes. We commit to keep the data for 1 years maximum. After this period, all information will be deleted. If you wish, you can request the removal of the data at any time. Your authorization to participate in this study is voluntary, and you may, if you wish, deny the consent and abandon the session at any time.

To participate in this session, we ask you to fill in the Consent Form bellow, agreeing or disagreeing with the sentences written.

Thank you for your collaboration!

* Indica uma pergunta obrigatória

1. I have read and understood the purpose of this study. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

2. I have read and understood the session I am being asked to participate. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

3. I, as a participant, authorize, during the session, the collection of information in the form of Images. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

4. I, as a participant, authorize, during the session, the collection of information in the form of Video Recordings. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

Figure A.1: Students' Informed Consent Form, part 1.

5. I, as a participant, authorize, during the session, the collection of information in the form of Screen Recordings. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

6. I, as a participant, authorize the use of the data collected during the session. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

7. I, as a participant, understood that I can have access to the data collected, during or after the study, by contacting the main researcher of the project. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

8. I, as a participant, authorize the processing of the data collected within the scope of the study for purposes of analysis, research and dissemination of results in scientific publications by the researchers of this project. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

9. I understand that the participation in this study is voluntary and I may withdraw at any time during the session without providing any explanation. If I withdraw, I will not be subject to any consequence and the data collected so far will be removed and destroyed. *

   Marcar apenas uma oval.

   - I agree
   - I do not agree

10. I authorize my participation in this session to contribute to the study described above, and I, as a participant, accept its conditions. *

    Marcar apenas uma oval.

    - I agree
    - I do not agree

Figure A.2: Students' Informed Consent Form, part 2.

Informed Consent Form

Dear Participant, we are conducting a study about the potential of using a Virtual Reality tool to teach and learn anatomy. Therefore, we require your participation to contribute to our work!

To take part in this study, you will participate in a session in which you will be presented with a quick demonstration of our prototype, followed by an experimentation phase where you are free to use the application and explore all the contents!

At the beginning of the session, you will be asked to fill a Demographic Profile form. Then we pass onto the session itself, where we will be collecting data via photographies, videos, and screen recordings of your performance, if you allow it!

All information obtained will be treated confidentially and may not be revealed to anyone. However, it may be used for statistical analysis and for scientific purposes. We commit to keep the data for 1 years maximum. After this period, all information will be deleted. If you wish, you can request the removal of the data at any time. Your authorization to participate in this study is voluntary, and you may, if you wish, deny the consent and abandon the session at any time.

To participate in this session, we ask you to fill in the Consent Form bellow, agreeing or disagreeing with the sentences written.

Thank you for your collaboration!

* Indica uma pergunta obrigatória

Figure A.3: Teachers' Informed Consent Form Header (the questions are the same as the Informed Consent Form for the students)

Demographic Profile Form

* Indica uma pergunta obrigatória

1. Gender *

   Marcar apenas uma oval.

   - Male
   - Female
   - Prefer not to say
   - Outra: ____________________

2. Age (number) *

   ____

3. Education *

   Marcar apenas uma oval.

   - Undergraduate Studies/Bachelor Degree
   - Graduate/Master Degree
   - Post-Graduate Degree
   - PhD Degree

4. Academic Background (e.g. Dentistry, Nursing, etc) *

   ____

5. Employment

   Marcar apenas uma oval.

   - Student *Avançar para a pergunta 9*
   - Not Employed *Avançar para a pergunta 9*
   - Employed *Avançar para a pergunta 6*
   - Retired *Avançar para a pergunta 9*

Employment

Figure A.4: Demographic Profile Form, part 1.

6. Specialty *

7. Subspecialty (if applied) *

8. Years of Experience (number) *

VR Experience

9. Is this your first experience with Virtual Reality technology? *

Marcar apenas uma oval.

- Yes, it is my first time
- No, it is not my first time

10. How often do you use Virtual Reality technology? *

Marcar apenas uma oval.

- Never
- Rarely
- Monthly
- Weekly
- Daily

Figure A.5: Demographic Profile Form, part 2.

Quiz Task 1

Prima "seguinte" quando o examinador assim o disser. A partir desse momento, o tempo decorrido será contado até submeter o exame.

* Indica uma pergunta obrigatória

Quiz

1. 1. Qual destes acidentes anatómicos mais provavelmente pode causar uma hemorragia extensa durante a recolha de um enxerto conjuntivo? *

   Marcar apenas uma oval.

   - Artéria Palatina Menor
   - Artéria Palatina Maior
   - Artéria Nasopalatina
   - Artéria Antral (Sinusal)

2. 2. Relativamente à região maxilar posterior, assinale a afirmação correta. *

   Marcar apenas uma oval.

   - O nervo alveolar superior médio apresenta-se constantemente próximo do ápex do 2º pré-molar superior.
   - A artéria platina maior anastomosa-se com a artéria nasopalatina.
   - O corpo adiposo maxilar (Bola de Bichat) situa-se para palatino da região dos 3ºs molares.

3. 3. Qual o acidente anatómico que não pode lesar durante a colocação de implantes entre os dentes 24 e 27? *

   Marcar apenas uma oval.

   - Artéria sinusal
   - Pavimento do seio maxilar
   - Nervo alveolar superior médio (caso exista)
   - Músculo grande zigomático

Figure A.6: Anatomical Quiz 1.

Quiz Task 2

Prima "seguinte" quando o examinador assim o disser. A partir desse momento, o tempo decorrido será contado até submeter o exame.

* Indica uma pergunta obrigatória

Quiz

1. 1. Relativamente à região mandibular anterior vestibular, qual o músculo que não tem inserção nesta zona? *

   Marcar apenas uma oval.

   - Mentoneano
   - Depressor da asa do nariz
   - Milohoideu
   - Todas as anteriores (todos os músculos se inserem na região da mandíbula anterior)

2. 2. Relativamente ao 5º sextante, quais os riscos vasculares que deve considerar aquando da colocação de implantes? *

   Marcar apenas uma oval.

   - Artéria sublingual
   - Artéria mentoneana
   - Artéria incisiva
   - Todas as anteriores (todos devem ser considerados na cirurgia de colocação de implantes nesta região)

3. 3. Quais as inserções musculares relevantes nas apófises geni? *

   Marcar apenas uma oval.

   - Genioglosso
   - Digástrico
   - Sublingual
   - Nenhuma das anteriores

Figure A.7: Anatomical Quiz 2.

Quiz Task 3

Prima "seguinte" quando o examinador assim o disser. A partir desse momento, o tempo decorrido será contado até submeter o exame.

* Indica uma pergunta obrigatória

Quiz

1. 1. Quais os acidentes vasculo-nervosos a considerar durante a osteotomia para colocação de implantes na região maxilar anterior? *

   Marcar apenas uma oval.

   - Nervo infraorbitário
   - Nervo nasopalatino
   - Artéria nasopalatina
   - Todas as anteriores (a, b e c devem ser considerados)

2. 2. Qual destes músculos é o mais medial dos que se inserem na região maxilar anterior? *

   Marcar apenas uma oval.

   - Músculo pequeno zigomático
   - Músculo nasal - parte alar
   - Elevador do lábio superior e asa do nariz
   - Elevador do ângulo da boca

3. 3. Qual o acidente anatómico que não pode lesar durante a colocação de implantes entre os dentes 13 e 23? *

   Marcar apenas uma oval.

   - Artéria nasopalatina
   - Pavimento das fossas nasais
   - Músculo pequeno zigomático
   - Nenhuma das anteriores (todos são acidentes anatómicos passíveis de lesão nessa região)

Figure A.8: Anatomical Quiz 3.

User Satisfaction

* Indica uma pergunta obrigatória

1. Participant Number *

Floating Labels

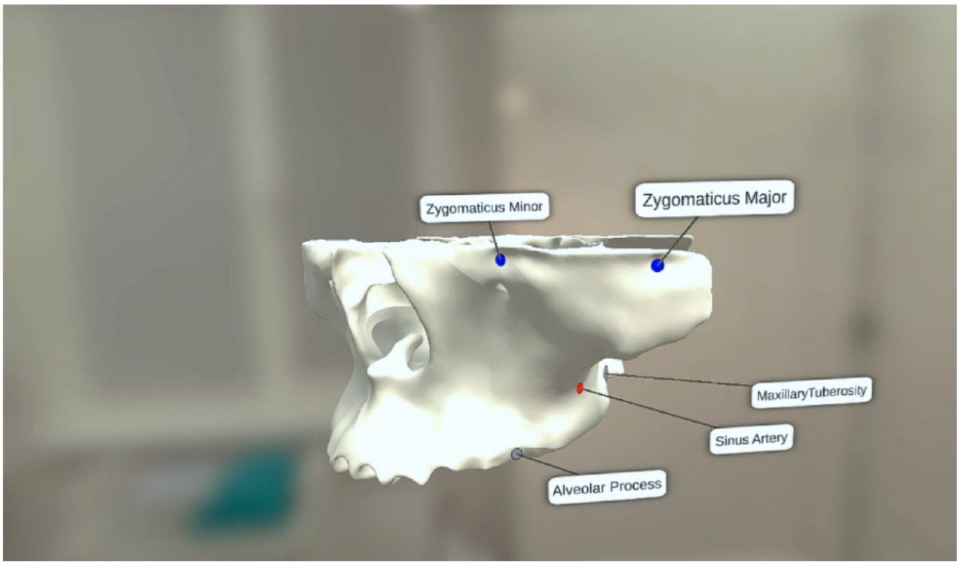


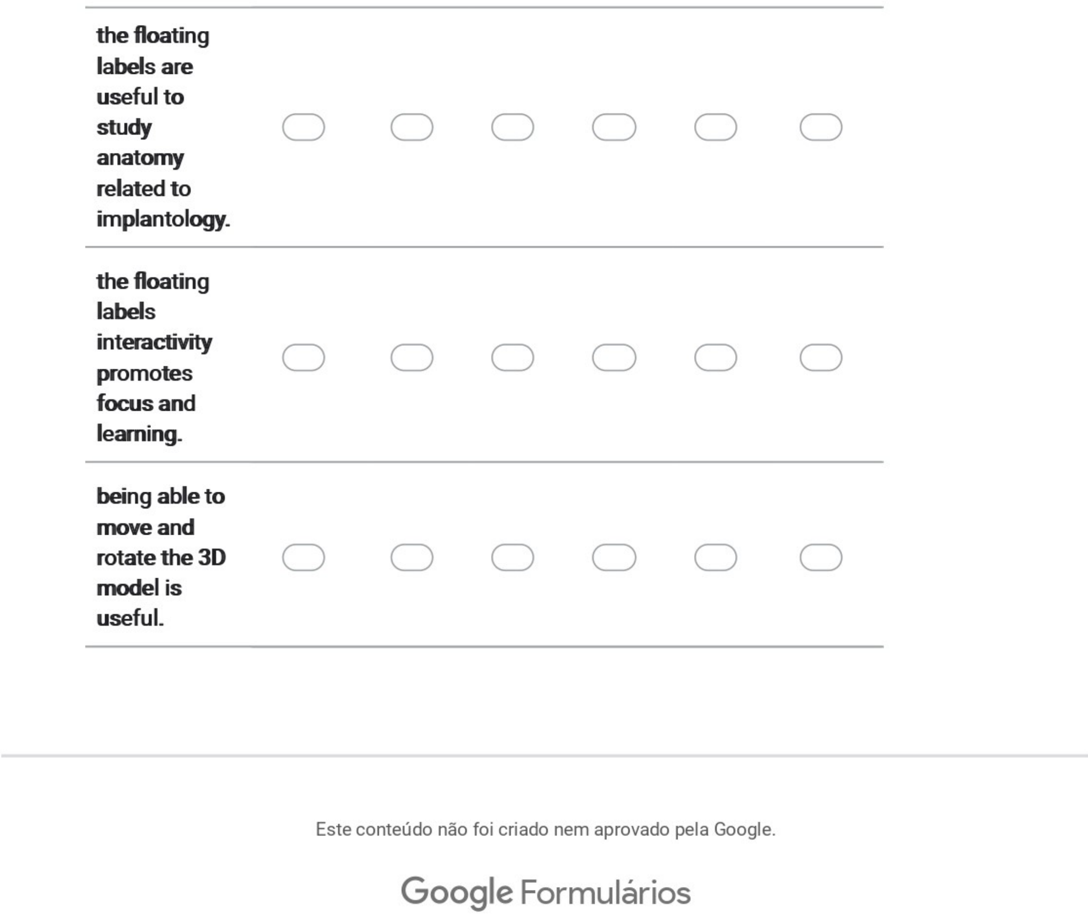
Figure A.9: Group A's User Satisfaction and Preference Form, part 1.

2. In general, regarding the Floating Labels layout, do you consider that... *

Marcar apenas uma oval por linha.

	1 - Strongly Disagree	2	3	4	5	6 - Strongly Agree
the use of the floating labels helped me to locate elements anatomically.	⬭	⬭	⬭	⬭	⬭	⬭
the floating labels helped me identify the different types of constituents.	⬭	⬭	⬭	⬭	⬭	⬭
the use of the floating labels helped me to memorize the constitution of the region being studied.	⬭	⬭	⬭	⬭	⬭	⬭
the use of the floating labels helped me perceived the anatomy of the region being studying.	⬭	⬭	⬭	⬭	⬭	⬭
the floating labels are useful.	⬭	⬭	⬭	⬭	⬭	⬭
the floating labels are easy to use.	⬭	⬭	⬭	⬭	⬭	⬭
the floating labels helped fast learning.	⬭	⬭	⬭	⬭	⬭	⬭

Figure A.10: Group A’s User Satisfaction and Preference Form, part 2.



the floating labels are useful to study anatomy related to implantology.						
the floating labels interactivity promotes focus and learning.						
being able to move and rotate the 3D model is useful.						

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Figure A.11: Group A’s User Satisfaction and Preference Form, part 3.

User Satisfaction

* Indica uma pergunta obrigatória

1. Participant Number *

Floating Labels

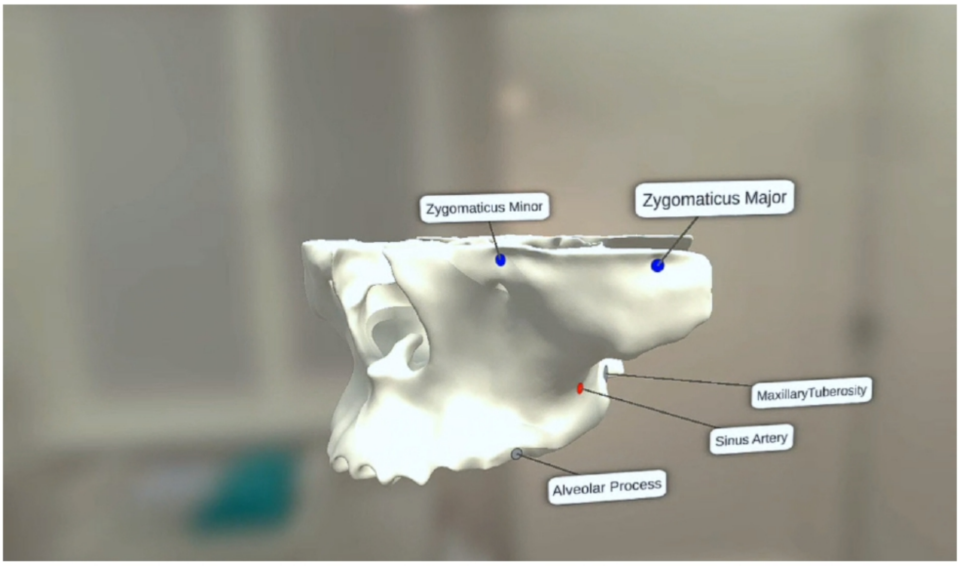

Figure A.12: Group B and Teachers' User Satisfaction and Preference Form, part 1.

2. In general, regarding the Floating Labels layout, do you consider that... *

Marcar apenas uma oval por linha.

	1 - Strongly Disagree	2	3	4	5	6 - Strongly Agree
the use of the floating labels helped me to locate elements anatomically.						
the floating labels helped me identify the different types of constituents.						
the use of the floating labels helped me to memorize the constitution of the region being studied.						
the use of the floating labels helped me perceived the anatomy of the region being studying.						
the floating labels are useful.						
the floating labels are easy to use.						
the floating labels helped fast learning.						

Figure A.13: Group B and Teachers' User Satisfaction and Preference Form, part 2.

the floating labels are useful to study anatomy related to implantology.						
the floating labels interactivity promotes focus and learning.						
being able to move and rotate the 3D model is useful.						

Side Graph

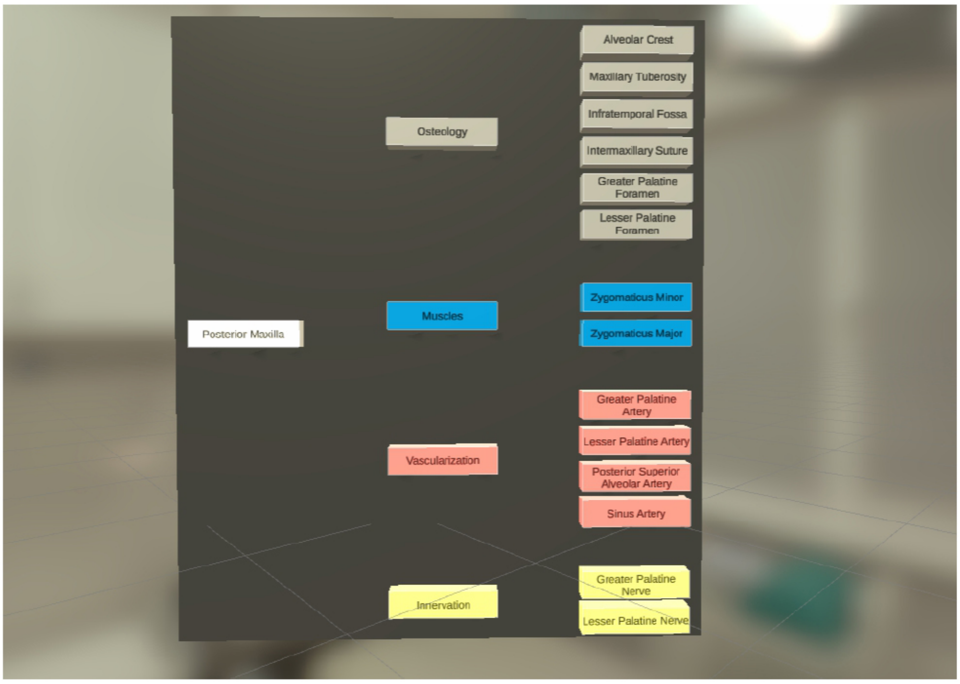

Figure A.14: Group B and Teachers' User Satisfaction and Preference Form, part 3.

3. In general, regarding the Side Graph layout, do you consider that... *

Marcar apenas uma oval por linha.

	1 - Strongly Disagree	2	3	4	5	6 - Strongly Agree
the use of the side graph helped me to locate elements anatomically.						
the side graph helped me identify the different types of constituents.						
the use of the side graph helped me to memorize the constitution of the region being studied.						
the use of the side graph helped me perceived the anatomy of the region being studying.						
the side graph is useful.						
the side graph is easy to use.						
the side graph helped fast learning.						

Figure A.15: Group B and Teachers' User Satisfaction and Preference Form, part 4.

the side graph is useful to study anatomy related to implantology.						
the side graph interactivity promotes focus and learning.						
the link between the side graph and the 3D model (clicking on the nodes) helps the anatomical study of the region.						
being able to grab and move the side graph is useful.						

User Preference

4. Which layout do you prefer?

Marcar apenas uma oval.

- Floating Labels
- Side Graph

Figure A.16: Group B and Teachers' User Satisfaction and Preference Form, part 5.

5. Which layout was the most appealing?

Marcar apenas uma oval.

- Floating Labels
- Side Graph

6. Rank the layouts, where 1 is the highest value (your preferred layout).

Marcar apenas uma oval por linha.

	1	2
Floating Labels		
Side Graph		

Este conteúdo não foi criado nem aprovado pela Google.

Google Formulários

Figure A.17: Group B and Teachers' User Satisfaction and Preference Form, part 6.

B

Source Code Excerpts

```
Unity Script (1 asset reference) | 0 references
public class DropdownStartMenu : MonoBehaviour
{

    // Dropdown value
    [HideInInspector] public int taskID;

    // Start and Close buttons
    [Header("Buttons")]
    public Button StartButton;
    public Button CloseButton;

    // Start Function
    Unity Message | 0 references
    void Start()
    {
        // Button handlers
        StartButton.onClick.AddListener(StartSimulation);
        CloseButton.onClick.AddListener(CloseProgram);

    }

    // Loads the scene selected on the dropdown meny by its index
    1 reference
    public void StartSimulation()
    {
        switch (taskID)
        {
            case 0: SceneManager.LoadScene("Level3_PosteriorMandible", LoadSceneMode.Single); break;
            case 1: SceneManager.LoadScene("Level1_PosteriorMaxilla", LoadSceneMode.Single); break;
            case 2: SceneManager.LoadScene("Level4_AnteriorMandible", LoadSceneMode.Single); break;
            case 3: SceneManager.LoadScene("Level2_AnteriorMaxilla", LoadSceneMode.Single); break;
        }
    }

    // Gets the index of the dropdown choice
    0 references
    public void GetDropdownIndex(int index) { taskID = index; }

    // Click on Close Button
    1 reference
    public void CloseProgram() { Application.Quit(); }

}
```

Figure B.1: *DropdownStartMenu* class.

```
Unity Script (95 asset references) | 0 references
public class ClickButtons : MonoBehaviour
{
    public GameObject label;
    public GameObject button;
    public LineRenderer line;
    Vector3 myVector = new Vector3(0.0f, 0.0f, -0.01f);

    [Header("Side Graph")]
    public GameObject sideLabel;
    public Material highlightMaterial;

    private Material originalMaterialSideLabel;

    // Start is called before the first frame update
    Unity Message | 0 references
    void Start()
    {
        line.positionCount = 2;
        line.enabled = false;

        // get original material from side label
        originalMaterialSideLabel = sideLabel.GetComponent<Renderer>().material;
    }

    // Activates/Deactivates the labes and their lines
    0 references
    public void showLabel()
    {
        if (label.activeSelf) {
            label.SetActive(false);
            line.enabled = false;
            sideLabel.GetComponent<Renderer>().material = originalMaterialSideLabel;
        }
        else {
            label.SetActive(true);
            line.enabled = true;
            sideLabel.GetComponent<Renderer>().material = highlightMaterial;
        }
    }

    // Update is called once per frame
    Unity Message | 0 references
    void Update()
    {
        // Sets the connection of the line between 2 game objects
        line.SetPosition(0, button.transform.position);
        line.SetPosition(1, label.transform.position - myVector);
    }
}
```

Figure B.2: *ClickButtons* class.

```csharp
        // Check whether we have the controllers attached
        if (leftController == null) { Debug.Log("Error: Left Controller not attached to the script."); }
        if (rightController == null) { Debug.Log("Error: Right Controller not attached to the script."); }

        originalMaterialSideLabel = this.GetComponent<Renderer>().material;                 // get the original material from the side label
        originalMaterialFloatingLabel = floatingLabel.GetComponent<Renderer>().material;    // get the original material from the floating label

        leftController.activateAction.action.performed += ShowFloatingLabel;
        rightController.activateAction.action.performed += ShowFloatingLabel;

    }



    2 references
    private void ShowFloatingLabel(UnityEngine.InputSystem.InputAction.CallbackContext obj)
    {
        try
        {
            RaycastHit res;
            if (rightRay.TryGetCurrent3DRaycastHit(out res) || leftRay.TryGetCurrent3DRaycastHit(out res))    // verify if we hit something
            {
                string colliderName = res.collider.name;        // name of the collider that was hit
                if (colliderName == this.name)                  // compare collider with "this" to avoid the collider "SideGraph"
                {
                    if (floatingLabel.activeSelf)
                    {
                        floatingLabel.SetActive(false);
                        floatingLabel.GetComponent<LineRenderer>().enabled = false;
                        floatingLabel.GetComponent<Renderer>().material = originalMaterialFloatingLabel;    // change floating label material to the original
                        this.GetComponent<Renderer>().material = originalMaterialSideLabel;                 // change side graph label to original material
                    }
                    else
                    {
                        floatingLabel.SetActive(true);
                        floatingLabel.GetComponent<LineRenderer>().enabled = true;
                        floatingLabel.GetComponent<Renderer>().material = highlightMaterial;    // change floating label material to highlight
                        this.GetComponent<Renderer>().material = highlightMaterial;             // change side graph label material to highlight

                        InvokeRepeating("FloatingLabelHightlight", 1f, 0f);                     // 1s delay to change from the highlighted material to the original material
                    }
                }
            }
        }
        catch (System.NullReferenceException) { }
    }


    0 references
    private void FloatingLabelHightlight()
    {
        floatingLabel.GetComponent<Renderer>().material = originalMaterialFloatingLabel;
    }
```

Figure B.3: *ClickSideGraphLabel* class.