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THE IMPACT OF METAVERSE TECHNOLOGIES ON
TEMPOROMANDIBULAR JOINT EDUCATION IN DENTISTRY

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ABSTRACT

THE IMPACT OF METAVERSE TECHNOLOGIES ON TEMPOROMANDIBULAR JOINT EDUCATION IN DENTISTRY

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The complex structure known as the Temporomandibular Joint (TMJ) is essential for chewing and speaking, and it also plays a significant role in the treatment of oral and dental diseases. Radiologists, dentists, and orthodontists are all interested in TMJ. However, due to its complex structure and habits, it can be challenging for dentists to visualize and understand patients' TMJ behaviours. The articular disc is a crucial component of the TMJ that facilitates hinging and gliding movements between the mandibular and temporal articular bones. TMJ issues are difficult to diagnose due to the intricate anatomical components and relationships involved. The visualization of the TMJ structures and their movements can be challenging when learning them. It seems that the traditional dental education methods may not be sufficient in providing an effective learning experience for dental students. This is a study that aims to address this issue by creating an instructional system that simulates the anatomic structures of the human TMJ in a 3D virtual environment. The simulations are presented in this work through virtual reality (VR) glasses with a metaverse user interface, which could potentially make it easier to understand the complexities of the TMJ. A virtual model is developed to simulate TMJ behaviours in this study, using virtual human body

components. The study describes the specifics of the built system, including the intended virtual model features and user interactions. The study details the experiences of teacher and student users in the Metaverse-based classroom, including their interactions with the virtual simulation model, other students, and instructors. This study is the first case to use synchronized or asynchronous learning models to provide TMJ courses with a metaverse-enriched educational environment. The findings of the study provide a model for effectively planning classrooms incorporating virtual reality and metaverse interactions in the future. The findings lend credence to the hypothesis that metaverse technologies may be created for better TMJ functional modelling and anatomical structure in three-dimensional virtual spaces, enabling students to experience and see the TMJ's activities from a variety of perspectives. It also enables them to collaborate on simulated virtual structures and have discussions with peers and professionals from around the world, all in a single virtual classroom.

Keywords: Temporomandibular Joint, Metaverse, Virtual Reality, Dental Education

ÖZ

METAVERSE TEKNOLOJİLERİNİN DİŞ HEKİMLİĞİNDE TEMPOROMANDİBULAR EKLEM EĞİTİMİ ÜZERİNE ETKİSİ

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Temporomandibular Eklem (TME), konuşma ve çiğneme aktiviteleri için hayati önem taşıyan, ağız ve diş hastalıklarının tedavisinde önemli olan karmaşık bir yapıdır. Radyologlar, diş hekimleri ve ortodontistler TME ile ilgileniyor. Ancak karmaşık yapısı nedeniyle diş hekimlerinin hastaların TME davranışlarını görselleştirmesi ve anlaması zor olabilir. Eklem diski, mandibular ve temporal eklem kemikleri arasındaki menteşelenme ve kayma hareketlerini kolaylaştıran TME'nin önemli bir bileşenidir. Karmaşık anatomik bileşenler ve ilgili ilişkiler nedeniyle TME sorunlarının teşhis edilmesi zordur. TME yapılarının ve hareketlerinin görselleştirilmesi, bunları öğrenirken zorlayıcı olabilir. Diş hekimliği öğrencilerine etkili bir öğrenme deneyimi sağlamada geleneksel diş hekimliği eğitim yöntemlerinin yeterli olamayabileceği görülmektedir. Bu tezde, insan TME'sinin anatomik yapılarını 3 boyutlu sanal ortamda simüle eden bir öğretim sistemi oluşturarak bu konuyu ele almayı amaçlayan bir çalışmadır. Bu çalışmada simülasyonlar, TME'nin karmaşıklıklarının anlaşılmasını potansiyel olarak kolaylaştırabilecek bir metavers kullanıcı arayüzüne sahip VR gözlükleri aracılığıyla sunulmaktadır. Bu çalışmada TME davranışlarını simüle etmek için insan vücudu bileşenleri kullanılarak sanal bir model geliştirilmiştir. Çalışma, amaçlanan sanal model özellikleri ve kullanıcı etkileşimleri de dahil olmak üzere, inşa edilen sistemin özelliklerini açıklamaktadır. Çalışma, sanal simülasyon modeli, diğer öğrenciler ve öğretmenlerle olan etkileşimleri de dahil olmak üzere, Metaverse tabanlı

sınıftaki öğretmen ve öğrenci kullanıcılarının deneyimlerini detaylandırmaktadır. Bu çalışmada, TME kurslarına metaveri ile zenginleştirilmiş bir eğitim ortamı sağlamak için senkronize veya senkronize olmayan öğrenme modellerini kullanan ilk durumdur. Çalışmanın bulguları gelecekte sanal gerçeklik ve meta veri etkileşimlerini birleştiren sınıfların etkili bir şekilde planlanması için bir model sağlıyor. Sonuçlar, öğrencilerin TME'nin işlevlerini çeşitli bakış açıları ve açılardan deneyimlemelerine ve gözlemlmelerine olanak tanıyan, üç boyutlu sanal ortamlarda gelişmiş TME anatomik yapısı ve fonksiyonel simülasyon için metaverse teknolojilerinin geliştirilebileceği fikrini desteklemektedir. Aynı zamanda tek bir sanal sınıfta, simüle edilmiş sanal yapılar üzerinde işbirliği yapmalarına ve dünyanın dört bir yanından akranları ve profesyonellerle tartışmalar yapmalarına olanak tanır.

Anahtar Kelimeler: Çene Eklemleri, Metaverse, Sanal Gerçeklik, Dişçilik Eğitimi.

To Feraye and Adel ...

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LIST OF SYMBOLS/ABBREVIATIONS

3D	Three Dimensional
TMD	Temporomandibular Joint Disorder
TMJ	Temporomandibular Joints
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

In Dentistry, education programs understanding Temporomandibular joints (TMJ), connected muscles and mouth open and shut patterns is very challenging for the students to comprehend. Therefore, it is a major issue to prepare appropriate instructional materials to help the students visualize and understand these anatomical structures [1],[2]. Developing a teaching tool that makes the TMJ easier to grasp is a promising use of virtual reality (VR) in dentistry education. VR has emerged as a promising tool in various fields, including medical education. The development of immersive VR technology for traditional dentistry education concerning the complicated temporomandibular joint in the human skull is the focus of this study.

The intricacy of TMJ is not only an issue for the lecturer in the teaching process but also is a major slowing factor for the student in the learning process with traditional educational methods [1]. Immersion VR technology has the ability to improve dentistry education beyond what is now possible by giving students a more dynamic and interesting learning environment [3]. The goal of this project is to develop an educational system that will enhance dental education programmes' comprehension and visualisation of the intricate temporomandibular joint and its related structures by using immersive virtual reality technology.

1.1 Inspiration of the Study

This study is to provide optimal solutions to the following initial questions.

- *How hard is it for the lecturers to develop teaching materials for TMJ lectures?*

Regarding this question, several face-to-face and online meetings were done with university lecturers. In summary, they were struggling with the visualization of the overall TMJ structure and its associated anatomical parts.

- *How hard is it for the students to understand teaching the TMJ?*

Once again, several face-to-face and online interviews were performed with 15 individuals. It is observed that students were putting extra effort into apprehending the TMJ structure and its associated anatomical parts.

- *What are the associated anatomical parts of TMJ and how do they work together?*

This question was the foundation of the overall study as TMJ, and its related anatomical parts were to be modelled in a three-dimensional (3D) environment.

- *Which extra technologies can be used to speed up the teaching and learning curves?*

In this sense, not only modelling but also an interactive environment design is to collaborate to efficiently help with the teaching and learning processes.

These research questions provide a comprehensive framework for addressing the challenges and knowledge related to the learning complexity of TMJ and will propose new approaches to ease these learning difficulties. Moreover, they help to identify the learning challenges associated with TMJ, enhance understanding of its anatomical components, and explore the potential benefits of immersive technologies on students in dental education.

Therefore, this thesis is organized as follows: in Chapter 2, the learning difficulties of TMJ are defined and the anatomical structures of TMJ are explained. The benefits of immersive technologies are clarified in Chapter 3. The Metaverse Education Environment for TMJ learning is proposed and presented as the new era of dental education in Chapter 4.

CHAPTER 2

BACKGROUND OF THE STUDY

TMJ of the human body has a complex structure. Even though the human motor system mechanics have been resolved, their integration into a system is still a tough process to resolve [4].

The mandible, or lower jaw, and the temporal bone, or side and base of the skull, make up the temporomandibular joints (TMJ), which provide movement and rotation in front of each other [5]. The temporomandibular joint is the complex joint that connects the lower jaw to the skull. It permits a range of coordinated motions necessary for tasks including swallowing, speaking, and chewing. This joint is one of the most complex and frequently utilised joints in the human body. It is made up of bones, muscles, ligaments, and related components [6]. These joints are involved in multiple functions, including rotational and gliding movements referred to as ginglymoarthrodial joints, which are crucial for activities like chewing and speaking, emphasizing the significance of the TMJ in daily life activities. In addition to being necessary for speaking, eating, and swallowing, the temporomandibular joint is also vital for maintaining proper head and body alignment [7]. Its intricate structure and functions extend beyond the local area of the jaw, impacting the coordination of movements in other joints and even affecting the muscles supporting the spine. This intricate integration with other parts of the body makes the TMJ a key component in the overall motor system mechanics. An abnormality or dysfunction in the TMJ can have far-reaching effects, leading to signs and symptoms that impact daily activities and overall well-being [8].

2.1 Traditional TMJ Training

Traditionally, conveying these concepts in a classroom setting has proven difficult. Visual aids and practical demonstrations are often needed to effectively teach the movement and positioning of the jaw disc. However, even with these tools, it can still be challenging for students to envision how all these components work together and understand the intricate interactions within the jawbone [9].

The complex mechanism known as the TMJ is essential to the mobility and operation of the jaw. Traditional classroom settings often struggle to effectively convey the complexities of TMJ anatomy and the various disorders that can occur [10].

Weighing the benefits and drawbacks of conventional dental education systems is the main argument supporting the need for virtual reality and immersive learning in dental education. Traditional dental education methods have long relied on textbooks, lectures, and hands-on clinical experiences to teach students the necessary knowledge and skills [11], [12].

Figure 2.1 shows the anatomy of the temporomandibular joint, which contains several components that are interconnected to move the jawbone, and the anatomy of the jaw. So, with the traditional methods, to learn this complexity of the TMJ by the textbook is not helpful for student to visualise how the system works in their mind.

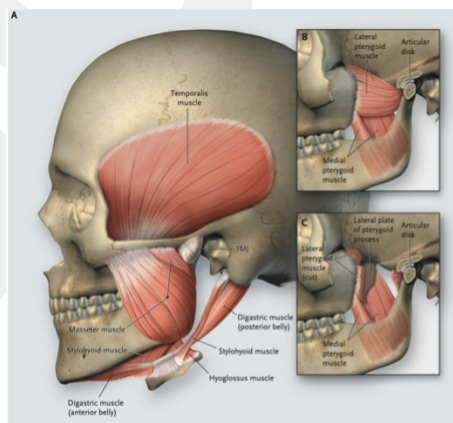


Figure 2.1 Anatomy of the Jaw [13]

Dentist education needs to combine literature information with 3D interactive visuals to have an in-depth understanding of jaw anatomy for effective treatment planning and execution [14]. For this reason, we have discovered that immersive learning techniques using virtual reality technology can boost the complexity of traditional teaching approaches.

With the traditional textbook educational system in dentistry, it is not possible to give students a full sense of the three-dimensional structure thinking of the temporomandibular complex anatomy [15].

The anatomy of muscles on skulls is complex. There are eight different pinpoints to the skulls and all work simultaneously together for smooth mouth movement. To have a better understanding of muscle anatomy, student needs to see the whole system working together and needs to see how each react in each step [16], [17]. Figure 2.2 shows the simplified muscle structure of the human skull to give a simple view to ease understanding of the main connection points of the muscles.

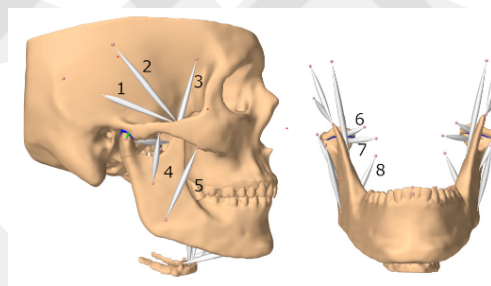


Figure 2.2 Point to Point Muscle [18]

Lectures, though informative, may not provide a sufficient level of engagement and interactivity for students to fully grasp and retain the material being taught. To understand of anatomy of the temporomandibular joint, students often rely on diagrams and models, which may not accurately represent the complexity of the joint and its surrounding structures.

To visualize how the mandibular head, articular disc, temporomandibular joints, lower jawbone, upper jawbone, and muscles work together during jaw movement is quite complex and easy to misinterpret without proper visualization tools [19]. It is a fully

complex structure that can be only understood by a system approach that will show how all components work together and interact with each other in each stage.

In jawbone movement, there are two different patterns while opening and shutting. This is a diagram called Posselt's diagram [20]. So, teaching Posselt's diagram without analysing and visualizing the other component's behaviour is incomplete and may not provide a comprehensive understanding of the jaw movement dynamics.

Figure 2.3 shows the opening and closing path of the jawbone that diagram is called Posselt's diagram.

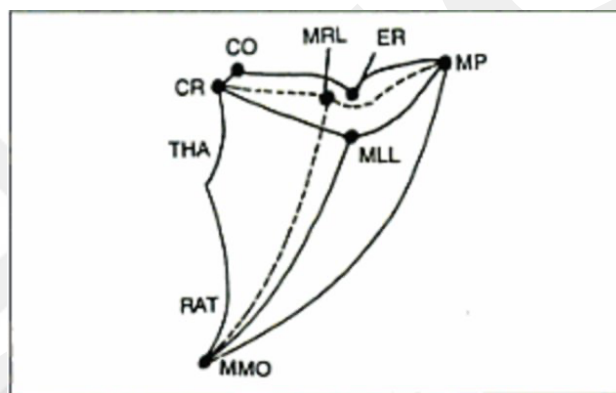


Figure 2.3 Posselt's Diagram [21]

Understanding the complexity of the jawbone system with traditional methods is not enough for proper learning. Without 3D visual thinking, students may struggle to grasp the intricate spatial relationships and movements of the structures involved in dental procedures.

In traditional teaching methods, students struggle to define and analyse disorder cases of jawbone without real-life examples or interactive tools. For example, an articular disc has different behaviour for different disorder scenarios [22], so firstly students must understand the healthy and disordered behaviour of an articular disc to understand the anatomy of the disc to compare when they meet for different cases [23]. The main aim is to overcome these challenges and provide students with a comprehensive understanding of the temporomandibular joint and its complexities.

2.2 Immersive Technologies and Their Contribution to Education

Researchers suggest computer simulations of the motor system to better understand such complex structures [4]. Interpreting the ontogeny, function, and development of the jaw muscles and the soft tissues within the adductor chamber continues to be a difficult task even after several chances to do so [24], [25]. In a recent survey study, researchers have identified that the detailed anatomy of the TMJ is one of the top priority topics of the learners from their dental curricula that would be beneficial when introduced with 3D learning resources [26]. Thus, the goal of virtual reality (VR) is to replace the physical world with a computer-generated one and allow people to interact as if they were really there. Virtual reality environment targets the sense, haptic and visual senses of students to ease learning as seen in Figure 2.4

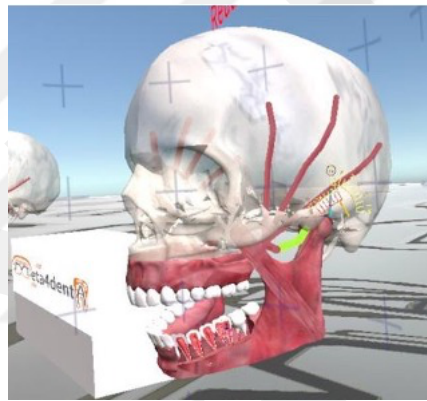


Figure 2.4 Virtual Reality Environment of TMJ

2.3 Immersion

The environment envelops or surrounds immersion. Ensuring a sensation of presence, or the impression that the environment being portrayed is experienced [27]. Virtual reality gives a fully established environment that allows users to immerse themselves in a simulated reality, providing a unique and interactive experience.

2.4 Interactivity

Interactivity is the capacity to manipulate simulation events by the use of one's physical motions, which in turn triggers simulation reactions [28]. In terms of student

engagement and learning results, the VR experience's interactivity is crucial (see Figure 2.5)

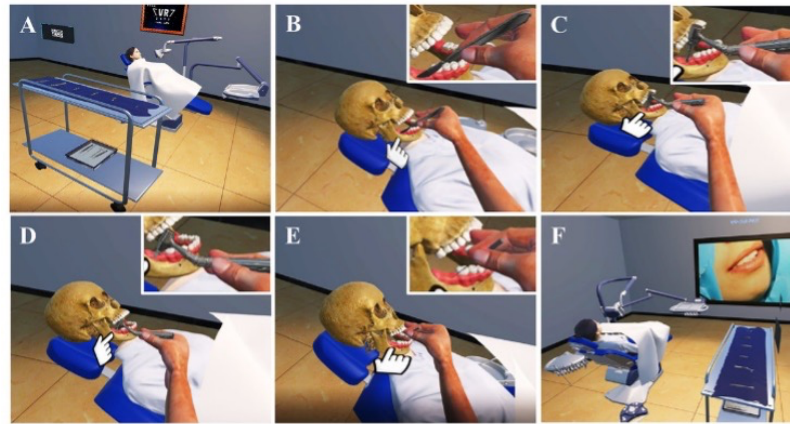


Figure 2.5 Interactivity of VR Environment [29]

2.5 Multi-Sensory

Multiple senses can be used to obtain the information in VR. Using audio, visual and haptic senses gives a captivating feel increasing to the sense of presence [30]. Virtual reality technologies target the multiple senses of students targeting to have deep learning [31]. These technologies aim to create immersive and interactive virtual environments in which students can interact with the system. These immersive virtual environments aim to transport students to a different world, allowing them to interact with the content on a much deeper level. VR has the power to captivate inactive students and breathe new life into the classroom by appealing to a variety of senses and offering an immersive, three-dimensional experience. The use of VR in education has been increasingly recognized for its potential to enhance engagement, focus, interactivity, and knowledge retention. It allows for the creation of virtual spaces where students can interact, communicate, and collaborate, providing opportunities for active learning and engagement in the learning process that were previously inaccessible (see Figure 2.6).

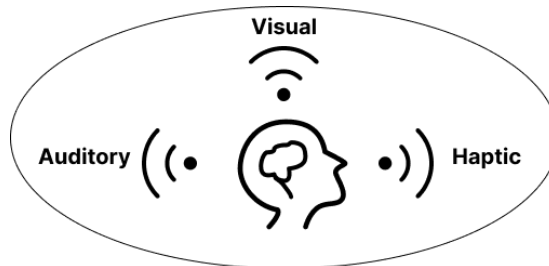


Figure 2.6 Multi-Sensory of VR

In dentistry education, as spotted those traditional methods are not effective in fully preparing students for real-world clinical situations. It can be split dentist education into literature and practical clinical practices. While literature-based learning can be effectively done through traditional methods such as textbooks and lectures, practical clinical practices require hands-on experience. This is where virtual reality can play a crucial role. Virtual reality allows dental students to immerse themselves in a realistic virtual environment, where they can practice various dental procedures and develop their clinical skills in a safe and controlled manner [32].

This advanced technology provides haptic feedback, allowing students to experience the tactile sensations associated with dental procedures. With the collaboration of UNU-IIST, the Asian Institute of Technology, and Thammasat University, a dental training system has been created that specifically focuses on providing a simulated yet realistic virtual reality environment for dental students [33].

By using virtual reality simulators, dental students can practice and refine their skills without the need for expert supervision and at little or no additional cost. These simulators have been developed by various companies, such as DenX Ltd. and Novint Technologies, and have shown promising results in dental education. Moreover, dental research and development, therapy, treatments, and early diagnosis have all benefited from the usage of virtual reality-based technologies [34].

The use of immersive virtual reality technology has been found to enhance learning and understanding of complex anatomical structures, such as the human skull [35]. Virtual reality-based simulation has the potential to significantly improve the clinical skills and self-confidence of dental students [36]. Students can continuously practise

and improve their techniques in a safe set up by using virtual reality. In contrast to traditional methods, virtual reality is more accessible for the students in terms of textbook and lecture-based learning may not fully prepare dental students for real-world clinical situations. Dental simulation training using virtual reality allows students to engage in repetitive and deliberate practice, leading to mastery of clinical procedures [37]. So, we have developed the idea to carry on traditional education methods to a virtual reality environment to get the students to learn by visualizing and experiencing real-world scenarios. It is more accessible, easy to reach the information and provides a realistic and immersive learning experience. Virtual reality in dental education can also address the limitations of using actual mechanical models [38]. Finding mechanic models for different cases, understanding the anatomy of teeth, and practising various procedures can be expensive and time-consuming. Some of the time, students cannot achieve what they do target. In contrast, virtual reality provides a cost-effective and efficient alternative, where students can practice on virtual dental models that closely resemble real-life scenarios [39]. The main point of virtual reality is to ease the learning curvature of the student through immersive interaction which are visual, tactile, and auditory [40]. This allows students to develop a deeper understanding of dental procedures, improve their diagnostic and clinical judgment skills, and enhance their overall competency in clinical settings. Because virtual reality education depends on experience-based learning that is more memorable and understandable synonym with long-lasting retention, dental education in a virtual reality environment can potentially revolutionize how dental students learn and prepare for their careers. It allows mixing literature learning with immersive learning experiences, allowing students to not only learn theoretical knowledge but also apply it in realistic scenarios [41].

The design, programming principles and usability test results indicate that virtual reality can be effectively used in dental education. This is in line with the experiences seen in medical education, where virtual reality-based simulations have been widely used to enhance clinical skills and boost students' self-confidence [42].

Virtual reality technology has the potential to revolutionize dentist education by providing realistic and immersive virtual environments for students to practice their

skills. Without the need for actual patients, these virtual environments may mimic a variety of dental procedures, giving students the opportunity to practise and improve their technical skills. Virtual reality can also provide an environment for learning that is safe and controlled, allowing students to make mistakes and grow from them without endangering actual patients. [43]. By integrating virtual reality into dental education, students can also benefit from enhanced visualization and spatial understanding. This technology can provide detailed 3D models of dental structures, allowing students to examine and manipulate them in a way that is not possible with traditional teaching methods. Virtual reality also has the benefit of instantaneous feedback. Real-time performance feedback is available to students. Virtual reality in dentistry education has shown significant promise for enhancing dental students' knowledge and abilities [14]. Dental students may practise operations and hone their abilities in a realistic and immersive learning environment using virtual reality, all without the need for real patients. By using virtual reality, dental students can experience various scenarios and challenges that they may encounter in real-life dental practices. This may support their growth in critical thinking, problem-solving, and self-assurance in their clinical judgement. Furthermore, the incorporation of virtual reality into dental education can address some challenges faced by traditional teaching methods. These challenges include limited access to diverse patient cases, the high cost of dental materials, and the ethical concerns involved in learning about live patients [43]. Virtual reality in dentistry education reduces these difficulties and permits more thorough learning by offering a secure and regulated setting where students may practise and make errors. With the aid of virtual reality (VR) tools, visual learning can be improved by enabling students to interact with realistic 3D models, perform virtual procedures, and receive immediate feedback. Traditional dental education methods frequently rely on textbooks, lectures, and supervised clinical practice, which may not fully prepare students for the complexities and uncertainties of real-life dentistry [44].

This not only enhances their understanding of dental concepts but also improves their technical skills and clinical decision-making abilities. All things considered, the introduction of virtual reality into dentistry schools might completely change how dental students are taught and prepared for careers in the field.

The three-dimensional (3D) modelling and simulation-based approaches now allow us to see and reconstruct this muscle architecture together and contribute to experts making more accurate predictions on this subject. In the literature, there are some attempts to create a 3D TMJ model with 3D virtual reality and mandibular function animation to provide study material for a better understanding of the anatomic structures of the TMJ [45]. Studies also report that 3D Virtual Reality (VR) representations of TMJ are useful for preoperative planning and can be used as an intraoperative guidance tool [46]. Therefore, new insights into the genetics, variety, and function of the jaw muscles may be obtained using these models [47]. However, there are very limited examples of TMJ simulations of the human body in the literature [48]. Accordingly, in this study, a real human TMJ simulation is developed for a 3D environment, and it is served for the study of dental education programs through a user interface with metaverse concepts. In this study, the details of the developed system are described.

CHAPTER 3

DEVELOPMENT OF THE VIRTUAL REALITY FOR TMJ

This chapter is given under three headings. First, the anatomical structures of the TMJ are summarized as these structures are very critical for developing the VR models. Secondly, the immersive VR technologies and their important features are summarized to guide the decision of appropriate technologies for the development of the proposed system. Finally, the design and development of the proposed system is summarized.

3.1 Anatomical Structures of TMJ

The mandible, or lower jaw, and the temporal bone of the skull are joined by the intricate joint known as the TMJ. It permits the jaw to move for speaking, eating, and yawning, among other functions. The TMJ consists of several anatomical structures that work together to facilitate these movements.

These structures work together to enable the complex movements of the jaw, allowing for functions such as biting, chewing, speaking, and facial expressions. Dysfunction of the TMJ can lead to conditions like temporomandibular joint disorder (TMD), which can cause pain, clicking sounds, and limitations in jaw movement.

Understanding the complexity of human skull structure plays a crucial role in the education of dentists. With a deep comprehension of dental anatomy, dentists can effectively perform clinical operative dentistry procedures. By incorporating data on human dental anatomy into their teaching, dental schools can reinforce the clinical relevance of these procedures and emphasize the need for thorough training.

The School of Dentistry at the Federal University of Pelotas in Brazil is one institution that acknowledges the significance of dental anatomy [49]. The Department of

Anatomy and Morphology, in particular, includes dental anatomy as part of the fundamentals of dentistry education in its curriculum.

Students in the dental course at this university undergo a comprehensive study of dental anatomy and carving. The initial part of the course focuses on systemic anatomy, which involves the study of the human body's systems and the cranial bones of the skull. By beginning with a solid foundation in systemic anatomy, students are equipped with the necessary knowledge to delve deeper into the complex structure of the human skull [49].

It is intriguing to note the paradoxical nature of the diminishing emphasis on gross anatomy in dentistry education. While the importance of gross anatomy seems to be declining, the field of developmental anatomy is rapidly gaining momentum. This branch of biology, which explores the development of anatomical structures, demands increased attention and dedicated curriculum time [50].

Developing a comprehensive understanding of dental anatomy is crucial in modern dentistry education [51]. The temporomandibular joint is important for understanding the functional relationships of the human dentition. In addition to the spatial relationships of teeth, dentists must also consider the underlying skeletal structures, such as the mandible and maxilla, to provide effective treatments and restorations.

The emergence of the field of "evo-devo," which focuses on the evolutionary aspects of anatomical development, further highlights the importance of dental anatomy in dentistry education. By studying the evolutionary history of the jaws and dentition, dentists can gain valuable insights into the form and function of teeth, allowing for more informed clinical decision-making.

In dental education, the anatomic structure of the human skull is quite complex not only for students for learning but also for the lecturers for teaching. The TMJ is a crucial component of the human masticatory system and is responsible for jaw movement [52]. The complexity of the TMJ stems from its integration with various muscles of mastication and the surrounding Orofacial structures. It is a highly intricate joint that undergoes constant movement, estimated to occur between 2000 to 3000

times a day. This frequent use is the result of its primary role in facilitating essential actions such as biting, chewing, and speaking [53]. Figure 9 shows the muscle structure of the jawbone. There are several places of linkage in the system between the temporal bone (side and base of the skull) and the mandible (lower jaw). As seen in Figure 3. 1, the connections have inner and external connection points.

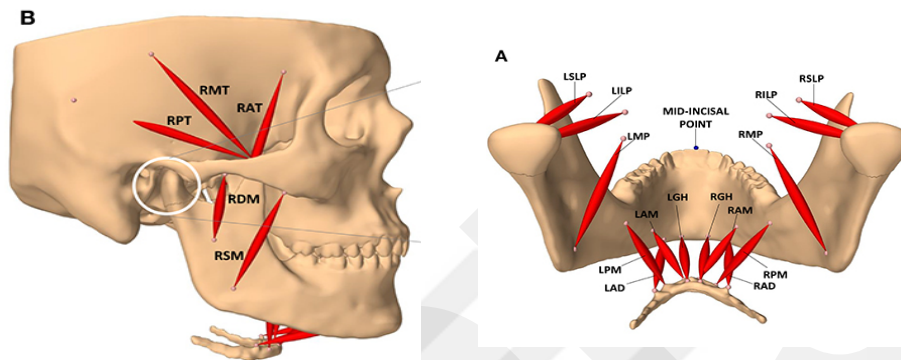


Figure 3. 1 Complexity of TMJ [18]

The anatomical structure of TMJ consists of plenty of components such as the mandibular condyle, articular disc, temporal bone, and surrounding ligaments and muscles (Figure 3.2).

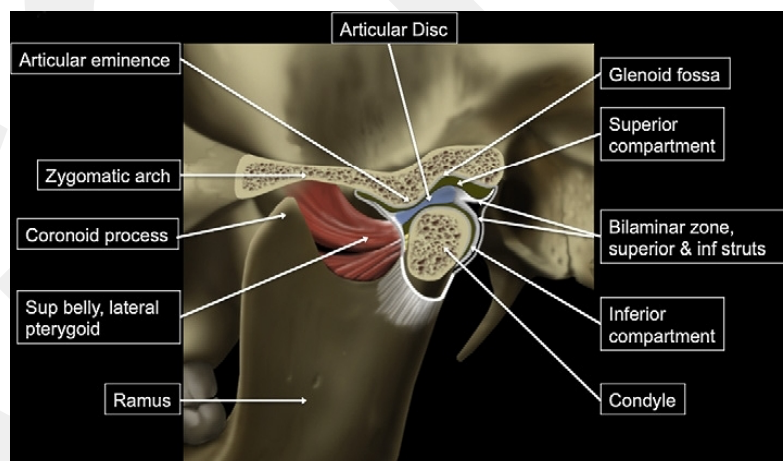


Figure 3. 2 Anatomical Structure of TMJ [54]

Due to its complexity, understanding the intricacies of TMJ anatomy and its associated disorders can be challenging for dental students [55]. This covers the intricate muscular structure, many sites on the skull, as well as the jaw's dynamic motions and

the location of the jaw disc. To understand how all anatomic structure elements together interact, visualization and practical demonstrations are crucial for dental students to grasp these concepts.

- One of the key parts of the TMJ that permits jaw mobility is the mandibular condyle. The articular disc divides it from the temporal bone where it articulates with the glenoid fossa. The mandible may move in three dimensions by hinging and gliding because of its complex arrangement. [56].
- The articular disc, which acts as a cushion between the glenoid fossa and the mandibular condyle, is an essential component of the anatomy of the TMJ. It assists in preserving the joint's correct alignment in addition to helping to disperse the pressures generated during chewing and other jaw motions. In order to diagnose and treat TMJ issues, it is essential to comprehend the location and movement of the articular disc [57].
- Temporal bone is another essential component of the TMJ. It forms the glenoid fossa, which provides a socket for the mandibular condyle to articulate with. The stability and range of motion of the TMJ are largely determined by the form and composition of the temporal bone. It is important for dental students to understand the anatomy of the temporal bone and its relationship with other components of the joint to comprehend how the TMJ functions as a whole [57].
- The surrounding ligaments and muscles of the temporomandibular joint are also integral to its proper functioning. Ligaments, such as the temporomandibular ligament and the stylomandibular ligament, give the joint stability and support, avoiding excessive movement and ensuring proper alignment. Understanding the attachment points and functions of these ligaments is crucial in diagnosing and treating TMJ disorders [58].

The masseter, temporalis, and medial pterygoid muscles—muscles involved in jaw movements—are essential to the TMJ's operation. These muscles are responsible for the powerful contractions needed for chewing and biting, as well as for the coordinated movements of the jaw during speech and facial expressions [59]. The main muscle involved in shutting the jaw and producing biting power is the masseter muscle, which is found in the jaw area. Jaw elevation and retraction are facilitated by the temporalis

muscle, which is located on the sides of the head. Deep inside the jaw, the medial pterygoid muscle aids in lateral motions and jaw elevation [60].

In addition to the anatomical aspects, the physiology of the TMJ is equally important to grasp. Understanding the physiology of the TMJ involves a deep dive into the intricate workings of the masticatory apparatus. To preserve harmony and balance during function, the relationship between the condyles and the dental parts is essential [61]. The arrangement and operation of the dental components of a normal dentition are intimately linked to the TMJ, resulting in a seamless integration of the two.

The TMJ moves in a complicated way when it is under strain during function. The TMJ is essential for carrying out a variety of jaw motions, including propulsion, laterality, and even mouth opening and shutting [62].

It is essential to comprehend both the entire anatomy and function of the TMJ in order to fully appreciate its complexity. By visualizing and studying the CT and MRI images of the TMJ, dental students cannot gain a better understanding of its morphology and topography [63].

One of the key components of understanding TMJ anatomy is the movement and positioning of the articular disc [64]. Teaching this aspect without visual aids can be quite challenging. The jaw has two different patterns when opening and four different patterns when shutting, each with its unique movement (

Figure 3. 3). These distinct movements can be difficult for students to fully comprehend without visual representation or practical demonstrations. The name of this movement is the Posselt diagram which is often used as a visual aid to understand TMJ movement patterns [20]. However, in a virtual reality setting, students can go beyond static diagrams and witness the dynamic nature of the joint in real-time.

They are able to see how the articular disc moves during jaw opening and shutting, how the condyles articulate with the temporal bones, and how the masticatory muscles affect the TMJ's overall movement (see Figure 3.3).

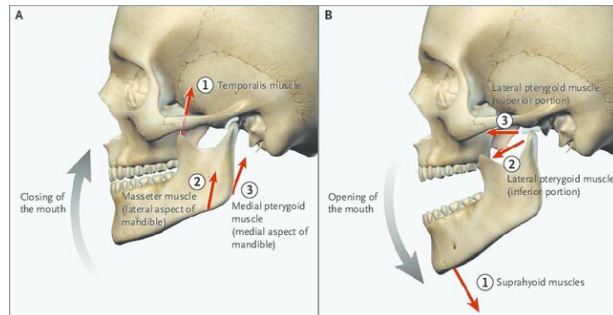


Figure 3. 3 Anatomy of the Jaw Movement [13]

The Posselt diagram is a graphical representation of the movements of the mandible, specifically depicting the different positions of the condyles in the temporomandibular joint during various jaw movements (see Figure 3.4). It was developed by Dr. Robert B. Posselt in the 1960s to visually illustrate the complex motion of the TMJ [65].

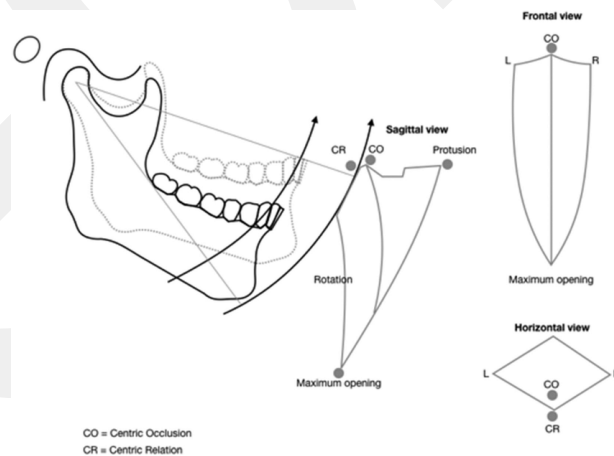


Figure 3.4 Posselt's Movement Diagram [66]

The complexity of the lower jaw's opening and closing actions, both vertically and horizontally, is seen in Figure 3.4. As a result, it is challenging for pupils to comprehend this intricate system via the use of conventional textbook approaches. For students to fully comprehend this complex system, they need to interact and engage with it using immersive technology.

Figure 3.4 is made up of a set of lines that show how the condyles move in various directions, including protrusion, retrusion, lateral excursion, and jaw opening and shutting [67]. These movements are crucial in understanding the functionality of the TMJ and how it contributes to various oral functions like swallowing, chewing, and speaking (Figure 3.2).

The Posselt diagram is derived from the simplified kinematic border movement model of the mandible in the sagittal plane. One may compute a simplified version of the Posselt diagram by using cephalometric radiographs [20]. This diagram provides a visual representation of the trajectory and range of motion of the mandible during different functional movements (Figure 3.4).

3.2 Immersive VR Technologies for TMJ Training Problems

To enhance the understanding of TMJ anatomy and its complex interactions, visualization is essential. For dentistry students, virtual reality technology may provide a distinctive and engaging learning environment.

Virtual Reality is a technology that combines the virtual world with real space [68]. This remarkable technology is transforming various industries, from entertainment to education, and beyond. By leveraging computer image processing and hardware technology, virtual reality allows people to experience and interact with a simulated environment using their senses of vision, touch, hearing, and even smell. The potential applications of VR are broad, extending to art display, art design, space design, and more.

In the realm of education, VR has become an invaluable tool for immersive learning experiences, particularly in fields such as science and medicine. The ability to create lifelike simulations opens new possibilities for training and skill development that

were previously limited to traditional methods. In the field of dentistry, VR technology has been used as a teaching tool to provide interactive and realistic dental education [69]. With the use of this technology, dental students may rehearse operations in a virtual setting and get practical experience prior to working with actual patients. Virtual articulators, computer-aided design, and computer-aided manufacturing technologies, among other VR innovations in dentistry, have completely changed the way dental students get their training. These advancements not only simulate real-world scenarios but also provide a safe space for trial and error, ultimately leading to better-prepared professionals.

Furthermore, the integration of haptic technology with virtual reality has allowed for the realistic simulation of dental techniques, including drilling in a jawbone and the insertion of oral implants. This level of precision and realism in simulating dental procedures through VR is unprecedented, providing students with an immersive and hands-on learning experience. In addition to its educational applications, virtual reality technology has also found its way into the medical field [70].

3.3 Employed VR Technologies

The notion of the metaverse has garnered noteworthy interest in recent times owing to the progressions in virtual reality technology. The term "metaverse" describes a virtual world where people can communicate with one another and their surroundings in a completely realistic, digitally generated setting [71]. The metaverse is not just a simple extension of the real world; it's a realm where the boundaries of physical reality are transcended, and people can engage in a three-dimensional space that mimics reality.

Virtual reality technology, like Oculus, has been instrumental in facilitating the creation and investigation of the metaverse. Oculus has become a key player in the metaverse landscape, especially with the launch of the Oculus Quest 2, which has brought immersive experiences to a wider audience than ever before.

One of the reasons for choosing Oculus as a leading VR technology in the metaverse realm is its exceptional combination of features, performance, and affordability. Oculus offers high-quality visuals, immersive audio, and intuitive controls, allowing

users to fully immerse themselves in the metaverse experience. Furthermore, Oculus has a robust ecosystem that includes a vast library of VR games, apps, and experiences, making it an attractive choice for users looking to explore and engage with the metaverse. Additionally, Oculus has made significant strides in improving accessibility by launching the Oculus Quest 2. This all-in-one, wireless headset boasts powerful hardware, a high-resolution display, and improved comfort, making it more accessible and user-friendly for a broader range of individuals. By investing heavily in research and development, companies like Facebook (the parent company of Oculus) have played a pivotal role in making extended reality technologies, including virtual reality, more accessible and affordable for the public. When comparing the price of the Oculus Quest 2 VR headset to those of its competitors, such as the Oculus Rift, HTC Vive, and PlayStation VR, it is particularly noteworthy for being reasonably priced without sacrificing quality. This has significantly contributed to the widespread adoption of VR technology and the evolution of the metaverse. The seamless integration of the Oculus Quest 2 into the metaverse has opened the doors to virtual experiences, social interactions, and entrepreneurial opportunities on an unprecedented scale. Moreover, the innovation and evolution of Oculus demonstrate a pivotal shift in the way we perceive and engage with virtual environments. Oculus has an advantage over its competitor VR technologies in terms of its affordability, portability, and capability [72]. When comparing the pricing of the Oculus with other VR headsets like the Oculus Rift, HTC Vive, and PlayStation VR, it is evident how much more affordable and easily accessible the Oculus Quest 2 is. Oculus Quest 2 was created by the META Oculus Quest 2 has revolutionized the VR market with its standalone capabilities, eliminating the need for external computers or additional equipment [73]. In our study, we have selected the Oculus Quest VR headset. The main reason for our META Quest VR Headset choice is the huge library the META offers its users. Another reason is that it is compatible with Unity and also META has a new signed contract with Unity to have collaboration for the future. The Oculus Quest 2 has emerged as a game-changer in the virtual reality market, revolutionizing the way users perceive and engage with virtual environments [74]. The price of the VR set is affordable for the users and reasonable to the competitors. So, Quest 2 offered us a smooth and great project experience in this project with its quality of output,

META library support, and affordability. In conclusion, the Oculus Quest 2 stands out in the market for its affordability, portability, and capability compared to other VR headsets [66]. Furthermore, we use the Unity software platform for our project to create cloud-based Virtual Reality projects on the Oculus Quest 2 headset. Oculus has very practical methods that the user can download the app to the VR Headset to run the multiplayer app and engage in immersive virtual experiences. So, due to these advantages, we have chosen the Oculus Quest 2 VR Headset for our project.

Owned by Meta (formerly Facebook), Oculus has created several virtual reality headsets, such as the Oculus Rift and Oculus Quest models. Here are some advantages commonly associated with Oculus VR headsets:

1. **Product Range and Versatility:** The Oculus Quest series, in particular, is known for its versatility, providing both standalone and PC-tethered options.
2. **Standalone Capabilities (Oculus Quest):** The Quest and Quest 2 models in the Oculus Quest series are independent devices; they don't need a PC or additional sensors. This provides users with a wireless and untethered VR experience, offering greater freedom of movement.
3. **Inside-Out Tracking (Oculus Quest):** Oculus Quest headsets use inside-out tracking technology that does not need external sensors. This simplifies the setup process and enhances the user experience by allowing for more natural movements within the VR space.
4. **Accessibility and User-Friendly Design:** Oculus has focused on making VR more accessible to a broader audience. The user-friendly design, ease of setup, and the absence of complex external hardware make Oculus VR headsets appealing to both enthusiasts and casual users.
5. **Content Library and Ecosystem:** Oculus benefits from integration with the broader Meta ecosystem, providing users with access to a diverse range of VR content. This includes games, educational experiences, and social applications.

6. **Wireless PC Connection (Oculus Air Link):** Oculus introduced features like Oculus Air Link, allowing users to play PC VR games wirelessly on their Quest headsets. This enhances the flexibility of PC-tethered VR experiences.
7. **Social VR and Multiplayer Experiences:** Oculus has invested in social VR experiences, enabling users to connect with friends in virtual spaces. This emphasis on social interaction enhances the overall VR experience.

Competitive Landscape:

The VR industry is dynamic, and competitors like HTC Vive, Valve Index, and PlayStation VR also offer compelling products. When choosing a VR headset, factors such as performance, content library, comfort, and pricing should be considered. The advantages of Oculus over its competitors depend on project requirements and user expectations. In our study, Oculus meets all the requirements fully that we need.

3.4 Design and Development of Proposed System

The benefits and drawbacks of creating a virtual reality-based instructional software to provide dentistry students with a more thorough and efficient learning experience were enumerated after analysing the conventional teaching techniques.

Pros of learning about temporomandibular disorders (TMD) using traditional textbook education are:

1. **Comprehensive Information:** Textbooks provide comprehensive information on TMD, which can be helpful for students to understand the condition in detail.
2. **Cost-effective:** Textbooks are a cost-effective option compared to other resources such as attending seminars or workshops.
3. **Easy Reference:** Textbooks are easy to reference and can be used as a quick guide for students during their studies.

4. Self-paced Learning: Students can learn at their own pace without any time constraints.

However, there are a few cons to traditional textbook education on TMD, such as:

1. Lack of Hands-on Experience: Textbook learning alone may not provide enough hands-on experience, which is crucial in the field of dentistry, especially when it comes to TMD diagnosis and treatment planning.

2. Outdated Information: Textbooks may not always have the latest information on TMD diagnosis and treatment procedures, which can be a drawback.

3. Difficulty in Visual Learning: Some students may find it challenging to understand certain TMD conditions or treatment techniques through a textbook alone.

4. Limited Interaction: Textbooks do not allow for interaction, which may make it harder for students to clarify their doubts or learn from their peers. Overall, while textbooks are a valuable resource for TMD education, a combination of various learning methods such as practical training, seminars, and workshops can help students gain a more comprehensive understanding of the subject.

By getting feedback from the dentistry professors and lecturers (Prof. Dr. Mehmet Ali Kılıçarslan, Dr. Fulya Basmacı, Dr. Dt. Aykut Gönder), the problems of TMJ learning complexity and why the students and lecturers were struggling in the dentistry education were defined. With the guidance of this feedback, solutions to offer a more immersive and interactive dental education experience in virtual reality were designed. Based on the feedback of professors and lecturers, the requirements to develop a new dental education VR application were captured. The disorder scenarios and challenges that dental students may face during their training were also considered and modelled.

The main problem in jawbone education can be listed below.

- Muscle anatomy is complex (Figure 3.5)

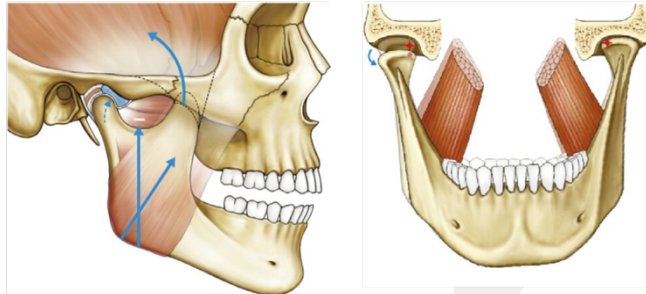


Figure 3.5 Muscle Complexity [75]

- Muscles have 8 different pinpoint skulls and teaching how these different muscle works and interact with other structures can be challenging to convey in a traditional classroom setting (Figure 3.6)

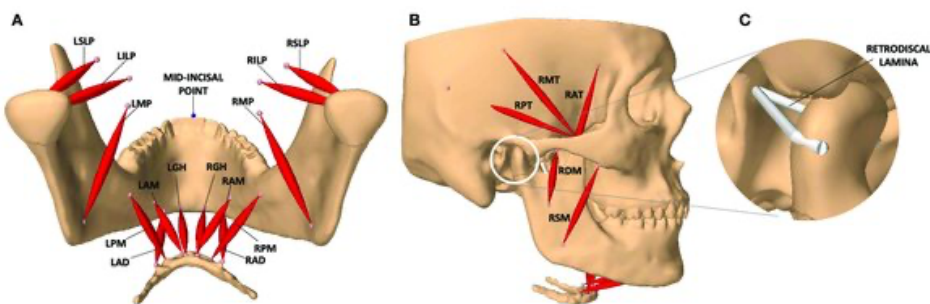


Figure 3.6 Muscle Anatomy [76]

- To teach jaw disc movement and positioning can be difficult without visual aids or practical demonstrations.

- The mouth has 2 different patterns when opening and 4 different patterns when shutting. Each of the movement is different (Figure 3.7).

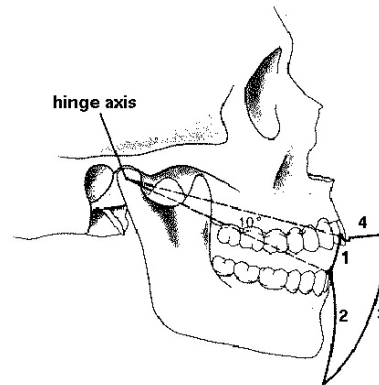


Figure 3.7 Posselt Figure [77]

- The key to jawbone education is visualisation, which helps one grasp how all these parts function together. For dentistry students to completely comprehend the intricacies of the jawbone and its activities, they must consider muscles, jawbone movement, cortical head disc movement, posset diagram, and disorder scenarios. Therefore, giving dentistry students access to a virtual reality environment that visualises all the component interactions might significantly improve their comprehension of these difficult ideas (Figure 3.8).

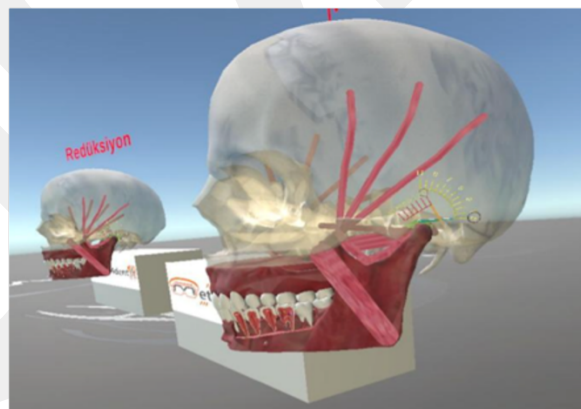


Figure 3.8 Developed Metaverse Environment

Figure 3.8 shows the created VR environment in which students and lecturers can interact with the real-time simulated human skull. The interaction targets the sense of students to make the learning by interaction and enjoying.

Metaverse for TMJ Course

To fully utilise the VR system, a three-dimensional representations of every relevant part of the temporomandibular joints and the muscles that are associated with them on the human skull were provided. Then, an interactive TMJ system in which each anatomical structure can be observed under different conditions was designed.

In a simulated setting, the Meta4Denta-TMJ teaching system helps learners get a better knowledge and experience of the human TMJ and its relationships to the muscles and mouth. First, a 3D model of the human TMJ was created in this setting.

Advanced 3D Modelling Techniques

The 3D human skull model is created using the human body's anatomical elements as a basis. As can be observed from Figure 3.9, information on the TMJ and other relevant human anatomical structures is created by excluding other anatomical structures.

Advanced 3D modelling techniques were used to create highly detailed and realistic virtual environments for immersive experiences. These techniques allow users to interact with the virtual environment, providing a more engaging and authentic experience. Additionally, advanced 3D modelling techniques have been employed to improve the accuracy and realism of virtual object creations, including realistic colours, textures, and physics. This has transformed the way designers approach concept development and design exploration, providing them with powerful tools to bring their ideas to life. To create a truly immersive virtual experience, cutting-edge 3D modelling software and technologies were utilized.

The modelling process commenced with a 3D scan of the human skull, which served as the foundation for the creation of all anatomical structures of TMJ. After transferring the model to the Rhinoceros 3D CAD programme, intricate sculpting and the creation of flawless surfaces ensued. In order to generate virtual environments that are exceptionally lifelike, sophisticated 3D modelling techniques were utilised. Remodelling the human cranium in accordance with a 3D scan file produced a streamlined 3D CAD model that enhanced visual quality in a virtual reality

environment and decreased the number of meshes for optimal rendering and real-time performance. Concurrently with the mesh quantity optimisation, Unity was used to assess the quality of the model surfaces.

The Unity game engine and the Rhinoceros 3D CAD program were utilised to generate the 3D model and simulate it within a virtual reality environment. Each of these programmes is an improvement over the other. Rhinoceros is a CAD program that generates 3D CAD models of superior quality. Additionally, Rhinoceros can optimise the quantity of meshes for VR performance and high-quality visuals. In a virtual reality environment, the game engine Unity can import 3D CAD models from Rhinoceros and apply the necessary materials, kinematics, and interactions. The purpose of these two applications is to collaborate in the modelling and virtual reality processes. Beginning the procedure was the acquisition of a 3D-scanned model of a human cranium. Utilising the scanned model directly is not recommended. It is composed of thousands of meshes, surfaces that are not uniform, and distorted surfaces. The scanned 3D model serves only as a reference when animating Rhinoceros in 3D. As shown in Figure 3.9, the human skull model in this study served only as a guide for 3D modelling. This 3D scanned model (Figure 3.9) consists of thousands of triangles to create the surfaces, so this model does not give the smooth surfaces when it is transferred to the VR environment.



Figure 3.9 3D Scanned Human Skull

The model fidelity, as illustrated in Figure 3.9, is unsuitable for implementation in a virtual reality environment. It requires remodelling to achieve quality and clean surfaces. This 3D scanned model was subsequently utilised to generate the 3D model. In pursuit of this objective, the model was constructed in Rhinoceros utilising a 3D model scan as a guide. As illustrated in Figure 3.10, subsequent TMJ anatomical structures were constructed upon this three-dimensional basal model.

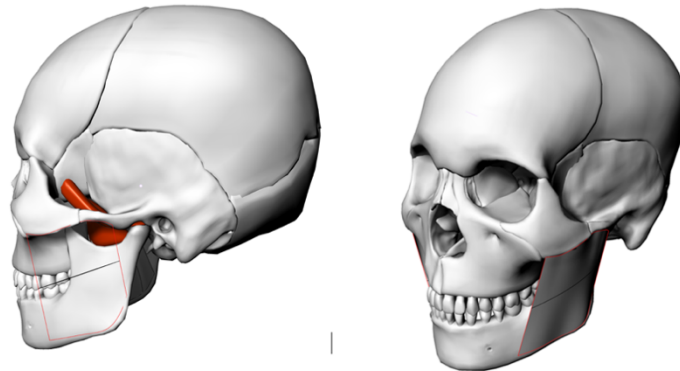


Figure 3.10 3D CAD Model created by Rhinoceros

After the foundational Human Skull model was completed, sophisticated 3D techniques were employed to meticulously model the anatomical structures of the TMJ. Due consideration must be given to the model side in light of the capability and efficacy of the programmes. In order to accomplish this, the Rhinoceros programme was responsible for 3D modelling and TMJ mechanic solutions in 3D CAD models, while Unity was tasked with populating the VR environment with content, physics, and interaction. In consideration of the research requirements, a model of the human cranium was constructed, encompassing the articular disc and upper and lower jawbones that comprise the TMJ-related musculature. This model also emulates the physical limitations of the Posselt diagram and articular disc motion along the path of the opening and closing mouth movements (Figure 3.11 and Figure 3.12).

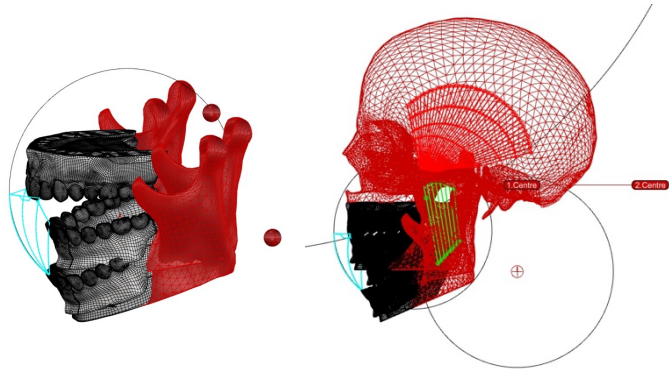


Figure 3.11 3D Model of TMJ

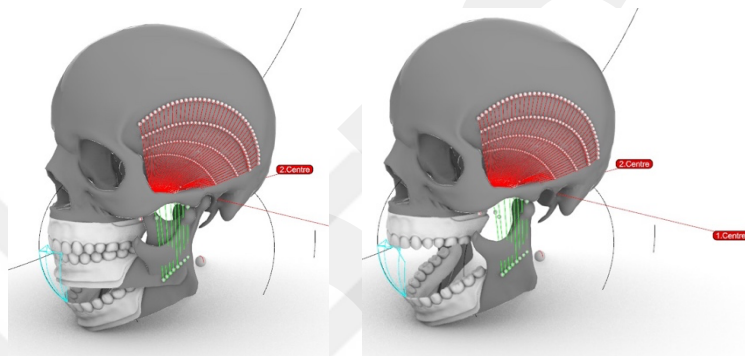


Figure 3.12 3D Model of TMJ

Once the 3D model process was completed in Rhinoceros, the model was exported as a .fbx file in preparation for importing it into the Unity Game Engine for virtual reality setup. Each component in the Unity game engine has been assigned a unique set of model materials. Subsequently, the lower mandible bone, articular disc, and musculature were allocated physics in order to simulate TMJ in a virtual reality environment in real-time (Figure 3.13).

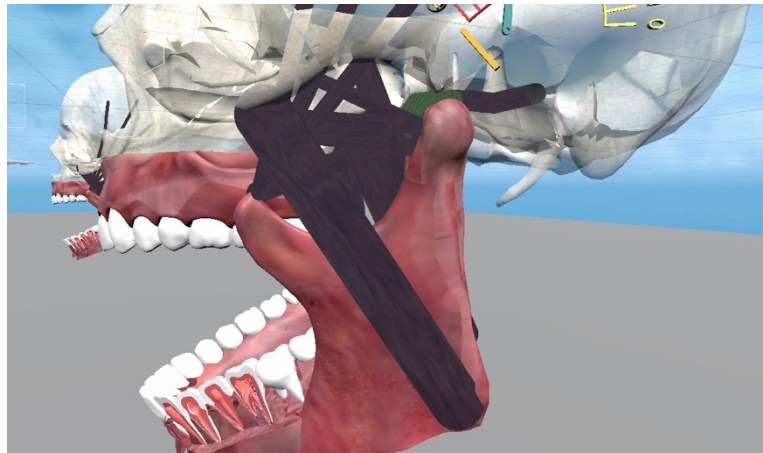


Figure 3.13: Interactive Model in Unity

The script in Unity utilised the C# library, while the META Oculus library was employed to support multiple users (avatars).

Muscle Script Documentation Overview

The LineConnector script utilises the LineRenderer component of Unity to establish dynamic connections between multiple GameObjects. It functions as an integral component of a more extensive system that simulates mandible movement by establishing connections resembling muscles as seen in Figure 3.14.

Usage

- Attach Script:
- Attach the LineConnector script to a GameObject in your Unity scene.
- Configure Objects:
- Assign the GameObjects you want to connect in the inspector to the `_objects` array. These
- GameObjects represent key points in your simulation.
- LineRenderer Setup:
- Ensure the GameObject with the LineConnector script has a LineRenderer component attached

Example Use Case

- The following script is employed to simulate mandible movement:

- `_objects` array holds GameObjects representing key points in the jaw.
- By establishing connections between these points, LineRenderer generates a simulation resembling muscles.

```

public class CeneHareketiOkTuslari : NetworkBehaviour
{
    [SerializeField] private GameObject IlkMerkez;
    [SerializeField] private GameObject IkinciMerkez;
    [SerializeField] private GameObject alt_cene;

    [SerializeField] private InputActionProperty Atusu;
    [SerializeField] private InputActionProperty Btusu;

    [SerializeField] private Material[] MuscleMaterials;
    [SerializeField] private bool isPosselt = true;

    [SerializeField] private GameObject AciTexti;

    [SerializeField] private GameObject OkIsaretiIlkMerkez;
    [SerializeField] private GameObject OkIsaretiIkinciMerkez;
    [SerializeField] private GameObject[] KasNoktalarıIlkMerkez;
    [SerializeField] private GameObject[] KasNoktalarıIkinciMerkez;

    [SerializeField] private GameObject[] posseltPoints;
    [SerializeField] private GameObject AltCeneParent;
    private int waypointIndex;
    [SerializeField] private int MaksAci;

    private bool isDone = false;
    private bool isOpened = false;
    private bool ilkMerkezDone = true;
    [SerializeField] private GameObject ilkMerkez0Pozisyonu;

```

Figure 3.14 A part of Jaw Muscle Code

CeneHareketiOkTuslari Script Documentation Overview

- The CeneHareketiOkTuslari script regulates the mechanics of mandible movement within a Unity scene. By incorporating Oculus Quest controllers and keyboard keys into the mechanism's design, the user is able to manipulate the jaw's opening, closing, and remaining position. In order to simulate mandible movement, the script is an element of a larger system that also includes network synchronisation, materials, and rotations (Figure 3.15).

```

using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class LineConnector : MonoBehaviour
{
    public GameObject[] _objects;
    private LineRenderer line;
    private Renderer[] _renderers;

    void Start()
    {
        line = this.gameObject.GetComponent<LineRenderer>();

        // Store the Renderer components in an array
        _renderers = new Renderer[_objects.Length];
        for (int i = 0; i < _objects.Length; i++)
        {
            _renderers[i] = _objects[i].GetComponent<Renderer>();
        }
    }
}

```

Figure 3.15 A part of the Jaw Muscle Code

Usage Attach Script

Attach the **CeneHareketiOkTuslari** script to a GameObject in your Unity scene.

Configure Objects

- Assign the required GameObjects and materials in the inspector to control jaw movement.

Input Actions

- Configure the input actions (**One** for opening, **Two** for closing) using Unity's Input System.

Script Functionality

- **Variables**
 - **IlkMerkez, IkinciMerkez, alt_cene:** GameObjects representing key components of the jaw.
 - **Atusu, Btusu:** InputActionProperty for opening and closing the jaw.
 - **MuscleMaterials:** Materials used for muscle-like visual effects.
 - **isPosselt:** A boolean indicating whether Posselt-like animation is enabled.
 - **AciTexti:** GameObject for displaying jaw angle text.
 - **OkIsaretilkMerkez, OkIsaretilkinciMerkez:** GameObjects representing arrows for indicating jaw movement.
 - **KasNoktalarilkMerkez, KasNoktalarilkinciMerkez:** Arrays of GameObjects representing muscle points on the jaw.
 - **posseltPoints:** Array of GameObjects representing waypoints for Posselt-like animation.
 - **AltCeneParent:** GameObject representing the parent of the lower jaw.
 - **MaksAci:** Maximum angle for jaw movement.
 - **JawMovement:** Networked variable indicating the state of jaw movement (1 for opening, 2 for closing, 3 for staying).

Methods

- **Spawned():** Initializes variables when the object is spawned.
- **FixedUpdate():** Handles user input, jaw movement physics, and Posselt-like animation.
- **NetworkJawOpen():** Initiates jaw opening through network synchronization.
- **NetworkJawClose():** Initiates jaw closing through network synchronization.
- **NetworkJawStay():** Initiates jaw staying through network synchronization.
- **JawMovementIndicator():** Updates the state of jaw movement based on network synchronization.

Animation and Physics

Opening Jaw:

- Rotates the first and second jaw components.
- Adjusts muscle points based on rotation.
- Handles Posselt-like animation if enabled.

Closing Jaw:

- Rotates the second jaw component.
- Adjusts muscle points based on rotation.
- Handles Posselt-like animation if enabled.

Posselt-like Animation:

- Moves the lower jaw towards predefined waypoints.
- Adjusts rotations to return to the initial position.

Example Use Case

- The following script is employed to simulate mandible movement:
- Avails user-supplied commands for opening, closing, and remaining.
- Realistic mandible movement mechanics and visual effects are managed.
- Network synchronisation is supported to facilitate multiplayer experiences.

Notes

- Establish the correct input action and material configurations to achieve the intended results.
- Conduct experimentation with customisation parameters such as MaksAci and animation waypoints.
-

Muscle Adjustment

- **Overview**
- This segment of the script is tasked with the responsibility of altering the corresponding muscle locations in response to the rotation of mandible components. Conditional tests are employed to ascertain the condition of the mandible, while specific transformations are implemented to simulate disc displacement with reduction in a realistic manner (Figure 3.16).

```
KasNoktalarIlkinciMerkez[1].transform.localEulerAngles = new Vector3((IkinciMerkez.transform.localEulerAngles.x / 12.6f * -42f), 0, 0);
KasNoktalarIlkinciMerkez[2].transform.localEulerAngles = new Vector3((IkinciMerkez.transform.localEulerAngles.x / 12.6f * -33f), 0, 0);
waypointindex = 0;

if (KasNoktalarIlkMerkez[0].transform.localEulerAngles.x > 1.5f && KasNoktalarIlkMerkez[0].transform.localEulerAngles.x < 2.3f)
{
    KasNoktalarIlkMerkez[0].GetComponent<LineRenderer>().material = MuscleMaterials[0];
    KasNoktalarIlkinciMerkez[0].GetComponent<LineRenderer>().material = MuscleMaterials[1];
}
if (KasNoktalarIlkMerkez[0].transform.localEulerAngles.x > 2.3f && KasNoktalarIlkMerkez[0].transform.localEulerAngles.x < 3.7f)
{
    KasNoktalarIlkinciMerkez[1].GetComponent<LineRenderer>().material = MuscleMaterials[1];
    KasNoktalarIlkMerkez[1].GetComponent<LineRenderer>().material = MuscleMaterials[0];
}
if (KasNoktalarIlkMerkez[0].transform.localEulerAngles.x > 3.7f && KasNoktalarIlkMerkez[0].transform.localEulerAngles.x < 5.5f)
{
    KasNoktalarIlkinciMerkez[2].GetComponent<LineRenderer>().material = MuscleMaterials[1];
    KasNoktalarIlkMerkez[2].GetComponent<LineRenderer>().material = MuscleMaterials[0];
}
if (KasNoktalarIlkMerkez[0].transform.localEulerAngles.x > 5.5f)
```

Figure 3.16 Disc Displacement

Creating 3D Models for TMJ

The 3D human skull model is created using the human body's anatomical elements as a basis. As can be observed from Figure 3.17, information on the TMJ and other relevant human anatomical structures is created by excluding other anatomical structures.

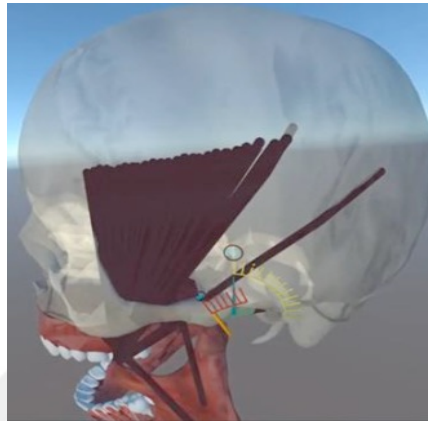


Figure 3.17 Modelled 3D Human Skull in Metaverse

The components of each anatomical structure have been modelled on the human skull and unrelated components have been eliminated for simple and effective learning. The aim is to get the student to focus on related parts to see how each other gets involved in jaw movements and their behaviours under different conditions and positions. The muscles on human skulls have been simplified based on the reference pinpoints of the muscle on the human skull to reduce complexity to increase visibility to have it more easily understood. An articular disc has been modelled and added between the upper and lower jaw bones. The regular and rare disorder scenarios to cover up all possible cases for the student that they may face in real life were modelled (Figure 3.18).

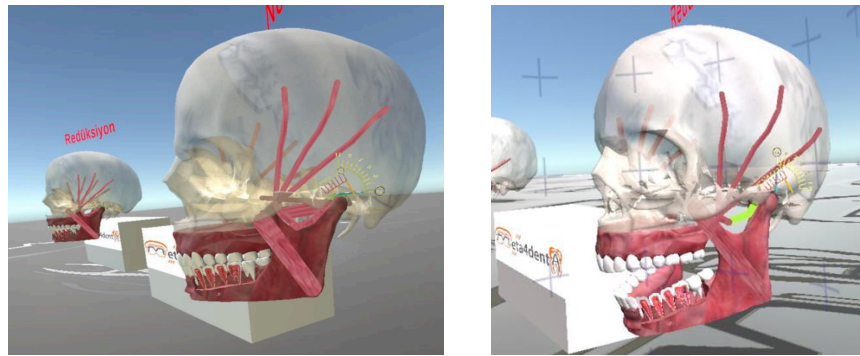


Figure 3.18 Simplified TMJ Model in Metaverse

Using Oculus VR glasses, a virtual reality (VR) environment presents the produced model. Users may navigate the model and open and close their mouths in this virtual world using a variety of alternate methods (see Figure 3.19). The model replicates every action of the TMJ in humans. Students walk around of the created models to see the details, and differences between healthy and disordered TMJ scenarios. The scene gives students to have interactive experiences as visual, auditory, and tactile.

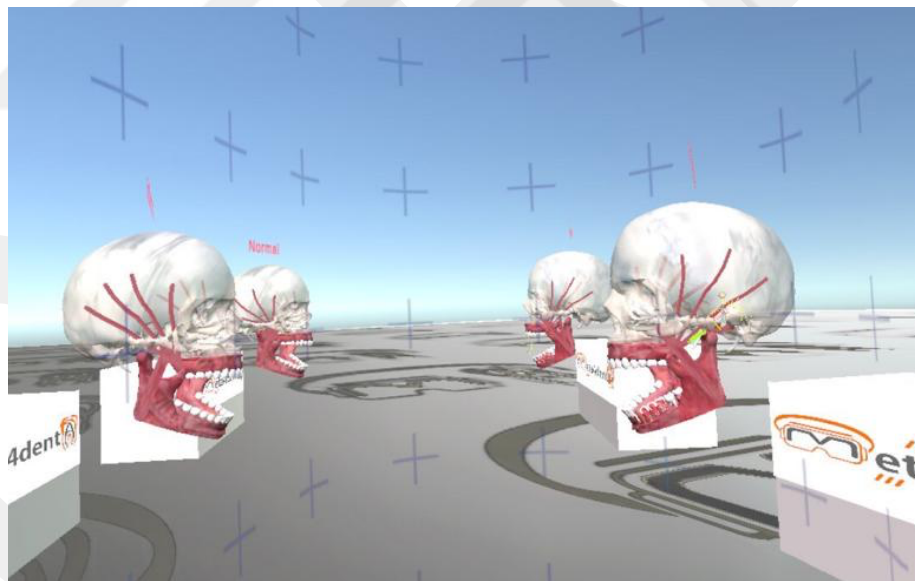


Figure 3.19 Interactive Metaverse Environment

Users can examine the 3D model from various perspectives, including inside it, as shown in Figure 3.20. This makes it easier for the user to see how the TMJ behaves in various situations and from various angles.

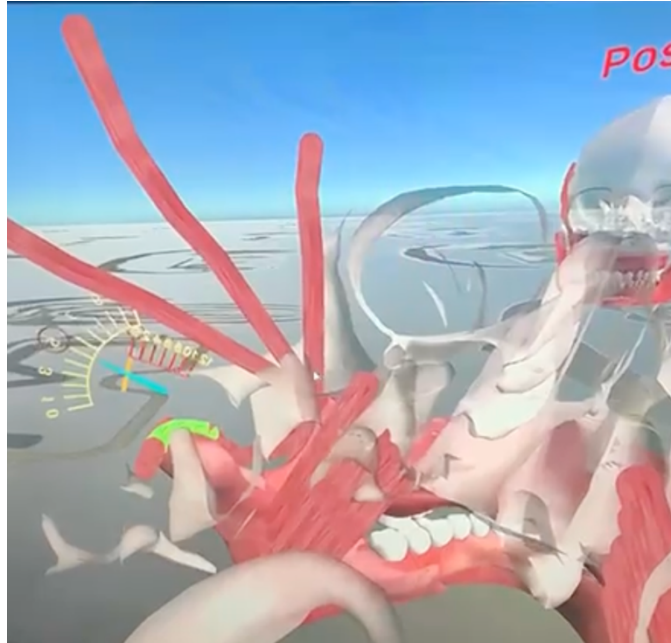


Figure 3.20 Inside View in VR Scene

Ultimately, it offers a deeper comprehension of various chin movements and how they interact with associated anatomical structures. In this manner, the user can view interactions and cause-effect relationships between various TMJ-related anatomical structures (Figure 3.21).

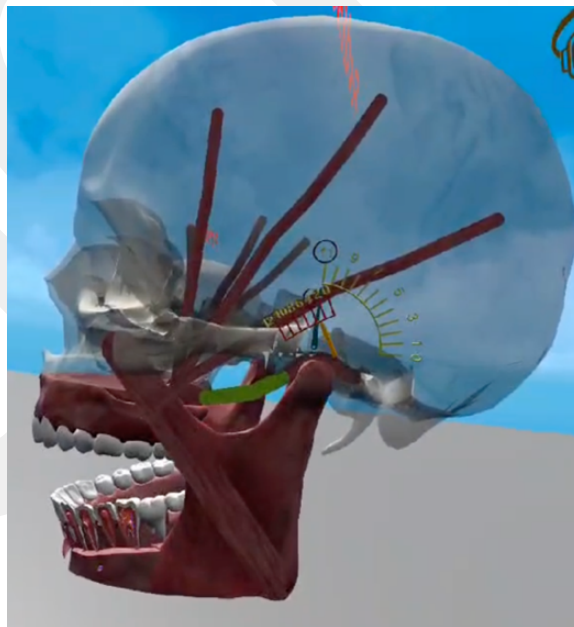


Figure 3.21: TMJ Related Anatomical Structures

For example, during this process, the relevant muscles can be observed. To make things easier to understand, the 3D model also displays the angles of the chin movements in Figure 3.22.

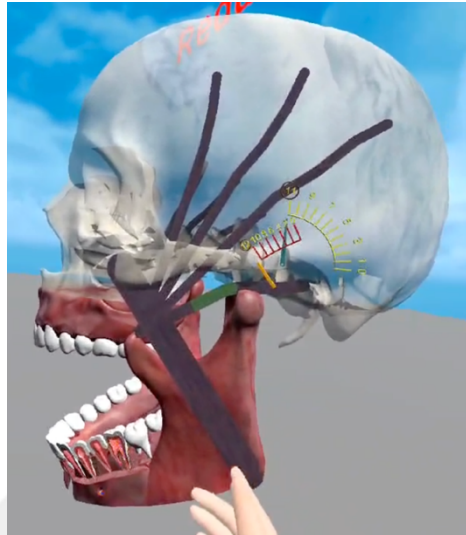


Figure 3.22 Display the Angle of the Chin Movement

The 3D environment also includes a representation of the posselt diagram for the posselt opening as shown in Figure 3.23.

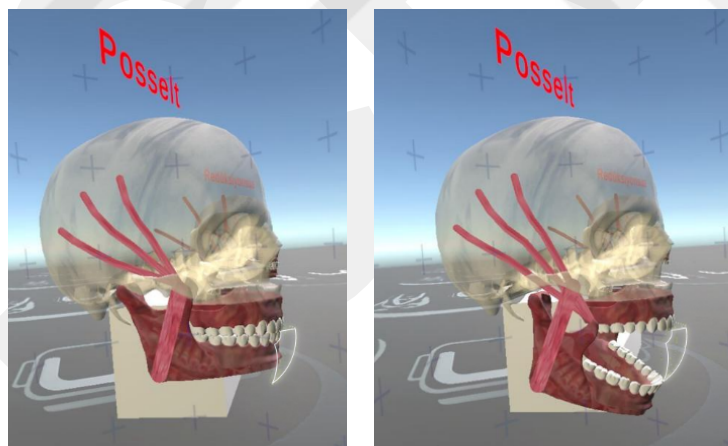


Figure 3.23 Posselt Diagram in VR Environment

Interaction of User with system

- In this virtual environment, the user may engage in multiple interactions. The controllers that come with the VR glasses are used to control the interactions.

The controller's buttons are designed to serve various functions to optimise user interaction. The following is a summary of the key interactions:

- The mouth of the 3D model can be opened and closed with the help of user controllers.
- Users can view a related Posselt diagram of it through the controllers as seen in Figure 3.4.
- The mouth of the 3D model can be closed by the users using the controllers.

The 3D model allows users to explore and study the movements and interactions between various anatomical structures from various viewpoints (Figure 3.24).

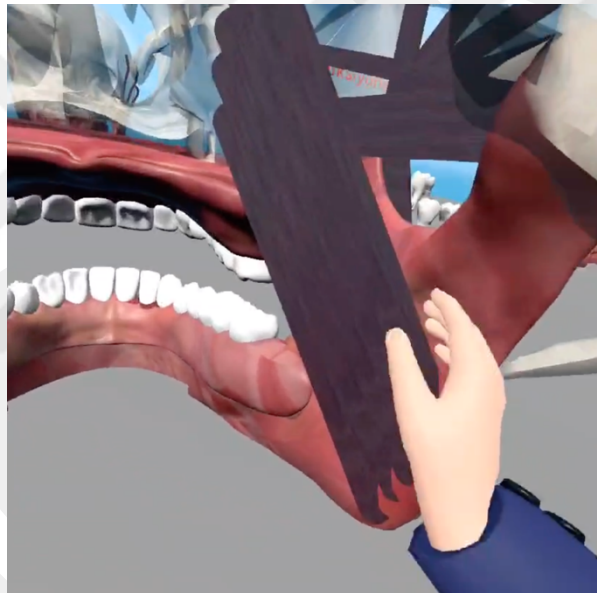


Figure 3.24 User Interaction in VR Environment

To view the interactions from the inside or different perspectives, users can also move around inside the 3D model as seen in Figure 3.25.

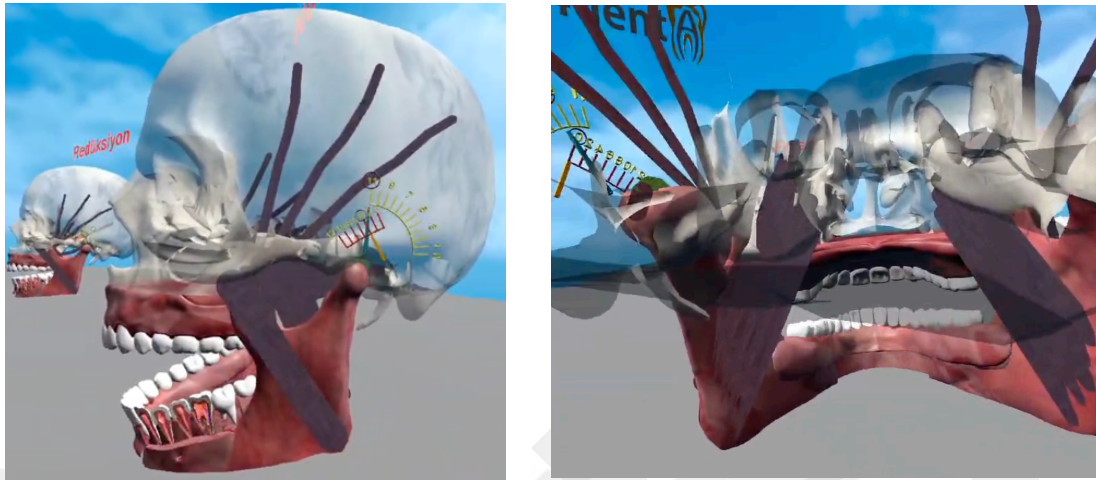


Figure 3.25 Inside and Outside View in VR Environment

Education in the Metaverse

The system is adjusted to the metaverse concept once the 3D model has been designed and developed and the user interface has been implemented to enable interaction and deeper system investigation. In this world, multiple users can sign up for the same account and gather in the same virtual space. Following registration, each user is represented in the system by a unique avatar. To help other players recognise each other, their names are also displayed above their avatars (Figure 3.26).



Figure 3.26 Multi-Player in VR Environment

Every user can establish a connection from anywhere in the world in this metaverse. With the VR glasses, they can hear and talk to each other. Therefore, this setting is suitable for setting up a virtual classroom where students can learn, discuss, and see the concepts, theories, and relationships related to the human TMJ as seen in Figure 3.26

Metaverse environment offers up to 20 people to get in the scene simultaneously. The purpose of the metaverse can be split into two parts based on its user scenarios.

1. Scenario: The lecturer and 20 students can get into a scene together. The speaker uses interactive teaching methods, such as displaying and conversing with students, to explain the anatomic anatomy of the TMJ on the human skull. The presentation demonstrates the jawbone's open and closed interaction to demonstrate how each anatomical structure functions with others in both healthy and pathological conditions. In fully interactive virtual reality situations, the instructor can also engage in real-time communication with students by asking questions and providing prompt answers. Additionally, the lecturer can quickly assess the students' level during the class or after it has ended.

2. Scenario: Students have unrestricted access to this virtual reality setting to practise again. If students want to practise and learn about the anatomic components of the

TMJ, they can enter the scenario at any time. In order to improve learning, kids may also examine the model together, brainstorm with their peers, and exchange ideas through discussion in the scenario.

3.5 Methods

An immersive VR technology-based software system is developed and released for testing by students and lecturers. First and foremost, it's critical to comprehend the difficulties of teaching TMJ in dentistry school. In this concern, interviews with three instructors on TMJ were conducted and the requirements of such an innovative technology-enhanced educational system were captured.

Accordingly, the anatomical structures are to be understood to better model these systems in virtual environments. The primary anatomical structures and their functional mechanism in conjunction with the linked anatomical structures were identified.

In the next step, research was conducted to better understand how immersive VR technologies can be used to ease of learning of this complexity for dental students. In that concern, a TMJ course was given to ten students in the developed metaverse environment, and their user experience reflections were collected through a questionnaire (see Appendix-A, and Appendix-B).

The direct user testing approach is employed to get quick input from experts and students about the usefulness of the TMJ app for dental education. In this instance, it was possible to test the product in October 2023 at the Dentistry Congress. The user group consisted mostly of dental instructors and students. During this implementation, an instructor first gave a lecture on the developed system through the VR glasses. The training session took fifteen to twenty minutes. After the training session, the questionnaire was given to the participants to get their reflections about the developed system.

Fifteen individuals (9 female and 6 male) who are associated with the dental industry and vary in age between 23 and 48 (average =32) were participated in this study voluntarily.

Table 3.1 Participants

Degree	n
Student	1
Dentist	9
Assistant	2
Assoc.Prof.	2
Prof.	1
Area	
Protetik diş Tedavisi	4
Ağız diş ve cene cerrahisi	1
Pratizyez	1
Not declared	9

As seen from Table 3.1, the user group profile had a dental profession. Prior VR experience was not necessary. However, 8 of them (53%) were already having VR earlier VR experience.

For this VR experiment, Quest 2 VR Glass units were utilised. Concerning the glass's price, it produces excellent results. It supports up to 20 multi-players and operates on a wireless connection that is cloud-based. Users in virtual reality environments feel more liberated as they explore the models thanks to the Wi-Fi connection.

Before entering the VR, area and exploring TMJ models, each user received training on using Oculus and its capabilities. They also engaged with both normal and disordered circumstances within the VR scene. They also encountered multi-player users, among whom may be professors imparting TMJ education or colloquies having TMJ education discussions.

Following the VR training experiment, each user completed a questionnaire to assess their virtual reality experience. This allowed the comparison of the immersive VR TMJ education methods with more conventional educational approaches and gathering input for future product development features.

In the VR app, users see the simplified TMJ models on human skull models with normal and disordered circumstances. They had a walk around of each model and interacted with each scenario to be able to see the details of the TMJ that targets the visual and auditory sense of users to speed up and keep learning long-lasting as depicted in Figure 3.27.

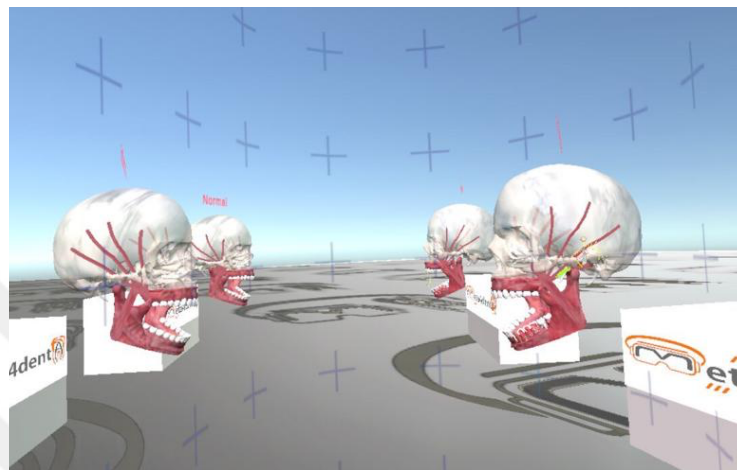


Figure 3.27 TMJ VR Scene

In a virtual reality setting, users interacted with the models to learn about the anatomy of the TMJ. To observe how each anatomic component of the TMJ functions in tandem with movement, the lower jaw was opened and closed. They also saw how the articular disc and intricate muscular system function during lower jaw movement. Users also viewed the TMJ regular model with disordered models' side by side in a VR setting seen in Figure 3.28.

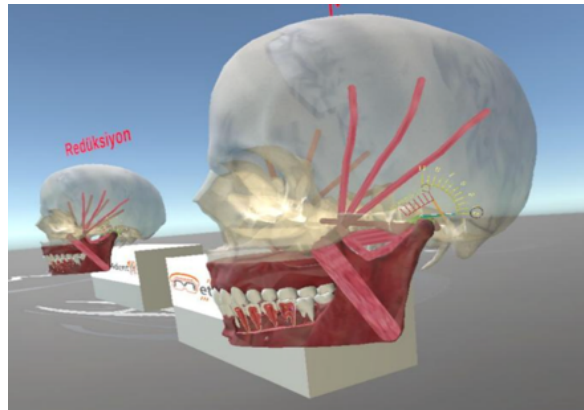


Figure 3.28 Regular and Disordered TMJ Model

After the VR experiment, the users were asked about their experience with this TMJ education app to understand what they felt, how much they were happy to use it in the future and how useful the app is for TMJ education.

CHAPTER 4

RESULTS

The survey was prepared in a way such that the replies may be used for different purposes. Below the results are given according to these purposes of the survey.

4.1 Comfort of the Application though the VR Headset

As explained in the method section, the experience of the participants with the developed VR environment took at most 20 minutes. During this period, if the participants were comfortable using the VR headset and suffered from physical conditions such as vertigo or dizziness, a question was asked. In this question, the participants are asked to the following question:

To what extent did you feel the following negative emotions about the application you used? (1: least, 5: most)

Their responses on the degree to which VR headsets impact their comfort are summarized in Table 4.1. As seen from Table 4.1, most of their responses show that, they did not feel uncomfortable. For all these uncomfortable feelings their responses have the lowest rates.

Table 4.1. Comfort Evaluations of the Participants

	1		2		3		4		5	
	n	%	n	%	n	%	n	%	n	%
Dizziness?	11	73.33	0	0.00	2	13.33	1	6.67	1	6.67
Does your head feel "heavy"?	9	60.00	1	6.67	1	6.67	2	13.33	2	13.33
Vertigo?	13	86.67	1	6.67	0	0.00	0	0.00	0	0.00
General discomfort?	12	80.00	1	6.67	1	6.67	0	0.00	0	0.00
Nausea?	13	86.67	0	0.00	0	0.00	0	0.00	1	6.67
Headache?	11	73.33	1	6.67	2	13.33	0	0.00	0	0.00

This indicates that, TMJ education may be completed safely in a VR headset since, as Table 4.1 shows, individuals feel at ease and do not experience any negative consequences from VR usage during this time.

4.2 Fun Level of the Application

The second survey item was about the fun level of the application. It aims to finding out how much the users had fun and what they felt when they were in the VR application. One of the arguments of the study is to make learning enjoyable. So, Table 4.2 shows the feelings of the participants which is about their fun, excitement, disappointment, and enthusiasm feelings. In this question, the participants are asked to the following question:

To what extent did you feel the following emotions about the application you used? (1: least, 5: most)

As seen from Table 4.2, for the positive questions like fun, satisfied, enthusiasm and excitement, the participants have given higher rates. For those questions, the ratio of the responses over 4.5/5 is higher than 70%. Similarly, for the negative questions like, bored, disappointed, nervous, stressful, and annoyed, the participants have responded very low rates. For those questions the ratio of 1/5 is higher than 70%.

Table 4.2. Fun Level Experiences of the Participants

	1		2		3		4		5	
	n	%	n	%	n	%	n	%	n	%
Fun?	0	0.00	1	6.67	0	0.00	3	20.00	11	73.33
Satisfied?	0	0.00	1	6.67	0	0.00	6	40.00	8	53.33
Enthusiasm?	0	0.00	1	6.67	2	13.33	6	40.00	5	33.33
Excitement?	1	6.67	2	13.33	1	6.67	5	33.33	6	40.00
Bored?	12	80.00	1	6.67	0	0.00	1	6.67	0	0.00
Disappointment?	11	73.33	2	13.33	0	0.00	1	6.67	0	0.00
Nervous?	14	93.33	0	0.00	0	0.00	0	0.00	0	0.00
Stressful?	14	93.33	0	0.00	0	0.00	0	0.00	0	0.00
Annoyed?	13	86.67	0	0.00	1	6.67	0	0.00	0	0.00

4.3 Possible Contributions to the Classical Education

The purpose of the third group of questions in the survey is to determine how TMJ VR education possibly enhances to the traditional TMJ education programs. For this purpose, we have asked the following item in the questionnaire:

I think that the metaverse-based application will make the following contributions to education (You can tick more than one option):

As seen from Table 4.3, all participants have put the choice “Increasing student interest/curiosity in the course”, at the first possible benefits of the developed VR environment. Additionally, majority of the participants declared their expectation on improved attention (87%) and performance (73%) of the students through the developed application.

Table 4.3 Possible Benefits of the Metaverse Application

	n	%
Increasing student interest/curiosity in the course	15	100.00
Sustained student attention	13	86.67
Improvement in academic performance of students	11	73.33
Providing more information/subjects in a shorter time	10	66.67
Ease of Use	7	46.67
The instructor's need to produce less content for the course	6	40.00

Additionally, 14 participants (93%) have also reported their willingness to utilise the TMJ VR education software for their own classes. To better understand the participants' attitudes on the possible contributions of the metaverse application, the following questionnaire items shown in the Table 4.4 were also asked. As seen from this table, mainly the participants have declared their positive attitudes through the metaverse application. They declared that the application will be useful (87%) and effective (87%) for the students. As seen from Table 4.4, mostly they have very positive attitudes on the impact of such an application on TMJ training.

Table 4.4. Contribution of Metaverse Based-Application

	Strongly Agree		Agree		Not Sure		Disagree		Strongly Disagree	
	n	%	n	%	n	%	n	%	n	%
I think metaverse-based applications will be useful in student education.	13	86.67	1	6.67	1	6.67	0	0.00	0	0.00
I believe that a Metaverse-based education regarding TMJ (Temporomandibular Joint) will be effective in the academic success levels of students.	13	86.67	1	6.67	1	6.67	0	0.00	0	0.00
I think that a metaverse-based application will help keep students' attention in the lesson.	11	73.33	2	13.33	2	13.33	0	0.00	0	0.00
I think that providing education to students with a Metaverse-based application will increase their academic success in terms of midterm and final grades.	9	60.00	4	26.67	2	13.33	0	0.00	0	0.00
I think that even after a certain amount of time has gone, the training offered by metaverse-based apps will be more lasting.	12	80.00	1	6.67	2	13.33	0	0.00	0	0.00

4.4 Learning Experience with the Metaverse Application

The primary goal of the study is to facilitate and improve TMJ learning in dentistry education. As a result, the poll also determined how well the app supported the learning process. In that concern there were three items in the questionnaire. The participants agreed on the beneficial effects of the TMJ Metaverse education, as Table 4.5 demonstrates.

Table 4.5 Benefits of Metaverse Based Application on Learning

	Strongly Agree		Agree		Not Sure		Disagree		Strongly Disagree	
	n	%	n	%	n	%	n	%	n	%
I understood the basic ideas/problems presented to me within the application	7	46.67	7	46.67	0	0.00	1	6.67	0	0.00
I learned through VR app.	6	40.00	8	53.33	0	0.00	1	6.67	0	0.00
The content increased my knowledge and understanding of the subject presented by the VR application.	8	53.33	6	40.00	1	6.67	0	0.00	0	0.00

When their responses on strongly agree and agree choices the learning experience of the participants with Metaverse application very high indicating they have learned

through the application (93%), increasing knowledge, and understanding subjects (93%) and basic ideas (93%).

The participants' interest on metaverse-based learning environment is also evaluated through six items given in Table 4.6. As seen in Table 4.6, they mainly like to know more about what they have seen in practice through the application (93%), enjoyed the content (86%), motivated (93%), interested (93%) and eager to explore the content further (983%). Also, they declared that the content triggered their curiosity (87%).

Table 4.6 Participants' Interest in Metaverse-Based Learning

	Strongly Agree		Agree		Not Sure		Disagree		Strongly Disagree	
	n	%	n	%	n	%	n	%	n	%
I would like to know more about what I see in practice.	8	53.33	6	40.00	1	6.67	0	0.00	0	0.00
I enjoyed the content so much that I want to learn more about this topic.	8	53.33	5	33.33	2	13.33	0	0.00	0	0.00
There were things in the content that triggered my curiosity.	10	66.67	3	20.00	1	6.67	1	6.67	0	0.00
I feel motivated to continue using the app.	11	73.33	3	20.00	1	6.67	0	0.00	0	0.00
I was interested to see what happens in app	11	73.33	3	20.00	1	6.67	0	0.00	0	0.00
I wanted to explore the app further.	11	73.33	3	20.00	1	6.67	0	0.00	0	0.00

4.5 Usability Experience with the Metaverse Application

As seen in Table 4.7 about the usability of the application there were some items in the questionnaire. The participants' responses on these items were also mostly positive. They have declared that, overall, the learning content was presented well (87%), providing useful feedback (80%), providing clear and understandable information (73%), responding well to their actions (86%), and their willingness to interact more in the VR application (73%).

Table 4.7 Usability of the Application

	Strongly Agree		Agree		Not Sure		Disagree		Strongly Disagree	
	n	%	n	%	n	%	n	%	n	%
Overall, the learning content was presented well.	7	46.67	6	40.00	1	6.67	1	6.67	0	0.00
The app gave me useful feedback on what I needed to do.	6	40.00	6	40.00	1	6.67	2	13.33	0	0.00
The information provided by the application (e.g. targets, help messages, images, text and sounds) was clear and understandable.	7	46.67	4	26.67	3	20.00	0	0.00	0	0.00
I can interact a lot with the virtual universe.	5	33.33	6	40.00	4	26.67	0	0.00	0	0.00
The virtual universe responded well to my actions.	5	33.33	8	53.33	1	6.67	1	6.67	0	0.00
Interactions with virtual objects were similar to interactions with real objects.	3	20.00	6	40.00	2	13.33	5	33.33	0	0.00
I used/controlled the app easily.	7	46.67	7	46.67	1	6.67	0	0.00	0	0.00
I had complete control over what I did.	6	40.00	3	20.00	5	33.33	1	6.67	0	0.00
While using the app, I had no problems doing the things I wanted.	7	46.67	4	26.67	2	13.33	2	13.33	0	0.00

However, in contrast to their answers on other usability factors (60%) their answers on the questionnaire item reflecting the resemblance of the interactions with the VR objects compare to the actual things were lower. This is acceptable as there is no haptic feedback in the VR environment. Besides, the participants also declared that they have easily used the application without any problems (72%) and controlled the system easily (93%).

4.6 Participants' Opinions: Graphics Quality of the Metaverse Application

To find out what users think of the TMJ app's visuals, some questionnaire items were designed. The application's visuals are crucial as they increase the likelihood that users will stick with the application. Most participants are happy with the TMJ application's environment and graphics, as seen in

Table 4.8.

The results of

Table 4.8 indicate that the participants liked the aesthetical design (80%), visuals of the application (93%), visually appealing of the application (86%), and enjoyment of the virtual environment (92%).

Table 4.8 Graphics of the Application

	Strongly Agree		Agree		Not Sure		Disagree		Strongly Disagree	
	n	%	n	%	n	%	n	%	n	%
The application was aesthetically pleasing.	8	53.33	4	26.67	2	13.33	1	6.67	0	0.00
The app's visuals were entertaining.	8	53.33	6	40.00	1	6.67	0	0.00	0	0.00
The app was visually fun.	8	53.33	5	33.33	2	13.33	0	0.00	0	0.00
I enjoyed the virtual environment.	10	66.67	4	26.67	1	6.67	0	0.00	0	0.00
The application's visuals were appealing.	6	40.00	6	40.00	2	13.33	1	6.67	0	0.00

4.7 Participants' Opinions about the Cognitive Load Gained by the Application

As seen from Table 4.9 the participants reported that, the cognitive load gained by the application was at a reasonable level (93%). They have reported that, it did not take a lot of their mental load (73%).

Table 4.9 Cognitive Load of the Application

	Strongly Agree		Agree		Not Sure		Disagree		Strongly Disagree	
	n	%	n	%	n	%	n	%	n	%
The cognitive load of the application was at a reasonable level.	8	53.33	6	40.00	1	6.67	0	0.00	0	0.00
Presenting too much information prevented memorization of what was important.	2	13.33	0	0.00	2	13.33	8	53.33	3	20.00
It took a lot of mental energy for me to get through the material the app showed me.	2	13.33	0	0.00	1	6.67	8	53.33	3	20.00

4.8 Participants' Engagement with the Application

The participants also reported their positive feedback about the engagement levels of the application. As seen from

Table 4.10, the reported that they have immersed themselves in practice (80%), ignored everything other than the application (80%) and felt themselves like they were in a virtual world (93%).

Table 4.10 Participants' Engagement with the Application

	Strongly Agree		Agree		Not Sure		Disagree		Strongly Disagree	
	n	%	n	%	n	%	n	%	n	%
I immersed myself in the practice.	5	33.33	7	46.67	2	13.33	1	6.67	0	0.00
I forgot/ignored everything around me, just focused on app.	4	26.67	8	53.33	1	6.67	2	13.33	0	0.00
I forgot where I was.	3	20.00	5	33.33	1	6.67	5	33.33	1	6.67
I felt like I was in the virtual universe.	6	40.00	8	53.33	1	6.67	0	0.00	0	0.00
I lost my sense of time.	3	20.00	4	26.67	3	20.00	4	26.67	1	6.67
I felt like I was living in another place and time.	4	26.67	8	53.33	1	6.67	2	13.33	1	6.67

CHAPTER 5

DISCUSSION AND CONCLUSION

In this study, anatomic structures of human TMJ are simulated in a 3D virtual environment and the simulations are provided to the users through VR glasses with a metaverse user interface. Such a system provides several potential benefits for different purposes. To better understand the influence of digital technology on temporomandibular joint repair operations, for example, a review study of thirty papers was undertaken. The research's findings indicate that aided and virtually planned procedures are superior to traditional techniques [78]. Hence, such simulations and 3D virtual environments potentially cause some positive improvements to better prepare surgeons for their surgical procedures. When the studies in the literature are analysed, it can be seen that there are some attempts to create such environments, showing several potential benefits of 3D virtual simulated models of TMJ.

However, by implementing these systems in the metaverse, a new perspective can be gained to provide an interactive experience for the trainees in a virtual world. Besides, as there are very limited specialists in TMJ anatomy, it also provides synchronized or a synchronized instructional opportunity for meeting experts and trainees from anywhere in the world in this virtual environment. Additionally, the virtual interactions with the simulated model and classmates as well as with the instructors possibly will improve the level of learning in this virtual environment and create a base for discussions and conversation like in real classrooms.

As a conclusion, in this study very complex anatomical structures of TMJ simulation and its experience in a metaverse are discussed. In the future, this environment and its possible instructional implementations need to be evaluated experimentally. However, this study shows the possibility of creating such virtual environments and its possible benefits for teaching and learning as well as surgical procedures such as surgical

planning and better strategical surgery decisions. By integrating these systems into traditional training programs, several benefits for the dental faculties and trainees can be gained.



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APPENDIX A

ORIGINAL QUESTIONNAIRE IN TURKISH

Meta evren (Metaverse) uygulaması hakkında geri bildirimleriniz:	Kesinlikle Katılmıyorum	Katılmıyorum	Kararsızım	Katılıyorum	Kesinlikle Katılıyorum
Uygulama estetik açıdan memnun ediciydi					
Uygulamanın grafikleri eğlenceliydi.					
Uygulama gorsel olarak çekiciydi.					
Sanal ortamdan keyif aldım.					
Uygulamanın grafikleri çekiciydi.					
Uygulama grafiklerinden memnun kaldım					
Uygulamanın bilissel yuku makul düzeydeydi.					
Cok fazla bilginin sunulması, önemli olanın ezberlenmesini engelledi.					
Uygulamanın bana sunduğu bilgileri incelemek için harcadığım caba zihinsel olarak yorucuuydu.					
Uygulamayı kolaylıkla kullandım/kontrol ettim.					
Yaptıklarım üzerinde tam kontrolüm vardı.					
Uygulamayı kullanırken, istediğim şeyler yapmakta sorun yaşamadım.					
Kendimi uygulamaya kaptırdım.					
Etrafımdaki her şeyi unuttum/gormezden geldim.					
Nerede olduğumu unuttum.					
Kendimi sanal evrenin içinde gibi hissettim.					
Zaman duygumu kaybettim.					
Kendimi başka bir yerde ve zamanda yasiyormuş gibi hissettim.					
Genel olarak, öğrenme içeriği iyi bir şekilde sunuldu.					
Uygulama bana yapmam gerekenlerle ilgili yararlı geri bildirimler verdi.					
Uygulama tarafından sağlanan bilgiler (örn. hedefler, yardım mesajları, resimler, metinler ve sesler) acık ve anlaşılırdi.					
Sanal evren ile çok fazla etkileşim kurabilirim.					
Sanal evren eylemlerime iyi karşılık verdi.					
Sanal nesnelere olan etkileşimler gerçek nesnelere olan etkileşimlere benzerdi.					
Uygulamada gördüklerim hakkında daha fazla bilgi edinmek istiyorum.					
İçerikten o kadar keyif aldım ki bu konu hakkında daha fazla bilgi edinmek istiyorum.					
İçerikte merakımı tetikleyen şeyler vardı.					
Uygulamayı kullanmaya devam etmek için motive hissediyorum.					
Uygulamada ne olduğumu görmek ilgimi çekti					
Uygulamayı daha fazla keşfetmek istedim.					
Uygulama içinde bana sunulan temel fikirleri/sorunları anladım					
Uygulama aracılığıyla öğrendim.					
İçerik, uygulama tarafından sunulan konu hakkındaki bilgimi ve anlayışımı artırdı.					
Meta evren (metaverse) tabanlı uygulamaların öğrenci eğitiminde faydalı olacağını düşünüyorum.					
TME (Temporomandibu ler Eklem) ile ilgili Meta evren (metaverse) tabanlı bir eğitimin öğrencilerin akademik başarı düzeylerinde etkili olacağına inanıyorum.					
Meta evren (metaverse) tabanlı bir uygulamanın öğrencilerin dikkatini derste tutmaya yardımcı olacağını düşünüyorum.					
Öğrencilere Meta evren (metaverse) tabanlı bir uygulama ile eğitim verilmesinin vize-final notları bazında akademik başarılarını artıracığını düşünüyorum.					
Meta evren (metaverse) tabanlı uygulamalar ile verilen eğitimin, eğitim üzerinden belirli bir süre geçtikten sonra bile daha kalıcı olacağı düşüncesindeyim.					

1: en az, 5: en çok	1	2	3	4	5
Bas donmesi?					
Basiniz "agirliyor" mu?					
Vertigo?					
Genel bir rahatsızlık?					
Mide bulantisi?					
Bas agrisi?					

Meta Evrende TME Eğitimi Görüş Anketi	
Cinsiyet?	
Yasiniz?	
Unvaniniz?	
Bransiniz?	
Oğrenme Tercihini (İsitsel/Gorsel)?	
Daha önce VR deneyimi var mı?	
Eğitim amaçlı VR a olumlu mu?	

1: en az, 5: en çok	1	2	3	4	5
Eğlence?					
Memnuniyet?					
Cosku?					
Heyecan?					
Sikilmis?					
Hayal Kırıklığı?					
Gergin?					
Stresli?					
Sinirli?					

Meta evren (metaverse) tabanlı uygulamanın eğitime şu katkıları sağlayacağını düşünüyorum (Birden fazla seçenek işaretleyebilirsiniz)	
Kullanım Kolaylığı	
Daha kısa sürede daha çok bilgi/konu verilebilmesi	
Öğrenci dikkatinde devamlılık	
Öğrenci akademik başarısında yükselme	
Öğrencinin derse ilgisini/ merakını artırma	
Eğitmenin ders için daha az içerik üretme ihtiyacı	

Bu ürün/uygulama aktif kullanım halinde olsaydı	
Evet	
hayır	

APPENDIX B

QUESTIONNAIRE IN ENGLISH

	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
Your feedback about the Metaverse application:					
The application was aesthetically pleasing.					
The app's visuals were entertaining.					
The app was visually fun.					
I enjoyed the virtual environment.					
The application's visuals were appealing.					
I was pleased with the application graphics.					
The cognitive load of the application was at a reasonable level.					
Presenting too much information prevented memorization of what was important.					
It took a lot of mental energy for me to get through the material the app showed me.					
I used/controlled the app easily.					
I had complete control over what I did.					
While using the app, I had no problems doing the things I wanted.					
I immersed myself in the practice.					
I forgot/ignored everything around me, just focused on app.					
I forgot where I was.					
I felt like I was in the virtual universe.					
I lost my sense of time.					
I felt like I was living in another place and time.					
Overall, the learning content was presented well.					
The app gave me useful feedback on what I needed to do.					
The information provided by the application (e.g. targets, help messages, images, text and sounds) was clear and understandable.					
I can interact a lot with the virtual universe.					
The virtual universe responded well to my actions.					
Interactions with virtual objects were similar to interactions with real objects.					
I would like to know more about what I see in practice.					
I enjoyed the content so much that I want to learn more about this topic.					
There were things in the content that triggered my curiosity.					
I feel motivated to continue using the app.					
I was interested to see what happens in app					
I wanted to explore the app further.					
I understood the basic ideas/problems presented to me within the application					
I learned through VR app.					
The content increased my knowledge and understanding of the subject presented by the VR application.					
I think metaverse-based applications will be useful in student education.					
I believe that a Metaverse-based education regarding TMJ (Temporomandibular Joint) will be effective in the academic success levels of students.					
I think that a metaverse-based application will help keep students' attention in the lesson.					
I think that providing education to students with a Metaverse-based application will increase their academic success in terms of midterm and final grades.					
I think that even after a certain amount of time has gone, the training offered by metaverse-based apps will be more lasting.					

Meta Universe_TMJ Education Questionnaire Survey					
1: lowest, 5: highest	1	2	3	4	5
Dizziness?					
Does your head feel "heavy"?					
Vertigo?					
General discomfort?					
Nausea?					
Headache?					

MetaverseTMJ Education Survey	
Gender?	
Age?	
Profession?	
Learning Preference (Auditory/Visual)?	
Have you had VR experience before?	
Is it compatible with VR for educational purposes?	

1: lowest, 5: highest	1	2	3	4	5
Fun?					
Satisfied?					
Enthusiasm?					
Excitement?					
Bored?					
Disappointment?					
Nervous?					
Stressful?					
Annoyed?					

I think that the metaverse-based application will make the following contributions to education (You can tick more than one option):	
Ease of Use	
Providing more information/subjects in a shorter time	
Sustained student attention	
Improvement in academic performance of students	
Increasing student interest/curiosity in the course	
The instructor's need to produce less content for the course	

If this product/application was in active use, would you prefer it in your own lessons? If no, briefly explain why.	
YES	
NO	