

Development of software for use of dental mannequins in virtual environments or virtual reality and the metaverse

Desenvolvimento de software para uso de manequim odontológico em ambiente virtual ou em realidade virtual e metaverso

Desarrollo de software para el uso de maniqués odontológicos en entornos virtuales, de realidad virtual y en el metaverso

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Abstract: This research aims to present an interactive tool called OdontoSim 3D, which simulates dental procedures, providing an immersive educational experience, allowing risk-free practice for patients, and improving clinical skills. The use of detailed 3D models and features such as zoom and rotation enabled accurate analysis. The virtual system offers advantages over the use of physical mannequins, such as the elimination of clinical risks and cost reduction. The repetition of procedures and real-time interaction with three-dimensional models improved student learning. The software also showed scalability, allowing expansion to more complex procedures.

Keywords: Educational application. Intraoral scanning. Dental education. 3D analysis.

Resumo: Esta pesquisa tem por objetivo apresentar a ferramenta interativa OdontoSim 3D, que simula a realização de procedimentos odontológicos, possibilitando uma experiência educacional imersiva, permitindo uma prática sem riscos ao paciente e o aprimoramento de habilidades clínicas. O uso de modelos 3D detalhados e de recursos como zoom e rotação permitiu análises precisas. O sistema virtual oferece vantagens em relação ao uso de manequins físicos, como a eliminação de riscos clínicos e a redução de custos. A repetição de procedimentos e a interação em tempo real com modelos tridimensionais aprimoraram o aprendizado dos alunos. O software também apresentou escalabilidade, permitindo a expansão para procedimentos mais complexos.

Palavras-chave: Aplicativo educacional. Escaneamento intraoral. Educação em odontologia. Análise 3D.

Resumen: El objetivo de esta investigación es presentar la herramienta interactiva OdontoSim 3D, que simula la realización de procedimientos odontológicos, lo que permite una experiencia educativa inmersiva, una práctica sin riesgos para el paciente y la mejora de las habilidades clínicas. El uso de modelos 3D detallados y de recursos como el zoom y la rotación ha permitido realizar análisis precisos. El sistema virtual ofrece ventajas con respecto al uso de maniqués físicos, como la eliminación de riesgos clínicos y la reducción de costes. La repetición de procedimientos y la interacción en tiempo real con modelos tridimensionales han mejorado el aprendizaje de los alumnos. El software también ha demostrado ser escalable, lo que permite ampliarlo a procedimientos más complejos.

Palabras-clave: Aplicación educativa. Escaneo intraoral. Educación en odontología. Análisis 3D.

1 INTRODUCTION

The teaching-learning process has been driven by this major technological transformation, offering greater autonomy to students and raising the standard of excellence in education. Dentistry, as a science, has been at the forefront of knowledge, with equipment and techniques involving digital workflows, including intraoral scanners, 3D tomography, and augmented reality. In this context, dentistry students in the pre-clinical phase are faced with theoretical and laboratory components of the specialties that precede clinical care for patients, such as Dentistry, Periodontics, Surgery, and Endodontics. Seeking to achieve excellence in procedures, dentistry demands technical dexterity, which is achieved by connecting theoretical content with practical experience and technology, so that these skills are developed by professionals through a long journey of training.

There is difficulty for students in observing and studying oral anatomy in the real world. Extracted human teeth are used as a learning tool, but they have limitations in terms of their handling as organs that require regulation and strict criteria for donation, storage, and loan in human tooth biobanks. The most widely used tool for simulating dental procedures on patients is a dental mannequin with plastic teeth. This product is equipped with an articulation system that allows occlusion between the mandible and maxilla, in addition to the presence of 32 teeth and pink aesthetics (gums). It can be used alone or attached to the head of the BOB (patient simulator) via a connector, providing an appropriate ergonomic fit. This configuration enables proper handling of clinical instruments and handpieces.

Students simulate procedures in the laboratory before clinical care of patients in order to provide greater safety, reducing iatrogenic errors, and providing greater self-confidence, as learning occurs in a protected, controlled environment, free of complications and with instant results. To perform these practices, the mannequins used for training additionally require the use of all the specific instruments for each discipline, in addition to the consumables related to the specific procedures. And for each attempt the student makes, more material is used, consequently increasing the cost and resources invested.

Furthermore, mannequins with high anatomical fidelity can range from tens to thousands of dollars. For this reason, the mannequins commonly used are cheaper, but do not demonstrate a great ability to mimic dental tissues. However, realism is a very important element in this process, and virtual reality technology offers great potential to create more realistic training, enable the acquisition of clinical knowledge and skills, and transfer these skills to a real clinical environment in dentistry.

Thus, the objective of this research is to develop the virtualization of a dental mannequin in software designed to allow students/professionals in the field to perform clinical procedures. The perspective is to measure the effectiveness of the dental mannequin developed with the incorporation of virtual reality and metaverse technologies by analyzing the significant improvement in clinical skills and theoretical knowledge compared to traditional teaching methods through practical testing. It also contemplates the assessment of student satisfaction with the use of the virtual reality and metaverse mannequin in comparison with traditional teaching methods; acceptance of the technology: assessment of the acceptance of the technology by students, including any resistance or challenges perceived in its adoption.

2 THEORETICAL REFERENCE

VR is a computer-generated three-dimensional immersive environment technology that simulates real-world characteristics, allowing users to easily explore and interact with it (Genaro; Capote, 2021; Genaro et al., 2022). This technology permeates the teaching/learning process by adapting to different forms of learning, i.e., individual cognitive styles (Barilli; Ebecken; Cunha, 2011).

It is possible to create highly interactive environments, allowing direct manipulation of environmental elements and receiving immediate responses to actions. For Barilli, Ebecken, and Cunha (2011), VR proves to be a powerful resource that enables visualization, interaction, and real-time response. Furthermore, through virtual characters, it creates the possibility of imprinting a personal character on behaviors and interactions in the virtual world,

being an “extension” of real life. This environment is considered by Genaro et al. (2022) to be non-threatening, synthetic, realistic, motivating, controllable, and diversifiable during learning, that is, a place conducive to the development of fine motor skills that require concentration and repetition.

In a study conducted by LeBlanc et al. (2004), the authors compare enhanced training in a virtual reality simulator with practice only in the laboratory in the development of technical dental skills. In this study, sixty-eight students were randomly assigned to practice their skills in a traditional preclinical dentistry laboratory or in combination with a virtual reality simulator. The results showed that students who used the virtual reality mechanism for six to ten hours improved significantly more than the others. The authors concluded that the use of virtual reality simulators is promising for the training of future dentists.

Other studies address the importance of teaching with the use of virtual reality simulation in the classroom, such as those by Hollis, Darnell, and Hottel (2011) at the University of Tennessee College of Dentistry, which acquired technology to make image-guided implant dentistry available to students, residents, and teachers, considering computer-assisted simulation an important teaching modality in preclinical training.

Another important factor to consider, according to Meese, O'Hagan, and Chang (2021), is stress reduction, decreasing the negative ramifications of exposure to its chronic and acute peaks in the face of the possibility of training during simulation and the actual post-intervention clinical procedure. However, the stress load that can be generated by the use of equipment still requires further study for an effective conclusion.

It is possible to simulate patients with certain clinical conditions so that students can train interventions, observe the effects and reactions in the virtual organism, increasing the student's experience and learning in various clinical scenarios (Genaro et al., 2022; Zafar et al., 2021), from basic to more complex ones, with better preparation for irreversible procedures, management of unexpected complications of the procedure, and prevention of possible damage, even increasing the availability of experiences, taking into account the limited availability of patients in teaching clinics (Serrano; Wesselink; Vervoorn, 2020). It is also possible to observe the training proce-

ture from different angles by moving around in the virtual space (Mansoori et al., 2022).

With the trial and error method, students can practice several times before dealing with real patients in this controlled environment training, allowing mistakes to happen as part of the learning process, but without causing harm to the patient (Zafar et al., 2021) and reducing the cost of consumables (Philip et al., 2023). This mechanism allows students to achieve the clinical competence and confidence necessary to provide safe care independently (Serrano; Wesselink; Vervoorn, 2019).

These benefits of VR are amplified when integrated into the metaverse, as this tool allows us to go much further, using more advanced technologies and offering an experience that combines traditional face-to-face and online teaching, making it much more immersive and collaborative. To this end, it even uses personalized avatars as digital representations of users that can be manipulated and shared with the same actions by users with sensors, controllers, or real-time tracking (Zhang et al., 2022).

Another positive aspect of learning in the metaverse is the possibility of recording learning, where information can be presented, stored, and shared, allowing both students and teachers to access and review or observe the learning process with continuous feedback (Mansoori et al., 2022). In addition, it is possible to include the number of hours of simulation and virtual tasks performed, as is the case in aviation (Rodrigues et al., 2023).

Depending on the level of presence, virtual reality technology can be classified as immersive, which includes interactivity and user participation in the virtual environment to create a sense of “present” virtual reality (Genaro; Capote, 2021). Immersive virtual reality uses physical technology (hardware) and logical technology (software), depending on devices that enable interaction between the user and the system. It is also possible to add sound features, offering a greater sense of movement and location, touch and force, and shape, allowing for more realistic sensations and increasing immersion and interactivity (Barilli; Ebecken; Cunha, 2011).

The improvement of tactile skills aims to enhance the simulation experience of pressure, vibration, force, and other sensations related to touch, using a force feedback haptic device. According to Barilli, Ebecken,

and Cunha (2011), it interacts with the operator's body through muscles and tendons, giving a sensation of force application in the opposite direction, consequently facilitating the development of eye-hand coordination and fine motor skills learning (Serrano; Wesselink; Vervoorn, 2020).

The development of a virtual dental mannequin for use in the metaverse allows for its 3D rotational manipulation, modeled and augmented by technologies. Students can observe the mannequin in 360°, using real or augmented dimensions, allowing for greater precision in the visualization and learning of techniques and skills (Zhang, et al., 2022). According to Genaro et al. (2022), an important gain is the development of virtual reality modeling language (VRML), which allows virtual reality applications on the internet through improved processing power of personal computers, widespread access to virtual reality, and increasing internet bandwidth (Barilli; Ebecken; Cunha, 2011).

The patient virtualization process starts with intraoral scanning, which captures dental geometry and generates a digital file in STL format. This file is then used for modeling in CAD software, allowing detailed visualization and manipulation of dental structures. Studies show that this approach improves the accuracy of dental devices and reduces production time, in addition to increasing patient satisfaction due to the better fit and aesthetics of the resulting prostheses (Mohammed; Maniruzzaman, 2021). Therefore, 3D scanning and modeling technologies represent a significant advance for modern dentistry, enabling more effective and personalized treatments.

3 METHODOLOGY

The study comprises experimental research. For the requirements gathering and software feasibility assessment stage, the research involved the formation of a multidisciplinary team composed of a dental surgeon, the development team from the Oxente Lab Creative and Innovative Business Technology Incubator at the Paraíba Technology Park Foundation, and the company Alcalitech. The meetings were held at the Paraíba Technology Park in Campina Grande, Paraíba, and were characterized as a single-center study with co-participants. To create the digital model, intraoral scanning

of the model patient was performed at a radiology clinic in the municipality of Campina Grande, Paraíba.

In the software validation stage, the selected sample participated in a pilot test to assess the skills and knowledge acquired, evaluate student satisfaction, and assess acceptance of the new technology relative to traditional teaching. This stage took place through an online videoconferencing platform and was documented by photos and videos.

Initially, intraoral scanning was performed. A male model patient, 21 years old, white, Brazilian, was randomly selected to undergo the procedure necessary for the development of the virtual dental mannequin. The scan was performed with an intraoral scanner, generating a digital file in STL format, which served as the basis for the creation of a three-dimensional model accurately representing the anatomy of the patient's oral cavity. This digital model served as the basis for the development of virtual CAD, ensuring that dimensions and anatomical characteristics were faithful to clinical reality. The use of a model patient allowed for the capture of individual anatomical characteristics and provided greater realism to the development of the dental mannequin. Thus, the virtual mannequin more accurately reflected the conditions found in the clinical environment.

The software development was structured into fundamental stages, with the participation of a multidisciplinary team composed of dentists, 3D modeling specialists, and programmers. This collaboration ensured that the software met clinical and educational needs, incorporating advanced technological tools. It also stood out for its graphic realism, with detailed three-dimensional models that accurately simulate anatomical structures. In addition, OdontoSim 3D provided personalized training, adapting to each student's learning pace and offering immediate visual feedback, which enhanced the teaching-learning process in dentistry.

After defining the requirements, three-dimensional models of teeth, gums, and other oral structures were developed based on the patient's STL model and OBJ (Object) models obtained from the Free 3D website. For this purpose, Blender, an open-source tool for 3D modeling, animation, rendering, and simulation, was used, ensuring high fidelity of anatomical details. With the 3D models ready and integrated, functionalities were developed

to simulate dental procedures, such as manipulation of 3D models, virtual cutting and wear tools, and selection of virtual instruments. A mechanism was implemented to reproduce, in a visual and interactive way, the response of oral tissues to interventions. This system ensured a realistic visual response and allowed for dynamic simulation of the manipulation of virtual dental instruments in real time.

The software development was validated using a data collection instrument, which was a structured questionnaire covering questions about the students' experiences with educational technologies, their perceptions of the effectiveness of the virtual reality dental mannequin, and their opinions on the integration of these technologies into the learning process. The validation sample consisted of students from the 10th semester of the undergraduate dentistry program at UEPB (State University of Paraíba), campus I, to represent the perspective of a group of students on the incorporation of virtual reality in dental education.

The procedure was developed according to the following steps: 1 – Sample Selection: selection of dentistry students from UEPB (State University of Paraíba); 2 – Informed Consent: obtaining informed consent from participants, explaining the purpose and nature of the study; 3 – Pilot Test: conducting the pilot test following the complete research protocol; 4 – Questionnaire Administration: application of the structured questionnaire in electronic format; 5 – Data Recording: proper recording of all responses and information collected.

Data analysis was performed as follows: 1 – Data Coding: assigning scores to questionnaire responses to facilitate organization and analysis; 2 – Tabulation and Summarization: organizing data into tables for visualization and summarization of responses; 3 – Interpretation of Results: interpretation of results in relation to established hypotheses, considering the opinions and perceptions of dental students on the effectiveness of the proposed technology; 4 – Final Report: preparation of a final report including the main findings, conclusions, and recommendations for future research.

This study was registered in the Human Research Registry (Plataforma Brasil), in accordance with Resolution No. 466/12 of the National Health Council/Ministry of Health, and submitted for content review by the

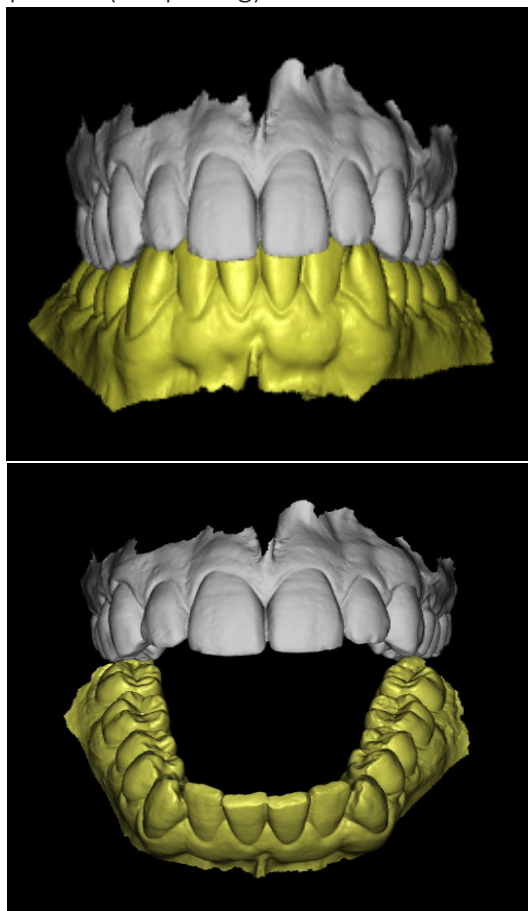
Research Ethics Committee of the State University of Paraíba (UEPB). It was approved on February 2, 2024, under opinion No. 6.631.112 and CAAE No. 76877323.1.0000.5187. The research was validated with the sample that signed the Free and Informed Consent Form (FICF). Finally, it is important to highlight that the results stem from participants' perceptions (questionnaire), avoiding inferences of superiority in relation to traditional methods without objective experimental support.

4 RESULTS

The first step in the research was to perform an intraoral scan of a male model patient, aged 21, white, Brazilian, to obtain a digital file in STL and a digital model to guide the development of a virtual CAD. This digital evaluation methodology was also used in the research by Su and Sun (2015) and Vitai et al. (2023), being a current and effective method of intraoral study. This step allowed us to evaluate all the characteristics of the guiding digital model in order to define the functionalities and the dimensional and ergonomic characteristics necessary to best suit preclinical laboratory practice and the real mouth situation, as well as to identify potential flaws and risks.

Scanning in occlusion and with the mouth open has complementary and essential purposes for the realistic simulation of dental procedures. Scanning in occlusion allows accurate recording of the fit between the upper and lower arches, which is essential for evaluating occlusal relationships, planning rehabilitations, and checking dental contacts after clinical interventions. Scanning with the mouth fully open provides complete visualization of the oral cavity's internal structures, including occlusal surfaces, gums, and mucosa, and is indispensable for simulating procedures that require extensive access, such as extractions, cavity preparations, and endodontic treatments. The combination of these two types of scanning provides the software with an accurate and functional anatomical basis, essential for an immersive and safe learning experience; see Figure 1.

Figure 1 – STL file of the model patient (in occlusion) and STL file of the model patient (in opening)



Source: Prepared by the author based on patient documentation (2025).

After discussing the software requirements with the multidisciplinary team, the first version of the software was developed. The initial screen, or 'cover', of the software was designed as a gateway to the virtual journey, presenting a layout that introduces the user to the system's features. The interface design was developed to provide simple and fluid navigation, facilitating understanding and use of the software from the first contact.

The functional and non-functional requirements of the OdontoSim 3D system were defined to ensure its efficiency, usability, and compatibility with the educational purpose of dentistry. Among the functional requirements of the project, the movement and rotation of objects stand out, allowing the user to manipulate the tool, tooth, caries, and restoration in three axes (X, Y, Z) using control buttons, enabling inspection of the model, as well as the devices discussed by Reymus, Liebermann, and Diegritz (2020) and Rodrigues et al. (2023).

Like the systems described by Huang (2018), the developed software uses three-dimensional models to simulate dental procedures with instant feedback to the user during the simulation. Compared to the device pointed out by Zafar (2021), OdontoSim 3D provides visual feedback on interactions in the virtual environment (such as collision between tool and caries), but does not fully evaluate, as LA VR does, whether the techniques are correct or incorrect. Furthermore, the software does not include real-time demonstration or collaboration features, which could be an opportunity for expansion in future updates.

3D models are loaded from STL files, in which materials are applied, and positions and scales are adjusted for a precise fit in the scene. Interactive Controls allow the user to modify the jaw's position using a slider, changing its height and rotation, as well as enabling adjustments to the color and intensity of the fill light. The Animation Function runs in a continuous loop, updating the scene and rendering objects in real time. Finally, the system's responsiveness ensures that the interface adapts to different screen sizes, automatically adjusting the scene when the window is resized.

The images captured from the patient's oral scan in STL were transformed into OBJ files to be integrated into the application, initially being used only in the "3D Analysis" tab. The other images used were models in OBJ (Object) format, which store three-dimensional polygonal meshes, obtained from the Free 3D website, to speed up the prototype's initial launch and validation. Nevertheless, all scanned images of future patients can also be converted to the new format and used virtually to simulate the procedure in real mouth conditions.

The developed software includes several components that ensure the

simulation's interactivity and realism. The Scene and Lights feature allows the creation of a 3D environment, including ambient and directional lighting to illuminate objects and highlight the jaw and maxilla models, helping overcome limitations in the detailing of dental anatomy. The Movement and Rotation Controls allow the user to move and rotate selected objects, such as tools, teeth, cavities, or restorations, using interactive buttons.

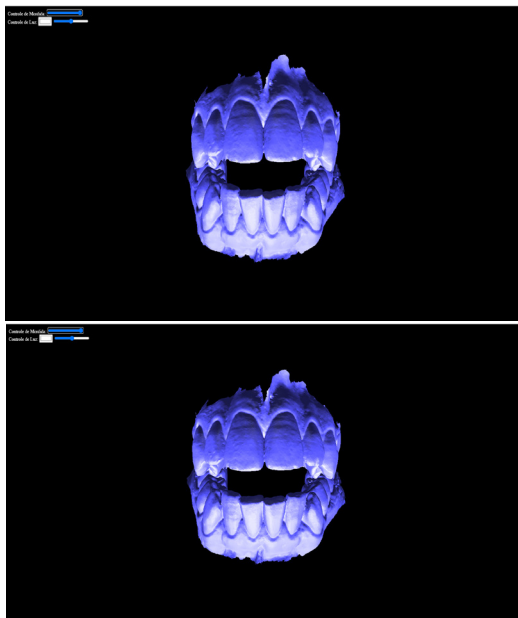
Collision detection, also present in Dentify (Rodrigues et al., 2023), has been implemented so that when colliding with the cavity or restoration, the affected point is attached to the tool and moves with it. Furthermore, object selection allows the user to choose which elements to move or rotate. Another relevant feature is mouse control, which allows the user to switch between manual control and mouse control to move the camera around the scene.

In the “3D Analysis” tab (Figure 6), functional requirements include jaw control, which allows movement via a slider, simulating opening and closing. In addition, lighting adjustment has been designed so that the user can modify the color and intensity of the light, facilitating the visualization of specific details. However, other features, such as those described in SIMtoCARE Dente by Rodrigues et al. (2023), that allow physical and sensory feedback could not be implemented.

Among the non-functional requirements, performance stands out as essential, ensuring that the application renders 3D objects smoothly, without delays during movement or rotation, and that it responds quickly to user interactions. Software compatibility was a key aspect of its construction, ensuring that the dental simulation ran correctly in modern browsers, such as WebGL and Three.js, including Chrome, Firefox, and Edge.

The system's usability was prioritized, with an intuitive interface, accessible controls, clear instructions for users, and visible, functional movement and rotation controls. Scalability was also considered, allowing the addition of new objects or features, such as dental tools or tooth parts, without needing to rewrite the main code. The loading of STL format models of the mandible and maxilla was incorporated into the “3D Analysis” tab (Figure 2), ensuring their correct display in the scene, while all interactions, such as jaw and light adjustments, occur in real time without noticeable delays.

Figure 2 – 3D models in STL format of the mandible and maxilla



Source: Prepared by the author using OdontoSim 3D software (2024).

The virtual dental system developed, OdontoSim 3D, was designed to be initially manipulated via computer and allowed the creation of an interactive and intuitive interface for manipulating 3D models of teeth, making it possible to simulate a less complex dental procedure: the removal of cavities, as well as the software described by Huang et al. (2018) and Rodrigues et al. (2023) and the application of restorations.

Regarding the main components for performing the caries removal and cavity restoration procedure, the instrument was represented by a cylinder that the user can move and rotate; the caries by a spherical brown dot positioned on the tooth, representing an area of caries; the restoration by a spherical white dot near the tooth, illustrating a dental restoration; and the tooth was loaded from an OBJ model of a tooth with a cavity.

Collision Detection implements logic to identify contact between the tool and the caries or restoration points, causing these elements to attach

to the tool and follow its movement. In addition, Mouse Control switches between manual commands and camera manipulation, allowing intuitive navigation through the virtual environment. Camera Controls were configured to enable movement around the model, ensuring detailed visualization.

For application validation, the sample signed the TCLE (Informed Consent Form) and performed the pilot test following the protocol: (a) Preparation and Selection of Tools: The “Enable mouse control” tool was enabled for viewing with the mouse to adjust angles and zoom; the instruments were selected in the software. (b) Moving the Instrument to the Caries: The movement commands were used to move the instrument to the position of the caries on the tooth; the angles and zoom were adjusted with the mouse for better visualization and accuracy. (c) Capturing the Caries: Upon reaching the ideal position of the caries, the “Reset Tool” button was clicked (the instrument captured the caries and returned to its initial position). (d) Moving the Instrument to the Resin: The movement commands were used to move the instrument to the position of the resin; the view was adjusted with the mouse to observe details during the movement. (e) Positioning of the Restoration: The instrument was moved to the cavity formed after caries removal; the viewing angles were adjusted again with the mouse as needed. (f) Application of the Restoration: Upon reaching the ideal position, click “Release the Restoration” (the instrument applied the resin, restoring the tooth in the desired cavity). (g) Final Review: The mouse was used to inspect the procedure from different 3D angles; the zoom was enlarged or reduced as necessary to assess the accuracy of the procedure.

After the pilot test, the data collection instrument was applied electronically, enabling the immediate recording and systematization of participants’ perceptions. Data analysis revealed that the software was evaluated significantly more positively across several dimensions, particularly in its contribution to learning. However, more critical perceptions emerged in relation to overall satisfaction. In this context, variables such as ease of use and engagement stood out, as they were comparatively better evaluated by participants, suggesting their relevance in shaping user experience.

Additionally, students’ criticisms concerning graphical realism and visual quality warrant a more in-depth analytical exploration, as such limi-

tations may directly influence users' perceptions of usefulness and ease of use. From this perspective, frameworks such as the Technology Acceptance Model (TAM) provide a useful lens to interpret how perceived system characteristics – particularly visual fidelity – can affect the acceptance and adoption of educational technologies, potentially moderating users' attitudes and behavioral intentions toward continued use.

When compared to traditional physical mannequins, OdontoSim 3D has notable advantages. Physical mannequins suffer wear and tear with repeated use, require high investment for acquisition and maintenance, and offer little immediate return on student performance. The virtual environment, on the other hand, allows unlimited repetition of procedures, reduces material and equipment costs, eliminates clinical risks, and provides real-time visual feedback, making it an accessible and efficient alternative for practical training in dentistry.

Given the results, the potential of OdontoSim 3D to transform dental education is evident, offering an immersive, safe training experience adapted to the demands of contemporary clinical practice. The dissemination of this technology within the academic community and the dental market represents an important step towards the development of more advanced computer-assisted procedural systems. With the necessary improvements, the software may in the future reach a level comparable to that of medical technologies, such as the Da Vinci robot, enabling more complex dental procedures to be performed with high precision and efficiency, thereby consolidating its position as a benchmark in technology-assisted digital dentistry.

The project has demonstrated scalability, allowing new objects and functions to be added. This capability was evidenced during the loading tests of additional models and other dental tools, validating that the system can be expanded to cover simulations of greater complexity in the future, such as different types of dental procedures and instruments. Performance requirements were met effectively, with fluid rendering and satisfactory response times to user interactions, both of which contribute to the usability and acceptance of the application in educational and professional contexts.

In addition to the technological advances and practical advantages the system brings, the benefits to the academic community are notable.

The introduction of virtual simulations into dental teaching allows students and professionals to perform clinical procedures more frequently and safely, without the need for physical materials or exposing patients to risks. This significantly improves the quality of teaching and learning, enabling students to develop their skills with greater confidence and precision. The virtual environment offers a rich platform for practicing clinical procedures, allowing errors to be corrected immediately and techniques to be perfected before being applied to real patients. Thus, it is understood that this innovative approach not only improves teaching, but also raises the level of preparation of professionals entering the market, bringing positive impacts to both education and clinical practice.

5 CONCLUSIONS

The aim of this work was to develop the OdontoSim 3D software and to assess its contribution to the advancement of dental education, based on the proposed general and specific objectives. OdontoSim 3D was designed to virtualize dental mannequins using three-dimensional models in STL and OBJ formats, which guarantee high anatomical precision. The software has features such as interactive simulation of clinical procedures, zoom, 360-degree rotation and articulated control of the mandible and maxilla. These features allow students to analyze the models in detail, reproduce procedures in an unlimited number of ways and receive immediate visual feedback, promoting continuous, safe learning at no additional cost.

The main findings from the application of the data collection instrument indicated high satisfaction with the software's effectiveness, along with identified improvements needed, particularly regarding realism and interaction. Recommendations include making adjustments based on the feedback received and continuing to develop the software to better meet dental students' needs. Such improvements may involve updates to the design, functionality, and especially the resolution of technical issues, such as collisions between 3D objects, to provide a more immersive and realistic experience. In short, analyzing the data revealed the need for continuous improvements to the software, with the prospect of it becoming an even

more valuable tool for academic training in dentistry, increasing learning efficiency and student confidence in clinical procedures.

However, the study also identified some limitations. The main one was the inability to integrate intraoral scan data into all software features. Due to budget constraints and the need to launch the prototype in a timely manner, this data was only incorporated into the “3D Analysis” tab and was absent from the “Perform 3D Procedures” tab, which reduced the level of realism expected in certain simulations. It was also highlighted that the virtual environment could be improved to more accurately simulate the response of oral tissues to the procedures performed.

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