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VIDA XR: Mixed Reality Tool for teaching anatomy to dental students

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Abstract Teaching dental anatomy faces challenges related to ethical concerns, cost of materials and quality of artificial representations. Virtual and augmented reality technologies have been explored for education and training in healthcare for the same motivations. In this paper we present a novel mixed reality tool that allows dental students to visualize and manipulate 3D models of tooth surface and tooth root, generated from microtomography scans. The development process by a multidisciplinary team is described, followed by results from performance evaluation and assessment by an expert panel. Performance was within the guidelines for applications in the adopted head-mounted device, and expert assessment was positive regarding its usefulness and ease of use. Future work includes assessing the tool's pedagogical effectiveness in anatomy classes.

Keywords: Mixed Reality, Dental Education, Microtomography

1 Introduction

Teaching anatomy in dentistry faces several challenges related to the cost of materials, quality and detailing of artificially produced parts through different processes, and ensuring the correct learning about the shapes and other characteristics of teeth. The use of virtual and augmented reality technologies in health education and training is becoming more popular as research validates their effectiveness as an alternative to address existing challenges and as new affordable technologies emerge on the market.

There are several definitions for virtual reality (VR), relating the term to specific technologies or user experience [Tori *et al*., 2020]. Jerald [2018] defines VR as ”a computer-generated digital environment that can be experienced and interacted with as if that environment were real” and that definition is adopted in this work. We also adopt the definition of augmented reality (AR) by Azuma *et al*. [2001] as a computer system with three properties: ”combines real and virtual objects in a real environment; runs interactively, and in real time; and registers (aligns) real and virtual objects with each other.” Meanwhile, Milgram and Kishino [1994] propose the term ”mixed reality” (MR) to encompass different systems (including augmented reality systems) ”in which real world and virtual world objects are presented together within a single display.” Lastly, Mann and Wyckof [1991] propose the concept of Extended Reality (XR) as ”any combination of a virtual environment with reality where the virtual environment is responsive to a real or complex-valued output from reality, by way of real-time computation.” while arguing that ”XR extends our senses and meta senses [...].” We adopt the term mixed reality to describe the type of interactive system that is the subject of this paper, while also alluding to the XR concept by providing 3D visualizations of internal structures of the teeth models as the students interact with them.

While mixed reality headsets such as Apple Vision Pro and Varjo XR-4 are sold at prices above US$3,000 [Apple, 2025] [Varjo, 2025], Meta Quest 3, released in the second semester of 2023, offers high quality mixed reality features for about US$500 [Meta, 2025]. In September 2024, a remarkable competitor to the Quest 3 emerged: the Pico 4 Ultra, in the same price range and with similar extended reality features [PicoXR, 2025]. This market trend points to a popularization of this technology, which may lead to wider adoption in classrooms.

In this context, this work aims to present the development and initial validation of VIDA XR, a new mixed reality tool aimed at teaching dental anatomy, with a focus on endodontics, a dental specialty that focuses on the internal structures of the tooth (i.e., the dental pulp and root canals). The goal of VIDA XR is to address existing challenges of providing an adequate representation of tooth surface and internal details, combined with interaction techniques that can provide a satisfying experience to students and can be adopted in teaching strategies. Three-dimensional models of teeth are produced from microtomography scans of real teeth, aiming to reproduce the anatomical details relevant to effective learning. Additionally, microtomography data allow endodontic representations to be visualized and manipulated , and thus, both external and internal visualizations are possible in VIDA XR. The development process involved a multidisciplinary team of engineers and dentists from the beginning. The system was validated by a broad panel of experts, regarding its acceptance in terms of usefulness and ease of use.

In the remainder of this text, the fundamentals of teaching dental anatomy and the application of virtual and augmented reality technologies in healthcare, and their effectiveness, will be presented. Next, related work is explored in order to position this project in the current context. The main activities for the system development are reported, followed by the presentation of the results of performance assessments, as well as acceptance testing by a panel of specialists. Finally, possibilities for future development and application of the VIDA XR system are presented.

2 Fundamentals of teaching and use of technology in dentistry education

This section presents theoretical references on the teaching of anatomy in dentistry and also on the application and effectiveness of virtual, augmented and mixed reality in health education, in particular in the teaching of anatomy in the context of dentistry.

2.1 Teaching anatomy in dentistry

Teaching dental or odontological anatomy is a goal that has become more challenging over time. In the past, it was possible to use anatomical specimens in abundance, allowing students to compose their records with intact specimens and also with different types of caries lesions and fractures. Since Law No. 9,434, of February 4, 1997 [Brasil, 1997], ethical care for the maintenance of specimens has limited those approaches and made the study worthy of the use of new forms of guidance for students in their construction of knowledge.

Legal considerations also prevented the use of anatomical parts in mannequins attached to phantom heads in laboratory training. Since then, acrylic resin teeth have been incorporated into training, but they have limitations in reproducing important features for anatomical studies, such as isthmus, apical delta, curvatures and flattening, which characterize the danger and safety zones of a tooth root that requires endodontic treatment, for example. Resin or plastic teeth that best reproduce important anatomical aspects also involve a considerable cost for the student. Often, the student will need to repeat procedures and, to do so, will have to acquire new specimens.

Computed Tomography (CT) scans were incorporated into clinical analyses in everyday dentistry and revealed fascinating aspects of dental anatomical knowledge. Fractures, persistent lesions, lateral canals and other aspects were revealed to professionals. In parallel with this unveiled knowledge, micro CT scans allowed for detailed anatomical analysis of dental pieces. All this available knowledge allowed for the analysis of new educational strategies, incorporating real images into devices that allow for accurate and easy study, allowing students to manipulate anatomical pieces and study their real characteristics.

2.2 Virtual and augmented reality simulation and training for healthcare

Virtual and augmented reality have been adopted in healthcare simulation and training systems, motivated by ethical, safety and scalability issues, customization and cost reduction. In this context, applications focused on surgical simulation, virtual procedural training and skills assessment can be found. Among the challenges for the development and application of such systems are the inherent need for multidisciplinary teams, the specificity of the requirements and the need for more rigorous validations on their effectiveness [Nunes *et al*., 2020].

Santos and Trevisan [2023] present a broad systematic literature mapping on the use of augmented reality in healthcare, comprising 160 works. The authors' findings highlight the need for better tracking techniques and improved assessment of the systems.

Dzyuba *et al*. [2022] present the results of a systematic literature review focused on the applications of virtual and augmented reality in dentistry, not limited to teaching anatomy. Based on the analysis of 14 selected works, the authors highlight the potential of the technology, adopted as a complement to other approaches.

Regarding the specific context of teaching anatomy with virtual and augmented reality, some recent works bring relevant results on the issue of effectiveness, and guidelines for the application of such systems.

García-Robles *et al*. [2024] evaluate the effectiveness of virtual and augmented reality systems as educational resources for learning anatomy, through a meta-analysis based on a systematic literature review. The authors conclude, based on the analysis of 27 selected studies, that such technologies promoted greater learning, when compared to conventional approaches, especially among undergraduate students. The selected studies were predominantly focused on the study of musculoskeletal anatomy and neuroanatomy. The authors also indicate that such technologies were more effective when used in a complementary way to conventional approaches.

Similarly, Bevizova *et al*. [2024] present a systematic literature review on the impact of virtual reality on anatomy teaching in dentistry. The authors selected seven articles for qualitative and quantitative analysis, establishing moderately positive effects from the adoption of virtual reality systems for anatomy teaching, when compared to approaches based on expository classes. On the other hand, the authors indicate that the effectiveness is lower than that obtained in clinical practice, with models generated by 3D printing or real teeth. The authors also suggest the use of virtual reality systems as a complement to traditional approaches.

3 Related work

It is possible to find works in the literature that employ virtual and augmented reality technology in teaching different topics of anatomy in dentistry. In this section, two works with the highest quality rating in the review by Bevizova *et al*. [2024] are discussed, as well as other recent works found through searches in databases of academic works.

Mahrous *et al*. [2021] compare four approaches to teaching tooth anatomy: natural teeth, 3D models visualized on a computer screen, models produced by 3D printing, and 3D models visualized with augmented reality technology. There is no information regarding the production of the 3D models used for the study. The authors report that natural teeth received the highest rating regarding educational value by studentes, while 3D printed teeth also had high educational value and highest ease of use. However, they also point out the limitations of those approaches, as natural teeth require disinfection and can be damaged by use, and 3D printing involves costs of printing devices and resin. The augmented reality approach is evaluated as the most interesting by students, and the authors discuss its potential in the future of dental anatomy education, although at the time of the study, the cost of devices is cited as a limitation.

An exploratory study reported by Kim-Berman *et al*. [2019] involved the use of augmented reality to administer a tooth identification test to dental students. The authors found correlations between the results obtained in the augmented reality system and in the tests performed with real teeth. The 3D models were obtained from a previously developed Virtual Dental Library, a repository of models created from resin models, natural teeth, and which can also be extended by uploading other 3D models. In this case, the teeth were visualized using a mobile device, and authors reported difficulties by the students to manipulate and view the models on the device.

Grad *et al*. [2023] presented a comparison of the use of 3D printed models and AR visualization with a HoloLens device for a cavity filling task. The models were produced from Cone-Beam Computed Tomography (CBCT) images segmented to produce surface models. The accuracy of reconstructions performed without a reference model, with a 3D printed model and with AR visualization were compared, with the best results coming from the 3D printed models. The authors conclude that AR visualization can be helpful in dental anatomy education, it does not replace physical models. Due to the nature of the study, the potential of visualization of internal structures of the teeth was not explored in that work.

In the work presented by Alsufyani *et al*. [2023], an immersive virtual reality system was developed for training the interpretation of panoramic radiographs. The virtual environment described in that work displays a skull model and a panel with the radiograph image, with structures selected in the image being simultaneously highlighted on the skull model. The virtual environment also includes a list of anatomical structures that can be viewed. The researchers evaluated the system with 69 students entering a dentistry course, divided into two groups: one used the system (test) and the other (control) received lectures. The authors note that, although performance in an anatomical structure identification test was better in the control group, some limitations of the test may have interfered with this result. Additionally, the authors observed that the attitude of the students in the test group was positive towards the use of the virtual reality system.

Kim-Berman *et al*. [2023] presented an immersive virtual reality system for interpreting CBCT images. The environment presents a skull model with the superimposition of CBCT image planes, allowing the user to relate regions of the image to anatomical structures. The system was evaluated with 90 novice dentistry students, through knowledge tests before, immediately after, and two weeks after using the system. Experience and presence questionnaires were also used after using the system. The authors observed a significant increase in student performance in the knowledge tests, which was maintained even after two weeks.

Regarding VR-aided tools for root canal anatomy education, the preliminary study by Reymus *et al*. [2020] highlights the effective and beneficial integration of such materials into the endodontics curriculum for undergraduate dental students. A comparison of two-dimensional radiography, CBCT scanning, and VR simulation revealed comparable knowledge retention for the latter two methods, with students expressing a preference for VR simulation, underscoring its value in fostering engagement and building confidence. Similarly, Alsalleeh *et al*. [2024] conducted a study comparing CBCT images and AR simulation for predoctoral dental students, concluding that the latter method facilitated more efficient learning and improved comprehension of the subject. However, it is noteworthy that prior CBCT interpretation in all AR experience scenarios may have influenced the results.

Diegritz *et al*. [2024] presented and validated a potential XR tool for teaching root canal anatomy to undergraduate dental students. The Tooth Anatomy Inspector application can be run on the VR headset Pico Neo 3 as well as Android or iOS tablets, enabling visualization of scanned natural teeth and their internal structures in virtual or augmented reality through transparency control. The application was voluntarily evaluated by 57 undergraduate dental students, previously trained in preclinical endodontics with traditional materials, and was deemed motivating and supportive of individual learning. While similar to Diegritz *et al*. [2024]'s application in aiming for equivalent educational outcomes, VIDA XR offers a broader range of functionalities, including visualization of internal structures via transparency control and cross-sectional views, comparison of pre- and post-procedure teeth, and a continuous mixed reality experience to maximize immersion. In another regard, the Tooth Anatomy Inspector overcomes a key limitation of VIDA XR: its exclusive reliance on a single device. Both projects, still in development, represent potential complements to undergraduate dental curricula.

The VIDA XR system is also part of an ongoing research effort in the development and evaluation of training simulators using virtual and augmented reality technology for healthcare education. Previous results include an immersive virtual reality simulator for training of vacuum blood collection [Souza-Junior *et al*., 2020], and an immersive virtual reality simulator for training of dental anesthesia procedures [Collaço *et al*., 2021].

From what has been presented in this section, it is possible to observe a variety of approaches that combine the use of virtual and augmented reality technologies with real data sources, such as computed tomography or X-ray examinations. In particular, for dental anatomy education, there are both approaches based on 3D modeled representations, and those obtained from scanning natural teeth. The VIDA XR proposal is aligned with these trends, by combining virtual models of teeth produced from microtomography with visualization and interaction through an extended reality system. The use of microtomography data is also exploited to provide visualizations of the external and internal structures of the teeth. Our approach also attempts to bring the ease of use of natural teeth and 3D printed models by allowing direct manipulation of the tooth models by hands, as previous works have indicated difficuties by students to interact with augmented reality interfaces.

4 Development

The initial phase of the development process was the understanding of requirements of the process of dental anatomy teaching that could be enhanced by VR and AR technology. Thus, the challenges in undergraduate teaching that could be addressed through the use of visual simulations via VR and AR were discussed in collaboration with dentistry professors. The main issue raised was the shortcomings in the representation of teeth for anatomy teaching: anatomy is typically studied through the visualization of two-dimensional imaging tests or artificial models simulating teeth, usually made out of resin. In the first case, there is the difficulty of translating the acquired knowledge into a three-dimensional visualization, and in the second, the fidelity of the models often leaves much to be desired. As the Faculty of Dentistry at University of São Paulo (FOUSP) was soon to have its own virtual catalog of teeth, with models generated by microtomography, virtual reality could be used to enable visualization and interaction with these more realistic representations. A second difficulty identified was the visualization of internal structures in three-dimensional view, which is essential for the study of endodontics. This study is generally conducted through the analysis of two-dimensional imaging tests and also faces the challenge of translating concepts into a three-dimensional perspective, which is an even greater challenge since these structures are invisible to the naked eye.

Based on these discussions, it was determined that the application to be developed should aim to complement laboratory practices for the study of anatomy, with a focus on endodontic anatomy. From this objective, the project requirements were identified. As this is a first version, the final product of the development was a feasibility study of the most important requirements, conducted with a reduced set of virtual tooth models. Future objectives include adapting the application to the complete set of teeth in the mouth of an adult human, including variations, and implementing functionalities aimed at integrating the virtual environment with the physical laboratory environment, including the possibility of multiple users interacting with the same virtual object.

In this context, the choice of mixed reality over virtual reality, which could also address the initial difficulties presented by the professors, was made primarily to bring the user experience of the application as close as possible to the current laboratory experience, thereby facilitating future integration with the laboratory environment. A second reason, significant in the context of a feasibility study, was the possibility of greater focus on the study objects and interaction with them, since there was no concern with creating a virtual scenario. Additionally, this choice resulted in a lighter application in terms of performance, as it reduces the number of objects being rendered per frame.

4.1 Materials and methods

The Faculty of Dentistry at USP provided STL models of three human teeth subjected to the microtomography process, both before and after endodontic access procedures. The models provided corresponded to the lower right and left first molars and the lower left second molar (46, 36, and 37, respectively, following the numbering of the International Dental Federation). For the lower right first molar (46), STL models of the root canal pre- and post-procedure were also supplied. Figure 1 illustrates the provided models.

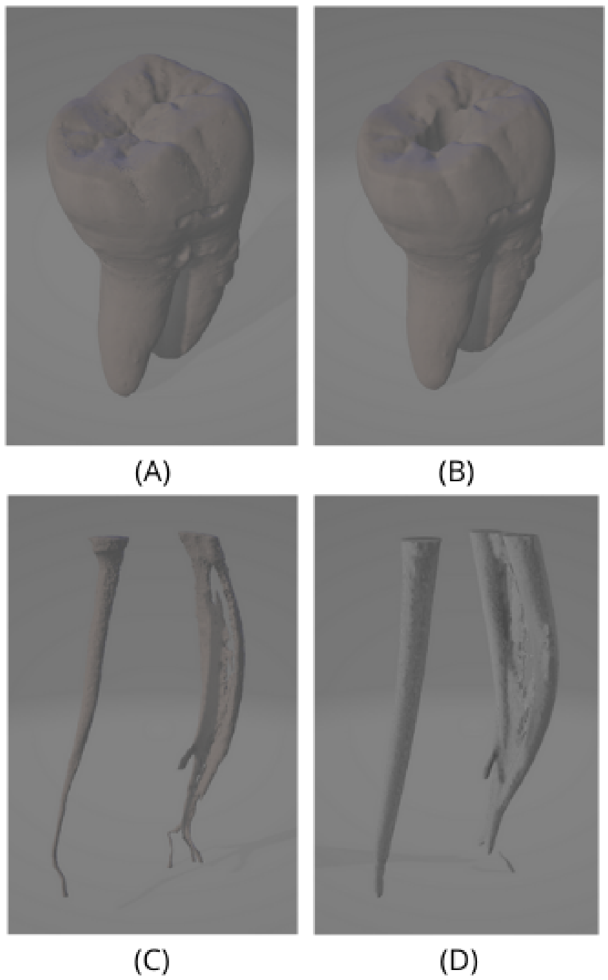

Figure 1. Examples of the provided STL models. (A) Pre-procedure tooth 46. (B) Post-procedure tooth 46. (C) Pre-procedure tooth 46's root canal. (D) Post-procedure tooth 46's root canal.

All models were processed using the Blender software (Blender Foundation) to undergo cleaning (removing external and disconnected vertices from the tooth body and/or canal), scaling down to prevent performance issues when rendering the objects within the application, and conversion to OBJ format (Wavefront .obj) to enable their manipulation in the Unity game engine (Unity Technologies). For the teeth whose root canals were not provided as separate objects (36 and 37), new objects representing their canals were generated: using editing tools in the Meshmixer software (Autodesk Inc.), the external faces of the teeth were removed to obtain new files containing only the internal structures. Since these canals were generated from the editing of another object already reduced in vertices, they are less trustworthy representations of their real counterparts and would ideally be replaced by models directly generated from microtomography, like those of tooth 46. These objects were created to maintain consistency in the application experience across all available teeth.

For all edits performed on the three-dimensional models, professors and postgraduate students from the Dentistry program were consulted regarding the quality of the resulting material for the purpose of analyzing structures within the application. This ensured that important structures were not mistaken for impurities during the cleaning of the models, that file reduction did not compromise analyses of the tooth surfaces, and that the artificial generation of root canal representations did not result in images significantly different from the real structures.

It is important to note that, while this version of VIDA XR includes only three tooth models, the production method of the models can be extended to microtomography data from all the other teeth, to generate the complete application.

4.2 Application development

The VIDA XR application was developed using the Unity game engine, targeting compatibility with the Meta Quest 3 extended reality headset, which offers extensive support for the development of virtual and mixed reality applications and had the best market price in the extended reality sector in 2024.

The planned functionalities were grouped into three main objectives: to enable visualization and interaction with the microtomography-generated models, the primary requirement requested by dentistry professors for anatomy teaching; to allow visualization of the internal structures of the models, essential for the endodontic applications suggested; and to make the user experience natural and intuitive, avoiding, whenever possible, the use of buttons and menus. In this manner, scripts were added to the models to enable interactions such as grabbing them, allowing movement in all degrees of freedom or scaling their size to facilitate visualization at different levels of detail. Additionally, opacity controls were implemented, which permit visualization of internal structures by adjusting the transparency level of dentin and canals, as well as a sectioning functionality that allows internal visualization of the teeth in a manner similar to images obtained from imaging tests. The specifications of each implemented functionality were always previously validated with anatomy and endodontics professors or suggested by them directly.

To bring the application experience closer to that of anatomy laboratories, the selection of teeth was implemented by removing the desired tooth from a base, which consisted of a 3D model of a mouth, similar to a dental cast or a phantom head, as used by dentistry students [Fugill, 2013][Bairsto, 2021]. The user removes the tooth from the base, and upon releasing it, the model enlarges in front of them and a menu that allows control of opacity, cross-sectional cuts, and visualization of models of the same tooth before and after a clinical procedure, enabling comparison between pre- and post-operation states, is shown. Only one tooth can be selected at a time to avoid visual clutter and potential performance issues in image rendering. To select a new tooth, the previously selected tooth must be returned to its position on the base. It is also possible to control the opacity of the gums and unselected teeth, allowing the user to visualize the positioning of the teeth and root canals within the mouth.

All floating menus in the application were designed to be freely movable or minimizable to mitigate the sensation of visual clutter and lack of naturalness, which could impair the user's immersion.

5 Results

The application starts with the visualization of the mouth model: a base where the three available tooth models for visualization and interaction are located, as shown in Figure 2. The user can freely move the base by grabbing it and can also control the transparency of the gums and teeth attached to the base through the associated menu.

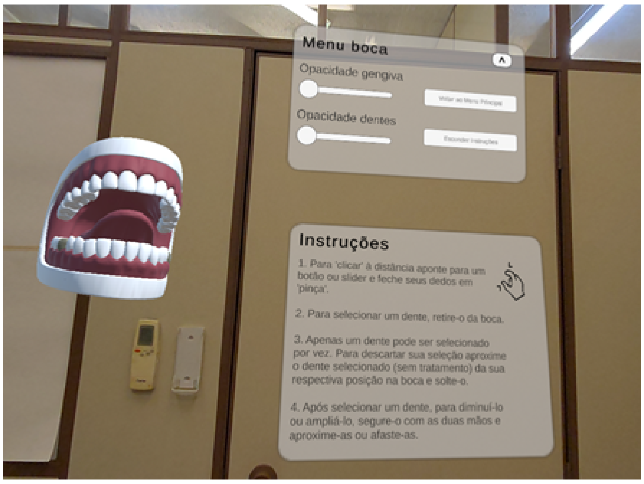

Figure 2. Initial scene.

Upon removing one of the three available teeth, the user gains access to the control menu for that tooth, as shown in figure 3, and through it can adjust the opacity of the dentin and canal (see figure 4), select the visualization of models of the same tooth after dental procedures, and view sectional cuts starting from the crown (see figure 5). The user can also freely move the selected tooth by grabbing it and change its scale by stretching or shrinking it with both hands. All functionalities available for the pre-procedure models are also available for the post-procedure models.

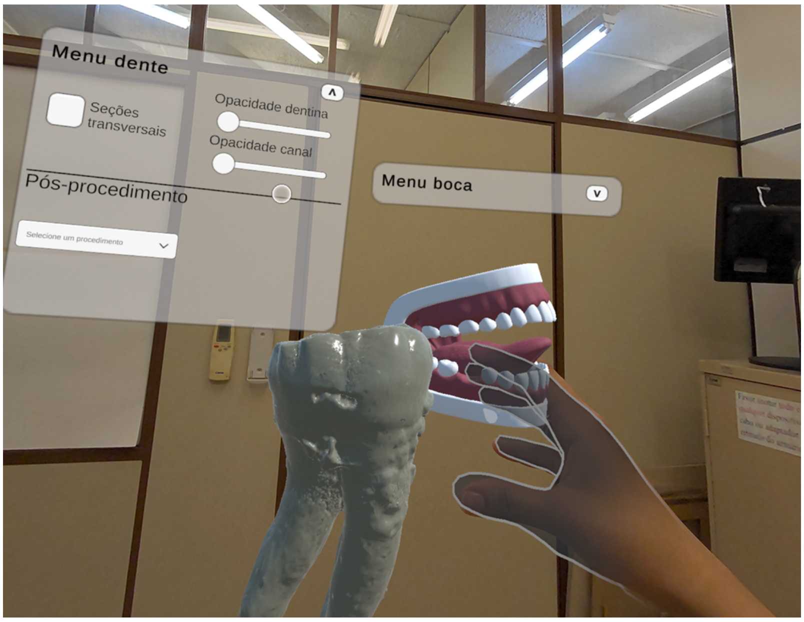

Figure 3. Selection of a tooth.

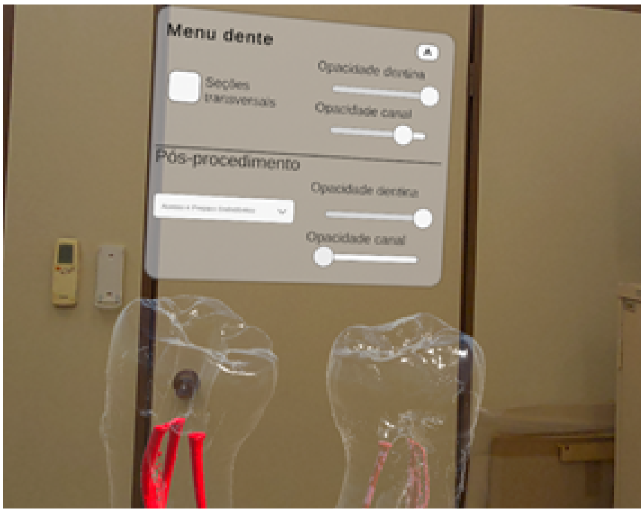

Figure 4. Use of the opacity control tool on the dentin and canals of pre- and post-procedure models.

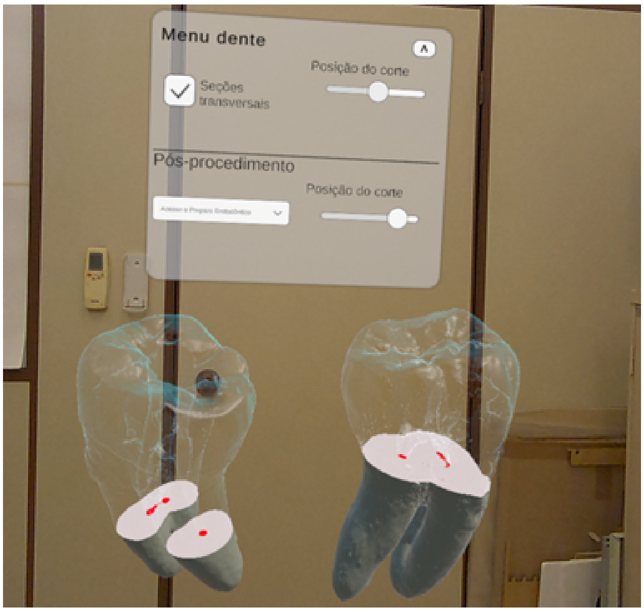

Figure 5. Use of the cross section tool on the dentin and canals of pre- and post-procedure models

5.1 Performance evaluation

The application was subjected to a performance evaluation using the Performance Analyzer tool from the Meta Quest Developer Hub program [Meta, 2024c]. Metrics recorded included GPU time (time spent by the GPU to render a frame), frames per second (FPS), percentages of GPU and CPU usage, and CPU and GPU levels during a 30-minute continuous use session of the application with the headset operating at a refresh rate of 72 Hz (default value).

The CPU or GPU usage level is a concept defined by Meta that indicates the clock frequency in the processing cores, directly related to the degree of energy efficiency at which the application operates [Meta, 2024a]. The levels are represented on a scale from 0 to 5, where 0 is the lowest clock frequency and maximum energy efficiency, while 5 is the highest clock frequency and minimum energy efficiency. The default value for both CPU and GPU is usage level 2. It is ideal to always maintain the application at the lowest combination of levels at which no frame rate drops occur [Meta, 2022]. During the evaluation session, the recorded levels were usage level 2 for the GPU and usage level 3 for the CPU.

Throughout the entire session, the average frame rate (FPS) remained stable at approximately 72 fps, with the exception of a drop to 67 fps, which quickly returned to the default value. The GPU time stayed below the maximum expected value (13,880 microseconds, the average time for a frame at a rate of 72 fps) throughout the session, and the CPU usage percentage consistently remained below 30% of its capacity, indicating the potential for reducing the usage level. On the other hand, GPU usage fluctuated around 80%, reaching peaks of up to 90% during the session, exceeding the 87% threshold recommended by Meta for a level change [Meta, 2022] [Meta, 2024b]. These occurrences did not impair the experience but highlight the need to reevaluate the GPU usage level configuration to prevent rendering issues in future versions of the application.

Overall, the results met the authors' expectations and demonstrated the potential for enhancing functionalities and models in the application. Another value that supports this conclusion is the amount of memory the application occupies on the device: only 88 MB, approximately 0.07% of the memory of the simplest Meta Quest 3 model (128 GB).

5.2 Validation by Expert Panel

As part of the project validation process, an evaluation was conducted with fifteen professors and postgraduate students, all with teaching experience, at the Faculty of Dentistry of USP (FOUSP). The goal of this validation step is to ensure that the implemented tool maintains its intended usefulness, as perceived by experts in the field. Once this is ascertained, further experiments can be conducted to evaluate its use in a pedagogical context. A questionnaire was developed based on the Technology Acceptance Model (TAM) proposed by Davis *et al*. [1989], with questions to be answered on a Likert scale. The aim was to assess the perceived ease of use and usefulness of the application, in accordance with the project objectives, while also considering possible external influences on this perception. Questions related to the perceived immersiveness of the experience were also included, as this is a critical factor for the success of the project.

A brief presentation of the project was given, and each participant in the validation had the opportunity to interact with the application, with assistance from the developers when necessary. After the experience, each participant was required to complete the evaluation questionnaire. The results, representing a selection of the key questions from the "ease of use," "perceived usefulness," and "immersion" sections of the questionnaire, are presented in Table 1.

The group of participants generally consisted of individuals with little to no experience with virtual reality, with the exception of two respondents who reported some familiarity with the technology. Thus, the evaluation of ease of use was conducted under the premise that the application does not require any prior knowledge in this area.

The overall perception, in terms of ease of use, was that the application is simple and intuitive, with no significant difficulties anticipated for its adoption in the classroom by both students and professors. A minority of participants noted some degree of difficulty in use. It was unanimous that the application would facilitate the work and learning of the participants, making them more engaging. All participants agreed that the application provides a good perception of the spatial relationships of dental structures and facilitates the understanding of complex concepts in Dentistry. The use of models based on records obtained from microtomography was highlighted as a valuable advantage for learning by all participants, with most fully agreeing that the models were sufficiently similar to their real counterparts. Regarding immersion, most participants reported feeling that the virtual objects truly existed and that interaction with them was natural. However, some pointed out a certain discomfort with the number of floating menus, which cluttered the visualization and detracted from immersion when they needed to be used.

The initial validation by a panel of experts was relevant in order to proceed with the development of the tool. The control interfaces, currently presented as floating menus, were the major source of discomfort during use. A new design iteration will investigate the use of gesture-activated controls to show and hide display options, as well as the anchoring of option menus to the tooth models while they are displayed.

6 Conclusion

Teaching dental anatomy to dentistry undergraduate students faces a number of ethical and practical challenges. In this context, the use of augmented and virtual reality technologies is promising, and there are a number of academic results showing their effectiveness, especially when combined with conventional approaches such as lectures.

We have presented the development of a mixed reality system to assist in teaching dental anatomy, with models of tooth surface and tooth root, created from micro tomography scans. The aim of the project is to provide a complementary educational tool with adequate visual fidelity and engaging interaction techniques. The performance of the system was assessed and is within the guidelines for mixed reality applications. A panel of specialists was also consulted to evaluate the acceptance of this technology, with positive results. However, some difficulties in the use of the interface, particularly with the floating menus, were found, indicating the need for improvements in those elements.

Since this phase of the project was focused on the technological development of the tool, the results are still limited regarding its use in a pedagogical context. Once the complete version of VIDA XR is implemented, including other tooth models and improved interface, a study of its pedagogical effectiveness will be conducted.

In the future, the VIDA XR system can be extended to support multi-user collaboration, so that a teacher can highlight and share information about specific tooth features, and students can view and manipulate a shared tooth model. Some of its functionalities can also be reproduced in resource-limited devices, as tablets, notebooks and smartphones, in order to broaden the application's accessibility.

Declarations

Authors' Contributions

IS, EA and LR contributed with formal analysis, investigation, software and validation. MM, LF and TM contributed with conceptualization, resources and validation. RT and RN contributed with conceptualization, funding acquisition, investigation, and supervision. IS and RN were the main contributors to writing of the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Table 1. Excerpt of the validation questionnaire results.

Section	Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Ease of use	The application is easy to use.	14	1	0	0	0
	The manipulation of virtual objects was simple and intuitive.	14	0	1	0	0
	The application responded well to my commands.	13	2	0	0	0
	The user experience of the application is pleasant.	15	0	0	0	0
Perceived Usefulness	I believe the application would facilitate my work or studies.	15	0	0	0	0
	I believe that adopting this application in the classroom would not require much time for students and professors to learn how to use the tool.	11	3	1	0	0
	I believe the application would make my work or studies more interesting.	15	0	0	0	0
	I believe the application allows a good perception of the three-dimensionality of the represented structures.	15	0	0	0	0
	I believe the application allows a good perception of the spatial relationships between the represented structures.	15	0	0	0	0
	I believe that using digital models of real teeth generated from imaging exams, rather than digitally created objects, is a valuable advantage of this application.	15	0	0	0	0
	The represented structures are sufficiently similar to their real counterparts for teaching their anatomy.	11	4	0	0	0
	I believe the application would facilitate the explanation and understanding of difficult-to-visualize concepts in dental anatomy.	15	0	0	0	0
	I believe the application complements traditional tools for teaching dental anatomy and endodontics well.	14	1	0	0	0
	I would like to integrate the use of the application into my dental anatomy or endodontics classes.	15	0	0	0	0
Immersion	During the use of the application, I felt that the virtual objects truly existed.	14	1	0	0	0
	During the use of the application, I felt that interactions with the virtual objects were natural.	13	2	0	0	0
	I believe the application is visually cluttered, and this impaired my experience.	1	0	0	2	12
	I felt that the use of floating menus with buttons and sliders hindered my experience.	1	2	1	3	8

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Availability of data and materials

The datasets (and/or softwares) generated and/or analysed during the current study will be made upon request.

References

Alsalleeh, F., Okazaki, K., Alkahtany, S., Alrwais, F., Bendahmash, M., and Al Sadhan, R. (2024). Augmented reality improved knowledge and efficiency of root canal anatomy learning: A comparative study. *Applied Sciences*, 14(15). DOI: 10.3390/app14156813.

Alsufyani, N., Alnamlah, S., Mutaieb, S., Alageel, R., AlQarni, M., Bukhari, A., Alhajri, M., AlSubaie, A., Alabdulkarim, M., and Faden, A. (2023). Virtual reality simulation of panoramic radiographic anatomy for dental students. *Journal of Dental Education*, 87(8):1200–1209. DOI: 10.1002/jdd.13240.

Apple (2025). Apple vision pro. Available at:`https://www.apple.com/apple-vision-pro/`.

Autodesk Inc. (2025). Meshmixer. Available at:`https://meshmixer.com/`.

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., and MacIntyre, B. (2001). Recent advances in augmented reality. *IEEE Computer Graphics and Applications*, 21(6):34–47. DOI: 10.1109/38.963459.

Bairsto, R. (2021). Phantom head. *British Dental Journal*, 231(3):152–152. DOI: 10.1038/s41415-021-3346-8.

Bevizova, K., Falougy, H. E., Thurzo, A., and Harsanyi, S. (2024). Is virtual reality enhancing dental anatomy education? a systematic review and meta-analysis. *BMC Medical Education*, 24(1):1395. DOI: 10.1186/s12909-024-06233-0.

Blender Foundation (2025). Blender. Available at:`https://www.blender.org/`.

Brasil (1997). Lei dos transplantes de Órgãos | lei nº 9.434, de 4 de fevereiro de 1997. *Diário Oficial [da] República Federativa do Brasil*. Available at: `https://www.planalto.gov.br/ccivil_03/leis/l9434.htm`.

Collaço, E., Kira, E., Sallaberry, L. H., Queiroz, A. C. M., Machado, M. A. A. M., Crivello Jr, O., and Tori, R. (2021). Immersion and haptic feedback impacts on dental anesthesia technical skills virtual reality training. *Journal of Dental Education*, 85(4):589–598. DOI: 10.1002/jdd.12503.

Davis, F., Bagozzi, R., and Warshaw, P. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, 35:982–1003. DOI: 10.1287/mnsc.35.8.982.

Diegritz, C., Fotiadou, C., Fleischer, F., and Reymus, M. (2024). Tooth anatomy inspector: A comprehensive assessment of an extended reality (xr) application designed for teaching and learning of root canal anatomy by students. *International Endodontic Journal*, 57(11):1682–1688. DOI: 10.1111/iej.14124.

Dzyuba, N., Jandu, J., Yates, J., and Kushnerev, E. (2022). Virtual and augmented reality in dental education: The good, the bad and the better. *European Journal of Dental Education*, n/a(n/a). DOI: 10.1111/eje.12871.

Fugill, M. (2013). Defining the purpose of phantom head. *European Journal of Dental Education*, 17(1):e1–e4. DOI: 10.1111/eje.12008.

García-Robles, P., Cortés-Pérez, I., Nieto-Escámez, F. A., García-López, H., Obrero-Gaitán, E., and Osuna-Pérez, M. C. (2024). Immersive virtual reality and augmented reality in anatomy education: A systematic review and meta-analysis. *Anatomical Sciences Education*, 17(3):514–528. DOI: 10.1002/ase.2397.

Grad, P., Przeklasa-Bierowiec, A. M., Malinowski, K. P., Witowski, J., Proniewska, K., and Tatoń, G. (2023). Application of hololens-based augmented reality and three-dimensional printed anatomical tooth reference models in dental education. *Anatomical Sciences Education*, 16(4):743–755. DOI: 10.1002/ase.2241.

Jerald, J. (2018). *What is Virtual Reality*. Association for Computing Machinery and Morgan & Claypool. Book.

Kim-Berman, H., Bui, D., Lee, K., Mitchell, V., Bonine, B., Benavides, E., Soki, F., and Ramaswamy, V. (2023). Student learning of head and neck anatomy using cone beam computed tomography and immersive virtual reality. *Journal of Dental Education*, 87(8):1180–1187. DOI: 10.1002/jdd.13224.

Kim-Berman, H., Karl, E., Sherbel, J., Sytek, L., and Ramaswamy, V. (2019). Validity and user experience in an augmented reality virtual tooth identification test. *Journal of Dental Education*, 83(11):1345–1352. DOI: 10.21815/JDE.019.139.

Mahrous, A., Elgreatly, A., Qian, F., and Schneider, G. B. (2021). A comparison of pre-clinical instructional technologies: Natural teeth, 3d models, 3d printing, and augmented reality. *Journal of Dental Education*, 85(11):1795–1801. DOI: 10.1002/jdd.12736.

Mann, S. and Wyckof, C. (1991). Extended reality, mit 4–405 (1991). Available at:`http://wearcam.org/xr.htm`.

Meta (2022). Power management. Available at:`https://developers.meta.com/horizon/documentation/native/android/mobile-power-overview/`.

Meta (2024a). Cpu and gpu levels. Available at:`https://developers.meta.com/horizon/documentation/unity/os-cpu-gpu-levels`.

Meta (2024b). Ovr metrics tool stats definition guide. Available at:`https://developers.meta.com/horizon/documentation/unity/ts-ovrstats`.

Meta (2024c). Performance analyzer and metrics. Available at:`https://developers.meta.com/horizon/documentation/native/android/ts-odh-logs-metrics/`.

Meta (2025). Meta quest 3. Available at:`https://www.meta.com/quest/quest-3/`.

Milgram, P. and Kishino, F. (1994). A taxonomy of mixed reality visual displays. volume E77-D, pages 1321–1329. Available at:`https://globals.ieice.org/en_transactions/information/10.1587/e77-d_12_1321/_p`.

Nunes, F. L. S., de Oliveira, J. C., dos Santos Nunes, L. S. M. E. P., Costa, R. M., and Queiroz, A. C. M. (2020). *Introdução a Realidade Virtual e Aumentada*, chapter Saúde. Editora SBC, Porto Alegre, 3 edition. DOI: 10.5753/sbc.6654.2.

PicoXR (2025). Pico4 ultravr-mr-headset. Available at:`https://www.picoxr.com/global/products/pico4-ultra`.

Reymus, M., Liebermann, A., and Diegritz, C. (2020). Virtual reality: an effective tool for teaching root canal anatomy to undergraduate dental students – a preliminary study. *International Endodontic Journal*, 53(11):1581–1587. DOI: 10.1111/iej.13380.

Santos, B. and Trevisan, D. (2023). Overview and tendencies of augmented reality applications in medicine. In *Anais do XXV Simpósio de Realidade Virtual e Aumentada*, page 26–37, Porto Alegre, RS, Brasil. SBC. DOI: 10.1145/3625008.3625013.

Souza-Junior, V. D. D., Mendes, I. A. C., Tori, R., Marques, L. P., Mashuda, F. K. K., Hirano, L. A. F., and Godoy, S. D. (2020). Vida-nursing v1.0: immersive virtual reality in vacuum blood collection among adults. *Rev. Latino-Am. Enfermagem*, 28. DOI: 10.1590/1518-8345.3685.3263.

Tori, R., da Silva Hounsell, M., and Kirner, C. (2020). Introdução a realidade virtual e aumentada. Porto Alegre. Editora SBC. DOI: 10.5753/sbc.6654.2.

Unity Technologies (2025). Unity. Available at:`https://unity.com/pt`.

Varjo (2025). Varjo xr-4 series. Available at:`https://varjo.com/products/xr-4/`.