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Adaptive Learning and Virtual Reality based Conceptual Framework for Dental Training

Meriam Sherif
meriam.sherif@bue.edu.eg

Nahla Barakat
nahla.barakat@bue.edu.eg

Abeer Hamdy
Abeer.Hamdy@bue.edu.eg

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Meriam Sherif
Department of Software Engineering
Faculty of Informatics and Computer Sceince, The British University in Egypt
Cairo, Egypt
meriam.sherif@bue.edu.eg

Nahla Barakat
Department of Artifical Intellegence
Faculty of Informatics and Computer Sceince, The British University in Egypt
Cairo, Egypt
abeer.hamdy@bue.edu.eg

Abeer Hamdy
Department of Software Enginerring
Faculty of Informatics and Computer Sceince, The British University in Egypt
Cairo, Egypt
nahla.barakat@bue.edu.eg

***Abstract*—Recently, there has been increasing interest in utilizing virtual reality (VR) technology in dental education and student training. VR based training can provide students with sufficient training and hands-on experience before entering the clinical setting, which in turn helps avoid risks ranging from small errors to severe consequences. However, previous research in this area is limited and none of the previous work proposed a complete, scalable framework for dental students' education and training. This paper proposes an improved virtual environment for dental training, through an adaptive learning approach, integrated with the VR environment, which is – to the best of our knowledge – the first framework proposed for this purpose. The framework consists of eight modules that aim to provide students with a holistic dental training experience, equipping them with the essential skills and confidence required for their future clinical practice. Furthermore, it aims to improve patient care and safety. In order to guarantee the effectiveness and usability of the proposed framework, a thorough evaluation will be conducted, encompassing both a system perspective, which involves assessing software metrics, as well as evaluating its usability.**

Keywords—dental training, virtual reality, software metrics

I. INTRODUCTION

Dental education approaches that provide limited hands-on training can result in insufficient student skills and potential harm to patients. Research has indicated that offering dental students adequate training and practical experience prior to entering the clinical setting can effectively prevent critical errors and potentially life-threatening situations. [1]. Adopting technology, such as Virtual reality (VR) could be utilized to overcome the gap between theoretical knowledge and real practice in dental education. Dental students can benefit from immersive and interactive simulations that enhance their understanding, visualization, and skill development. VR-based dental training offers a safe and controlled environment for students to practice various procedures, receive immediate feedback, and refine their techniques, ultimately leading to improved patient care and safety. The traditional clinical training for dental students is divided into two stages. In the first stage, students practice on artificial teeth placed within a manikin head using real dental tools, which minimizes the risk of harm to patients. In the second stage, students treat real patients under the supervision of their professors to gain real-world experience. However, they may still lack some skills, and errors may occur due to lack of experience. Therefore, before treating real patients, students must have a thorough understanding of dental tools and organ characteristics to prevent errors [2]. Poor skills can lead to dental mistakes, which may have serious consequences. Effective dental training can improve the skills of dental students, minimizing the risk of errors and improving patient outcomes.

The COVID-19 pandemic has resulted in a shift away from traditional teaching methods as education has moved online, leading to an increase in digital and virtual tools. In dental education, virtual reality (VR) has become more popular as a training tool for students before they work on real patients. VR involves creating an immersive environment within a computer-generated 3D image that students can access through a VR headset. Virtual reality technology provides a controlled and safe environment for dental students to develop their skills by practicing on virtual patients for extended periods of time. This technology offers students an opportunity to gain a real-life experience before working on real patients, which can help them to build their confidence and refine their skills. VR allows students to make mistakes and learn from them without causing harm to real patients.

The use of new technologies in dental training and education has garnered significant attention from researchers who aim to improve dental training through technology evaluation. This research area is deemed important as using new technologies can enhance students' skills, making them more professional without incurring significant material costs. New technologies offer unlimited training opportunities, and students do not need to purchase expensive materials, unlike traditional methods. Moreover, students' knowledge and understanding of dental procedures can be enhanced after using new technologies in dental education . Ultimately, using new technologies in dental education can help students develop their skills and prepare them for real-life situations, ensuring that they can provide high-quality dental care to their patients.

A. Research Questions and Contribution

The research questions are:

1. What is the impact of the VR framework on dental students' confidence in performing tooth drilling and filling procedures?
2. What are the effects of adaptive learning mechanisms within the proposed VR framework on students' skills progression?
3. What are the effect of immediacy and frequency type of feedback on the student's performance?
4. What are the most time-consuming tasks, the ones that need the most feedback and the most common errors?

5. Does the Dentistry VR framework lead to statistically significant improvements in dental students' performance in tooth drilling and filling procedures compared to traditional training methods?

The Contribution:

- Microlevel (individual student):

1. Error Detection and Correction Algorithm: Developing an algorithm that can automatically detect common errors made by students during the VR dental procedures and provide timely feedback and corrective guidance.
2. Skill progression Assessment Algorithm: An algorithm that analyzes the quantitative data collected will be designed. This algorithm can identify areas of improvement, highlight specific skills that need attention, and suggest personalized additional training sessions to enhance the students' skills.

- Macro-level (over group of students):

1. Student interaction's Analytics: Patterns analysis and trends identification will be one of the major outcomes of the proposed framework. This can provide insights into how students interact with the system. This will use the data collected from data management module and the confidence and evaluation rating data questionnaires.

B. Background

According to research, virtual reality (VR) is a beneficial resource in dental education as it enables students and professionals to improve their skills and knowledge through practice in a secure virtual environment before applying them to real-life patients [3] [4]. VR technology creates a computer-generated environment that simulates users' senses, providing an efficient teaching tool for dental training [3]. VR can offer a realistic experience that closely resembles physical reality [3]. This is particularly important for dental education, as students may find it challenging to view and understand oral anatomy in the actual world [4]. The potential of virtual reality (VR) technology to transform dental education and improve patient outcomes by producing better-trained dental professionals has been recognized. Numerous research studies have been conducted to highlight the benefits of VR in dental education, demonstrating that the technology can lead to improved learning outcomes and increased student engagement. The subsequent paragraphs will discuss some of these studies.

According to Mansoory et al. [4], using virtual reality (VR) in dental education has a significant impact on students' knowledge and skills, reducing the risks that could negatively affect patients' health and increasing the level of safety for students in clinical settings. Their study showed that students were highly satisfied with VR technology, and faculty members found it to be effective. In particular, 87% of students found that VR was an attractive, usable, and motivating tool for learning complex dental procedures [4]. Additionally, VR simulators were found to be an effective way to evaluate the performance of dental students [4]. Similarly, Morales-Vadilo et al. [5] found that using VR in dental education can improve students' understanding and make studying more enjoyable. Students in their study reported being excited and motivated by the VR experience, which helped improve their learning outcomes and memorization skills [5]. Tower et al made scoping review [6], which highlighted the growing recognition of VR as a valuable tool for training dental students. Overall, these studies demonstrate the benefits of using VR in dental education and training, including improved student satisfaction, increased safety, and better learning outcomes.

The integration of virtual reality (VR) technology in dental education can offer numerous benefits to students' learning experiences. Firstly, VR technology can be utilized to demonstrate the expected outcomes to patients before undergoing dental procedures, which can help them make informed decisions [3]. Secondly, the use of VR technology can enhance students' understanding of anatomical interactions and provide an attractive learning environment [4]. Thirdly, VR can aid in improving students' fine motor skills and hand-eye coordination in clinical settings, which are essential for performing dental procedures [7]. Fourthly, VR can create a realistic virtual environment that allows students to monitor patients and conduct clinical examinations while being supervised by a teacher, without posing any risk to actual patients [4][8]. Finally, VR simulators can enable instructors to better engage students and enrich their own knowledge [9]. Overall, the implementation of VR technology in dental education can provide a safe, effective, and engaging learning environment for students, improving their skills and knowledge in dental procedures.

The Unity Test Framework, also known as the Unity Test Runner, is a built-in testing tool within the Unity editor that is designed to test applications [10-12]. This framework does not require a separate download and can test the application under both play and edit modes [12]. To write test cases using the Unity Test Runner, the NUnity library is required [12]. This framework is useful in identifying bugs and performance issues within the Unity project. Additionally, the performance-testing framework is an extension package that focuses on the performance metrics of Unity applications [10]. To assess the performance of the Unity project, performance test cases can be created using the Unity Test Runner window [10].

II. RELATED WORK

This section presents three existing dental training simulators for different tasks.

DentSim\DentX system have phantom head that the student will work on [13][14]. The student will have 3D glasses so that he will see what he is doing in 3D on a screen monitor. DentSim system focused on tooth preparation and how to help students to visualize the theoretical concepts [15]. Moreover, it made quizzes on specific concepts. From the disadvantages, it needs a supervisor while the student is training on the system. Also, it is highly cost in maintenance, and it does not provide students with real patient cases [15].

Simodont have a 3D gales and monitor [15][16]. It is used for crown and bridge preparations [15]. It has different clinical cases, but it lacks individual learning and evaluation. One of its disadvantages is that it cannot train students about positioning requirements.

PerioSim is another VR training simulation that utilizes haptic technology [17][18]. PerioSim utilizes the PHANToM haptic device, a Dell Xeon 50 workstation with 3D capabilities, 3D goggles, and a 3D stereoscopic monitor [18]. The PHANToM haptic device provides the user with a sense of touch and interaction with the teeth or other objects within the simulation, while also providing force feedback through a handheld stylus that the user moves. This combination of visual and haptic feedback allows students to feel as if they are performing the procedures themselves, providing a more realistic and effective training experience. The primary goal of PerioSim is to help students more in studying by seeing everything in 3D [18]. PerioSim is used in Periodontal which is the field of gum treatment.

Based on related works, it has been shown that there is a research gap in the field of VR based dental training; where there are no integrated frameworks which combine different modules and/or components together. In the past simulators, they depended on human supervision which takes time, and no one has used the timely feedback which will help students more. Moreover, no one has made the data management module which contains data collection and analysis for all the students. This is important for providing insights to educators on the most common mistakes made by students. More research is needed to make more effective and comprehensive frameworks to help dental students in enhancing their performance and skills in a more engaging and efficient manner.

content, training/interaction, feedback, log, and data management, student performance assessment and system quality assessment. This conceptual framework was found to be the best approach after conducting huge research on the topic. Previous studies showed how is the VR effective in dental education and will add a great value to this framework with the use of the haptic technology. The proposed framework will fill the gap in the field of dental education by providing one application that integrates all necessary features or modules. Each module of the framework has a specific function, and the integration of these modules creates a complete and comprehensive system. First starting with the VR headset is set up, and then a user profile is created for each user individually. The user profile interface allows multiple users to access the system, and each user has a separate profile that will save his data during the whole session. The user can then choose, from the content module, the model he wants to train on, then starts the training/interaction module. In this module, the user will be able to train on specific tasks with its dental procedures. If the user makes any mistake, the system will provide him feedback on what the wrong procedure he did and what is wrong and how to correct it. Furthermore, the haptic device will also provide the user with additional feedback during the training phase. Throughout the training session, the system will save the user's data in the log and data management module, which will be analyzed later. Finally, an evaluation will be conducted for both the entire system and students to assess the system's effectiveness. The modules are discussed in the following sections in detail.

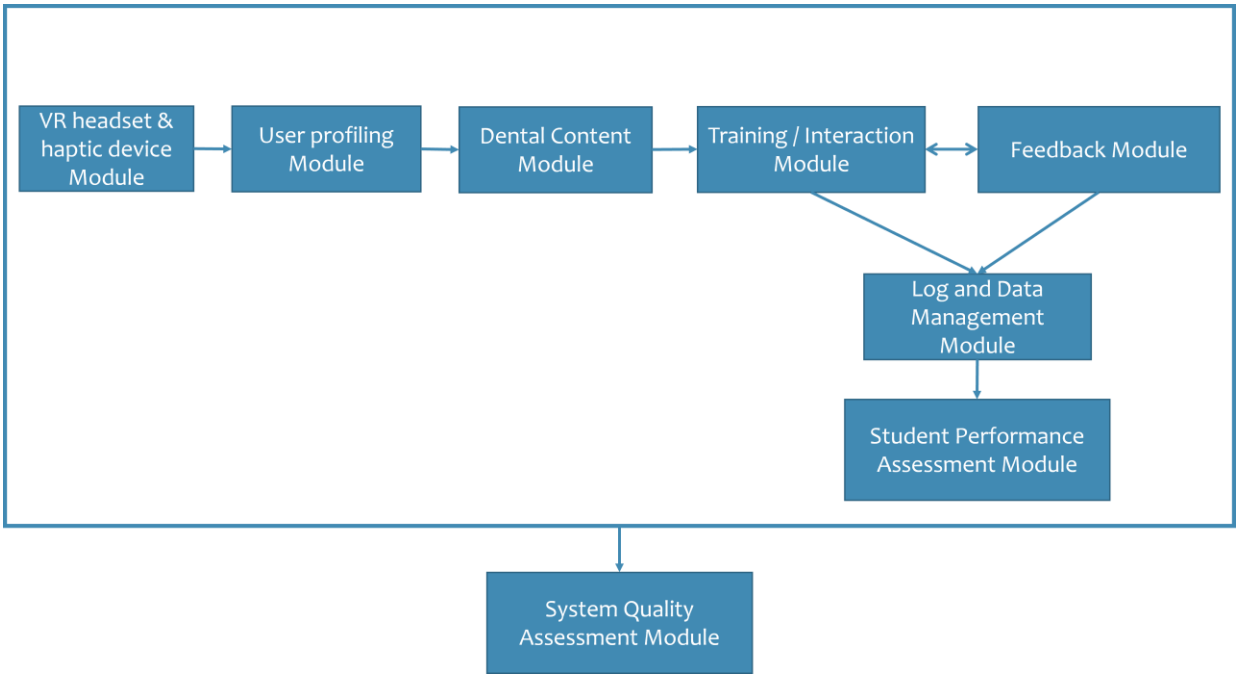

Fig. 1. The proposed conceptual framework for dental training application using VR and haptic device.

III. Proposed Framework

The proposed conceptual framework aims at utilizing adaptive learning along with VR and haptic devices to provide a virtual environment that facilitates dental training by providing an effective and complete training experience. The framework consists of eight modules as depicted in fig.1. The eight modules are: VR headset, user login,

A. VR headset Module

The Oculus Quest 2 VR headset was used in the proposed framework. A VR headset is a head-mounted device that includes a display screen, stereo sound, sensors, and controllers [19]. It enables users to move in any direction and it offers the user a 360-degree viewing experience of the seeing everything in virtual world. The

VR headset allows users to interact with the virtual environment and it tracks the user's motion. Controllers are required to point, select, drag and drop, or navigate between objects in the virtual world [19]. The Oculus Quest 2 headset comes with lenses that cater to different vision requirements, with one for people who have no visual impairments and two lenses for those who do [20]. Head tracking is used to track the user's head movement and control the view, much like a mouse on a laptop [20]. To integrate the Oculus Quest 2 headset with the framework, Unity is used. The XR plugin management and Oculus integration plugin from the asset store needs to be installed to connect the headset to Unity easily. The incorporation of the Oculus Quest 2 VR headset into the proposed framework enhances the training experience by providing a 360-degree immersive environment. The headset enables students to interact with the virtual environment and practice dental procedures in a safe and controlled setting. By integrating the Oculus Quest 2 headset, the framework provides a comprehensive training experience for dental students.

B. User Profiling Module

The application is designed to be accessible to multiple users. Each user has their own user interface and user log to save their data. The user interface will offer beginner and intermediate exercises, tailored to the user's level of experience, making the application appropriate for users at different levels. The user progress is saved throughout the entire session. By incorporating these features, the framework provides a personalized training experience for each user, allowing them to progress at their own pace and improve their skills effectively.

C. Content Module

The content module is composed of two parts: 3D models and dental content. The 3D models will be of molars, and in this framework, there are two types of 3D models. The first type will be models captured by an intraoral camera or scanner, which generates a 3D model with STL or OBJ extensions that can be easily plugged into Unity. The second type of 3D models are free 3D models that can be integrated and downloaded into Unity. The second type of 3D model refers to the environment inside the virtual reality, such as the drill tool or any dental tools, and the virtual location itself. By incorporating these 3D models, the framework offers users a realistic and immersive dental training experience.

Dental content simulating various procedures put this framework focus on drilling a molar and filling it. To simulate the drilling of a tooth, the framework employs three algorithms: vocalization, marching cubes, and collision detection. The first algorithm, voxelization, transforms any object into volume data stored in a 3D voxel array [21][23]. To render the voxels, each voxel from the grid is represented as a cube positioned in space according to its coordinates in the grid [21]. The voxelization algorithm examines whether each voxel belongs to an object and assigns a value of 1 or 0 accordingly [23]. A scalar density grid is generated from the 3D model of the tooth, and a material map is created to assign the degree of tooth damage [22]. Since volumetric models do not have explicit surface representations, the marching cubes algorithm is utilized to extract the tooth's surface from the voxel grid [21][22]. This algorithm divides the voxel grid into cubes consisting of eight adjacent voxels [21]. Subsequently, collision detection is performed to check for collisions between the tooth and the handpiece [21]. In simulating dental procedures, it is important to consider the realism of the tooth and the steps involved. For instance, a tooth consists of three layers; thus, the drilling process must take into account the depth of drilling and the layers of the tooth. By incorporating these algorithms, the framework provides an immersive and realistic dental training experience, enabling students to acquire essential skills and knowledge in a risk-free environment.

D. Training/interaction model Module

This module is composed of two integral components, namely the training and interaction parts. The purpose of the training module is to educate students on executing dental procedures, which are drilling a molar and filing it. Drilling a molar means that removes the decays or caries. The decay in the molar has 6 positions which are called classes. The molar will have a trajectory to guide the student and there will be points that the student will interact with the different layers of the molar. Meanwhile, the interaction section employs a touch haptic device, a technology that can generate tactile sensations for the user by exerting forces, vibrations, or movements [24]. Haptic devices are similar to game controllers and are used in dental education to enable users to interact with a virtual environment that simulates real-life situations [24]. The haptic device used in this framework is equipped with software that calculates the required forces to make the user feel the object being manipulated [24]. It is designed like a pen and provides the user with a tactile sensation while also allowing free movement. This device is essential as it gives the student a sense of touch and provides force feedback, allowing the student to assess their performance [24]. To integrate the haptic device into the framework, a plugin is installed on the assets, connecting it to Unity.

E. Feedback Module

This module offers two distinct feedback mechanisms. The first one is timely feedback that immediately informs the student if they have made a mistake while performing a procedure. This feedback system guides the user towards the correct path to complete the task successfully. For instance, if the student drills more than necessary or reduces a tooth part excessively, the system will alert them that they are making a mistake. Moreover, if the user takes the wrong path while performing a specific task, the system will redirect them towards the correct path. The feedback can be in the form of a notification, sound alert, or animation if the student removes anything from the tooth. The haptic device acts as the second mechanism of providing feedback to the student, giving them insights on the amount of force and movement of their hands. By sensing the degree of force applied by the user, the device can offer haptic feedback to aid the student in interpreting their performance. Additionally, all of the student's actions during the procedure are saved for future assessment of their overall performance. Furthermore, the system records all of the

user's actions during the task for future evaluation of their performance. This feature enables the student to review their progress and identify areas that require improvement.

There will be an adaptive learning between the training/interaction module and feedback module. Adaptive learning is to personalize the learning experience based on individual needs and progress. The educational content and training exercises can be tailored to the specific requirements and proficiency levels of each student.

F. Log and Data Management Module

This module comprises two essential components, namely log and data management. Unity helps in customizing log. The user log saves the user's movement or the interface they use, which is crucial in the application as it records every action taken by the user. The recorded user log will be utilized by another module to analyze and work on it further. During the application's operation, a new log entry is added every time the user executes an action, and Unity saves everything, including messages, warnings, errors, and all user activities. The log file is a vital component in analyzing the user's performance, identifying and rectifying errors, and enhancing the application's functionality. It includes all the relevant information, including data not displayed in the console window.

The data management module is in charge of producing a database that stores all the data of the students. This information is crucial in evaluating the student's performance during a particular task, which can help identify areas that require improvement. The data management can have for example: accuracy, completion time, error rates during procedures, number for feedbacks and their types, overall score, speed, precision, common errors, decay class, the depth of the drill and video. The data management module will be helpful for students and professors.

G. Student Performance Assessment

The module utilizes data from the data management module to evaluate student performance by providing a detailed report of their task performance and a recorded video, including correct and incorrect procedures, and an objective score. This feedback mechanism helps students identify their strengths and weaknesses and motivates them to improve their skills to achieve better scores in the future.

H. System Quality Assessment

After the completion of all other modules, the system quality assessment module will assess the system in two ways: through a usability evaluation by students and a software metrics evaluation of the entire system. The usability evaluation will gather feedback on the system's ease of use and overall user experience, while the software metrics evaluation will evaluate the system performance based on predetermined criteria. The module will use both evaluations to provide a comprehensive assessment of the system's usability and performance and identify areas for improvement before deployment.

1) Studnets' evaluation : The system's usability will be assessed by conducting a survey among dental students before and after they use the application. The survey will evaluate the system's usefulness, ability to simulate real-life dental scenarios, and overall satisfaction of the students with the application. Based on the survey results, necessary improvements will be made to enhance the user experience for future students and to gauge the effectiveness of the system in supporting their learning.

2) Entrie system evaluation: The application and framework will undergo a comprehensive evaluation, including an assessment of code quality. Code quality will be evaluated using software metrics such as cyclomatic complexity which is a testing metric used to measure the complexity of an application or software, depth of inheritance which is a metric specific to object-oriented programming. It measures the number of classes between a node and a root in a class hierarchy, maintainability index which calculates if the code is maintainable or not. It calculates an index value between 0 and 100, and class coupling which measures if one class is dependent on and connected to another class or not. Knowing the number of classes that a particular class uses is beneficial, and the four software metrics mentioned earlier are selected because they are the most appropriate for Visual Studio Code (C#). Evaluating the code quality is essential in comprehending the code's reliability and maintainability, which allows developers to prepare for any potential risks and correctly test the application. Additionally, the performance of the system is assessed using embedded Unity test frameworks, including the Unity test framework and the Performance testing framework, which were previously discussed in Section I. Introduction in B. Background.

IV. SCENARIO FOR FILLING A MOLAR

This is a sample scenario for training on the procedures of filling a tooth.

A. VR headset Module

The student will wear the VR headset and enter a simulated dental environment.

B. User Login Module

The student will log in to their account and all their activities will be recorded in their log. Following that, they will select the option to receive instructions on filling a tooth.

C. Content Module

A 3D molar will be shown, he will see all the dental tools and he will see the place as if he is in a real clinic.

D. Training/interaction model Module

To learn how to fill a molar, the student will begin by using explorer (sickle probes) to check the molar's condition. If the student detects any softness or yellow/brown colors, it signals the presence of caries. If caries is present, the student will know first the decay class to start the procedures. The student will have a trajectory to guide him. He will use a high-speed drill tool (contra) to remove all decay. A haptic device will allow the student to feel as though they are using a real dental tool, experiencing the force and speed necessary for the procedure. The tooth's anatomy consists of three layers: enamel, dentin, and pulp. If the caries is deep and the pulp layer is near, the student

should switch to a low-speed contra or excavator to remove soft caries and avoid reaching the pulp. If the student uses a high-speed drill tool in this scenario, they could reach the pulp layer, which would require a root fill. Once all caries is removed, the student will fill the molar with a material to restore it to its normal state. These steps provide the necessary training for filling a molar.

E. Feedback Module

The student will receive feedback through sound and notifications if they make a mistake. For instance, if the student selects the wrong tool, a notification will appear on the screen. Similarly, if the student applies too much force or speed, the haptic device will provide feedback, and a notification will inform the student of the error. If the student was far from the trajectory, there will be a notification for him. Additionally, if the student leaves caries behind while filling the molar, they will receive a notification that guides them on how to correct their technique. In case the student drills in the wrong location, the program will redirect them to the correct site. Finally, the haptic device will offer feedback to the student if they move their hand incorrectly, allowing them to correct their technique. This feedback system ensures that the student is aware of their errors and can make the necessary adjustments to enhance their abilities.

F. Log and Data Management Module

The student's actions will be saved in the database, and after completing the task, their performance will be assessed. A score and report highlighting both their correct and incorrect procedures will be presented. The system as a whole will also undergo two evaluations.

G. Student Performance Assessment Module

The initial evaluation involves the student completing a survey to assess the system's usability.

H. System Quality Assessment Module

The second evaluation involves assessing the entire system code quality by using software metrics and the Unity testing framework and also comparing the performance of students who used VR-based training with those who had traditional training methods.

V. CONCLUSION

This paper introduces a conceptual framework for dental training that is based on adaptive learning and virtual reality. The use of the adaptive learning in the proposed framework will have benefits which are personalized content, individualized feedback, adaptive scenarios, and progress tracking and assessment. The framework allows the students to develop their practical skills through immersive simulations and engaging haptic feedback. The students will be provided by timely feedback on their progress and the professors will be provided by feedback on the performance of every individual student, in addition to the performance of a group of students. The data management module which consists of data for all students will help professors to evaluate the student's performance and to compare it with the traditional techniques. The proposed framework will be evaluated from both of the System and Usability perspectives to assess its effectiveness and usability. The proposed framework aims to address the challenge of students feeling unprepared when they transition into the workforce. By providing a realistic and engaging training experience, the integrated framework equips students with the necessary skills and knowledge to perform dental procedures effectively. The approach guarantees that students can seamlessly transition into the industry and use their education efficiently. In general, this structure has the possibility of transforming dental training by offering a more interesting and productive learning experience for students.

REFERENCES

[1] L. Szalewski, D. Wójcik, M. Szalewska, and J. Szymanska, "Dentistry students' self-assessment of their practical skills - A survey study," *J. Stomatol.*, vol. 73, no. 6, pp. 334–341, Dec. 2020, doi: 10.5114/JOS.2020.102052.

[2] S. Show and A. Kanti Dey, "Haptics: The virtual reality in periodontics," 2020, doi: 10.22271/oral.2020.v6.i3f.985.

[3] S. Fahim *et al.*, "Augmented Reality and Virtual Reality in Dentistry: Highlights from the Current Research," *Appl. Sci.*, vol. 12, no. 8, Apr. 2022, doi: 10.3390/APP12083719.

[4] M. S. Mansoory, S. M. Azizi, F. Mirhosseini, D. Yousefi, and H. Moradpoor, "A study to investigate the effectiveness of the application of virtual reality technology in dental education," *BMC Med. Educ.*, vol. 22, no. 1, pp. 1–9, Dec. 2022, doi: 10.1186/S12909-022-03543-Z/TABLES/3.

[5] R. Morales-Vadillo, J.-O. Guevara-Canales, V.-C. Flores-Luján, J.-M. Robello-Malatto, R.-H. Bazán-Asencios, and C.-E. Cava-Vergiú, "Use of virtual reality as a learning environment in dentistry," 2019.

[6] Towers, Field, Stokes, Maddock, and Martin, "This is a repository copy of A scoping review of the use and application of virtual reality in pre-clinical dental education", Mar. 2019, doi: 10.1038/s41415-019-0041-0.

[7] S. B. Issenberg, W. C. McGaghie, E. R. Petrusa, D. L. Gordon, and R. J. Scalese, "Features and uses of high-fidelity medical simulations that lead to effective learning: A BEME systematic review," *Med. Teach.*, vol. 27, no. 1, pp. 10–28, Jan. 2005, doi: 10.1080/01421590500046924.

[8] C. F. Cayo, L. A. Cervantes, and R. Agramonte, "VR systems in dental education," *Br. Dent. J. 2020 22810*, vol. 228, no. 10, pp. 738–738, May 2020, doi: 10.1038/s41415-020-1689-1.

[9] E. Roy, M. M. Bakr, and R. George, "The need for virtual reality simulators in dental education: A review," *Saudi Dent. J.*, vol. 29, no. 2, pp. 41–47, Apr. 2017, doi: 10.1016/J.SDENTJ.2017.02.001.

[10] "Unity Performance Testing Tools & Benchmarks | Product Blog • Sentry." https://blog.sentry.io/unity-performance-testing-tools-and-benchmarks/ (accessed May 07, 2023).

[11] "Introduction To Unity Unit Testing | Kodeco." https://www.kodeco.com/38240193-introduction-to-unity-unit-testing (accessed May 07, 2023).

[12] "Unity - Manual: Unity Test Runner." https://docs.unity3d.com/2017.4/Documentation/Manual/testing-editortestsrunner.html (accessed May 07, 2023).

[13] R. Mladenovic, *The Usage of Augmented Reality in Dental Education*. Springer, 2020. doi: 10.1007/978-3-030-42156-4_8/FIGURES/12.

[14] Welkm Alexander, S. Christian, R. M, K. Bernd, and M. G, "DentSim—a future teaching option for dentists," *Int. J. Comput. Dent.*, May 2004, Accessed: May 06, 2023. [Online]. Available: https://www.researchgate.net/publication/8204448_DentSim-a_future_teaching_option_for_dentists

[15] H. M. Nassar and A. Tekian, "Computer simulation and virtual reality in undergraduate operative and restorative dental education: A critical review," *J. Dent. Educ.*, vol. 84, no. 7, pp. 812–829, Jul. 2020, doi: 10.1002/jdd.12138.

[16] "Home - Simodont Dental Trainer - Taking away limits in dental education." https://www.simodontdentaltrainer.com/ (accessed May 06, 2023).

[17] A. D. Steinberg, P. G. Bashook, J. Drummond, S. Ashrafi, and M. Zefran, "Assessment of Faculty Perception of Content Validity of

PerioSim©, a Haptic-3D Virtual Reality Dental Training Simulator," *J. Dent. Educ.*, vol. 71, no. 12, pp. 1574–1582, Dec. 2007, doi: 10.1002/J.0022-0337.2007.71.12.TB04434.X.

[18] E. Aluckal, G. Renjith, and A. Paulose, "Virtual Reality applications in Dentistry - A world to be unveiled," *J. Orofac. Res.*, vol. 11, pp. 1–4, Mar. 2022, Accessed: May 06, 2023. [Online]. Available: https://mansapublishers.com/index.php/jofr/article/view/3353

[19] "How Do Virtual Reality Headsets Work? - XR Today." https://www.xrtoday.com/vr/how-do-virtual-reality-headsets-work/ (accessed May 06, 2023).

[20] P. Rajesh Desai, P. Nikhil Desai, K. Deepak Ajmera, and K. Mehta, "A Review Paper on Oculus Rift-A Virtual Reality Headset," *Int. J. Eng. Trends Technol.*, vol. 13, no. 4, pp. 175–179, Jul. 2014, doi: 10.14445/22315381/IJETT-V13P237.

[21] Y. Y. Dyulicheva, D. A. Gaponov, and O. Y. Poleshchuk, "About the Features of the Virtual Simulators Development and their Usage in Dental Education", Sep. 2021.

[22] Y. Dyulicheva, D. A. Gaponov, R. Mladenović, and Y. Kosova, "The virtual reality simulator development for dental students training: a pilot study," *Int. Work. Augment. Real. Educ.*, vol. 2898, May 2021. Available: https://www.semanticscholar.org/paper/The-virtual-reality-simulator-development-for-a-Dyulicheva-Gaponov/4ca16b722c6ff9af665c598a680a06af7d835f7d

[23] E.-A. Karabassi, G. Papaioannou, and T. Theoharis, "A Fast Depth-Buffer-Based Voxelization Algorithm," *J. Graph. Tools*, vol. 4, no. 4, pp. 5–10, Jan. 1999, doi: 10.1080/10867651.1999.10487510.

[24] S. Gali and P. Archana, "(PDF) The Technology of Haptics in Dental Education," *Jorunal Dent. Oro-facial Res.*, vol. 14, Aug. 2018, Accessed: May 07, 2023. [Online]. Available: https://www.researchgate.net/publication/328758804_The_Technology_of_Haptics_in_Dental_Education