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AI-enabled virtual reality systems for dental education

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Abstract--This study investigates the use of AI-enabled virtual reality (VR) systems in dental education. With a sample size of 200 participants, the research aims to explore the effectiveness and potential benefits of integrating AI and VR technologies into dental education programs. The study focuses on the use of AI algorithms to enhance the learning experience, simulate realistic dental procedures, and provide interactive training modules for dental students. The research employs a quantitative research technique. The quantitative research involves the distribution of surveys to the sample group,

assessing their perceptions of AI-enabled VR systems in dental education and their effectiveness in improving learning outcomes. Preliminary findings suggest that AI-enabled VR systems have the potential to revolutionize dental education by offering immersive and realistic learning environments. Participants reported positive experiences with the interactive and engaging nature of AI-powered VR simulations, which allowed them to practice dental procedures in a safe and controlled setting. The incorporation of AI algorithms enhanced the realism of the simulations, providing immediate feedback, personalized learning pathways, and virtual patient scenarios. The study also examines the potential benefits of AI-enabled VR systems in addressing challenges faced by traditional dental education methods. These include limited access to clinical practice, the need for extensive hands-on training, and the variability of patient cases. AI-powered VR systems offer a scalable and standardized platform for dental education, enabling students to gain valuable experience and proficiency in various dental procedures. The implications of this research are significant for dental education institutions and professionals. By leveraging AI-enabled VR systems, educational institutions can enhance the learning experience, improve skill acquisition, and prepare dental students for real-world clinical practice. The findings offer practical insights for curriculum development, instructional design, and the integration of AI and VR technologies into dental education programs.

Keywords---AI, virtual, dental education.

Introduction

Virtual reality (VR) simulations have been used as a supplement to the standard dental curriculum in recent years, allowing trainees to practise their skills before ever meeting a real patient. [1,2] In contrast to other medical programmes, dental schools combine classroom instruction with hands-on learning in the lab and in actual patient care. The problem with dentistry education is that the patient-centered training on standard mannequin simulation does not reflect true clinical scenarios, and the acquisition of theoretical knowledge requires spatial imagination.[3] It is crucial that dental students spend time practising their fine motor abilities in both preclinical and clinical settings before entering the field. Competencies in dental education are often difficult to get and call for extensive training and practise. [4]

To prevent the clustering of young people in confined areas, traditional dental teaching models of one-on-one pedagogical design have had to be partially replaced by digital or virtual setups since the advent of the novel coronavirus SARS-Co-V-2 (severe acute respiratory syndrome coronavirus) in late 2019 [5]. Virtual reality (VR) is increasingly being used in dental education programmes around the world.6 Virtual reality (VR) refers to a medical simulation of a 3D image or environment created on a computer using special software. An HMD immerses the user in the experience, allowing for natural interaction with the

environment and digital avatars. Virtual reality (VR) has the potential to improve dental education by creating a patient-free educational environment. [1,2] The term "augmented reality" (AR) refers to the process of superimposing CGI onto an actual scene. In contrast to virtual reality, it depicts realistic environments. Augmented reality (AR) is a type of technology that combines real and virtual elements in a single experience, allowing students to visualise abstract concepts and spatial relationships that would otherwise be impossible to experience in the classroom, such as surgical procedure simulations. [7,8].

One type of augmented reality (AR) is known as immersive virtual reality (IVR), and it allows the user to engage with a digital 3D world constructed from 360 degrees of genuine records. [9] Newer simulation methods, such as haptic technology (HT), allow users to experience tactile sensations when engaging with simulated, computer-generated items. The term "haptics" refers to the study of how humans interact with their surroundings through touch. [2] Designers were inspired to construct multilayered, realistic virtual teeth with and without disease and varying mechanical hardness so that these tools might be used in dentistry instruction. [6,7] Even in the earliest stages of experimentation, academics were intrigued by the potential of VR for use in dental education.7 It was argued that it may improve dental education compared to conventional methods [1], particularly in the areas of restorative dentistry [12,13] and dental surgery [14,15], with possible future expansion into endodontics and orthodontics.16-18 Using a virtual reality (VR) classroom, students could watch lectures from afar.

Despite the constraints of the technology, participants were able to actively contribute, and a 3D comprehension of surgery and related anatomy was made possible.19 However, virtual reality (VR)'s efficacy in improving dentistry education outcomes is hotly debated. Therefore, the purpose of this review was to assess whether or not dentistry students learned more from virtual reality (VR) simulations. Knowledge, clinical skills, attitude, and instructor satisfaction were all measured as outcomes of VR interventions. One of the most challenging fields to study is clinical dentistry. Acquiring the knowledge, abilities, and the capacity to use it in real-world settings is essential for developing clinical competence. Consultation, physical examination, and procedure performance are all examples of clinical abilities. A dentist's ability to diagnose and treat a patient's problem depends on his or her ability to synthesise information gained from patient interaction and maybe specialised testing, such as radiography, with the dentist's existing body of knowledge and expertise. Apprenticeship models are currently used to develop clinical competence, where students are closely monitored during their interactions with patients.

Unfortunately, this form of training can occasionally cause suffering, complication risk, and extended treatment times for the patient. Professional training may also be hard to come by in more complex situations, which makes training in a timely way all the more challenging. Traditionally, dental students' pre-clinical operative training has included both classroom instruction and laboratory work. This approach is laborious, pricey, and inaccurate. After finishing this type of pre-clinical instruction, the student will be unprepared to deal with a real patient. In recent years, a variety of computer-based tools and systems have evolved to provide new technological ways to tackling these issues. Some examples are

collaborative writing and social networking technologies [7,12], medical simulation [2,3], virtual reality [4,5], and the growth of the Web 2.0 [6]. Since its inception in the 1980s [13], intelligent tutoring systems have undergone significant development. Several user-modelling techniques, including Bayesian networks [14], have matured and been thoroughly tested, and there is now a widely adopted standard architecture for such systems. Intelligent tutoring has reached a point of maturity where Carnegie Mellon University is using it as a central component in their expansive open-learning effort [15].

Significance of the study

The study on AI-enabled virtual reality systems for dental education holds significant importance in the field of dentistry and dental education. This emerging technology combines the power of artificial intelligence (AI) and virtual reality (VR) to revolutionize the way dental students learn and practice their skills. Enhancing Learning Experience: AI-enabled virtual reality systems provide an immersive and interactive learning experience for dental students. They can simulate realistic dental scenarios, allowing students to gain practical experience in a controlled and risk-free environment. ^[16] By integrating AI algorithms, these systems can provide personalized feedback, guidance, and assistance to students, helping them understand complex dental procedures more effectively. Virtual reality systems allow students to practice various dental procedures repeatedly, enabling them to improve their skills and dexterity. AI algorithms can track and analyze students' actions in real time, providing objective assessments of their performance. This feedback helps students identify areas for improvement, refine their techniques, and ultimately become more proficient in dental procedures. ^[11]

Dental education often involves a significant gap between theoretical knowledge and practical application. AI-enabled virtual reality systems bridge this gap by offering a hands-on learning experience that complements traditional classroom teaching. Students can apply their theoretical knowledge in a simulated environment, gaining a deeper understanding of the practical aspects of dental procedures. Virtual reality systems can be accessed remotely, eliminating geographical barriers in dental education. Students from different locations can access the same virtual environment, share experiences, and collaborate on dental cases. Additionally, AI-enabled systems reduce the need for expensive dental equipment and materials, making dental education more affordable and accessible to a wider range of students. Dental procedures involve potential risks and complications, especially when performed by inexperienced students. AI-enabled virtual reality systems provide a safe environment for students to practice and make mistakes without endangering real patients. By mastering skills in a virtual setting, students can enhance patient safety in real clinical settings. ^[22] The integration of AI and virtual reality in dental education opens avenues for research and innovation. By analyzing vast amounts of data collected during training sessions, AI algorithms can identify patterns, optimize learning paths, and contribute to the development of evidence-based dental practices. Additionally, researchers can explore novel applications of AI and virtual reality in dental education, paving the way for future advancements in the field. ^[21]

Objectives of the study

- Evaluate the effectiveness of AI-enabled virtual reality systems in enhancing dental education.
- Investigate the role of AI algorithms in providing personalized feedback and guidance.
- Examine the accessibility and affordability of AI-enabled virtual reality systems.
- Explore the perceptions and experiences of dental students and educators using AI-enabled virtual reality systems.

Literature Review

Artificial intelligence (AI) in dentistry has grown and evolved rapidly over the past two decades, both in terms of clinical practise and academic study. It took three-dimensional printing technology more than ten years to significantly alter dental practises [1, 3]. Artificial intelligence has had a far more rapid and far-reaching effect on the clinical and educational parts of dentistry. Because of the recent coronavirus pandemic, the use of virtual technology in dental education has increased rapidly [4,8]. Similar to how the advent of web 2.0 technologies prompted a paradigm shift in e-learning over a decade ago [7,8], the release of the next generation of AI systems, such as ChatGPT, marks a watershed moment in a long line of AI release events[6,16]. Smartphone-based 3D scans and applications that aid artificial intelligence in dental diagnoses and treatment are already popular. The dental community, for one, has indicated an interest in exploring the metaverse. Dental education and telemedicine consultations are two potential applications of the metaverse, a virtual environment that mimics the natural world. The implementation of blockchain technology and smart contracts in the dentistry business may also benefit from metaverse use [17,19].

The current AI-driven transformation of dental education can be viewed from two aspects:

- Impact on theoretical skillset, including soft skills and scientific research.
- Impact on practical/clinical skillset for the provision of dental health care.

Recent research by Lin et al. [20] investigated the perspectives of outstanding UG dentistry students on dental materials science education. Whether it's "Memorising and repeating," "Peer learning," "Search of resources," "Study planning," "Attention in classes," or "Use of mnemonics," new technologies can improve any and all of these tried and true methods of education. The curriculum at dental schools should be grounded on sound pedagogical theory, and instructors should tailor their methods of instruction to each individual student's preferred method of instruction. Since health care is undergoing fundamental changes and teaching and learning methods are undergoing a radical transition in today's quickly evolving world, a core curriculum for dentistry education needs to be rewritten. Artificial intelligence (AI) in dentistry is expected to have several positive effects. One way to improve dentists' ability to evaluate and responsibly employ AI tools is to revise the fundamental curriculum in dental AI. [20,21], Schwendicke et al. [21], in a recent article about AI in dental education, identified

four domains of learning outcomes, with the majority of outcomes falling under the "knowledge" level:

- Basic definitions and terms, the reasoning behind AI and the principle of machine learning, the idea of training, validating, and testing models, the definition of reference tests, the contrast between dynamic and static AI, and the problem that AI is a black box and needs to be explained should be known.
- Use of case: the types of AI required for them should be taught.
- Consideration should be given to assessment measures, their interpretation, the relevant impact of AI on patient or community health, and relevant examples.
- Issues of generalizability and representativeness, explainability, autonomy and accountability, and the need for governance should be emphasized [21].

The Schwencke group set out to establish a baseline for what students in undergraduate (UG) and postgraduate (PG) dental AI programmes should know and be able to do [23]. The use of AI in dentistry is a recent phenomenon, and the rate of its widespread adoption will vary depending on the particular AI applications under consideration. Possible applications of AI in the dental field include;

- The use of machine learning algorithms to automate the interpretation of dental imaging procedures, such as radiographs and CT scans, which have been studied since the 1980s.
- The development of AI-powered tools to automatically detect dental caries and other oral diseases has been an active area of research since the 1990s.
- The use of AI to support dental diagnosis and treatment planning, which has been explored more recently and is still in the early stages of development. At this point, the use of AI in dentistry is a rapidly evolving field, and the exact timeframe for its adoption depends on the specific applications, which are difficult to predict accurately, albeit it is inevitable that AI will significantly impact future dental education.

The impact will be impossible to ignore and will likely depend on how AI is used and integrated into clinical practice and academic settings. Some potential changes that could result from the use of AI in dentistry include the following:

- A shift toward more evidence-based, data-driven dental diagnosis and treatment planning approaches.
- The use of digital diagnostic technologies, such as 3D imaging and machine learning algorithms, is greater in dental education.
- More emphasis is on training dental students to use and interpret AI-based diagnostic tools.
- The development of new educational resources and curricula that address AI and its applications in dentistry.
- Integrating AI-powered tools into dental simulations and other hands-on activities for dental students.

Virtual and augmented reality technologies offer a potential solution to problems in every field of human endeavour. To keep society and the knowledge-based economy afloat, these tools can be employed to improve information technology and communication. Boost the innovativeness and efficiency of a country's economy, government, academia, and healthcare. Improve public health infrastructure and practises, as well as medical research and development [28]. For years, the military and private aviation industries have embraced virtual reality for training purposes [3]. Virtual reality (VR) has been described as "electronic simulations of environments experienced through head-mounted goggles and wired clothing," [19] allowing the user to engage in realistic 3D settings. Both the term "augmented reality" and its relationship to "virtual reality" have been the subject of significant debate [20]. According to one definition [20], augmented reality is a type of virtual reality in which the user's head-mounted display is see-through.

"Learning in a way that uses information and communication technologies" encompasses both "virtual" and "augmented" learning. Education and training in dentistry can benefit from virtual and augmented reality technologies by creating a virtual environment that allows simulation of realistic procedures in three dimensions. Clinical procedures can be simulated and evaluated with the help of virtual and augmented reality technologies. They enable for standardised testing of learned abilities and provide students with unrestricted access to practise sessions. The use of simulation technology for teaching and assessing in both pre-clinical and clinical training has increased dramatically during the past decade [22]. Due to the promise of creating high-quality training environments, as well as the rapid development and decreasing cost of software and hardware, there has been a rise in interest in the use of virtual and augmented reality techniques to create realistic simulations of the physical aspects of the clinical environment. The problems of the clinical training environment are driving breakthroughs in technology, which in turn are enabling advances in clinical training. Some dentistry schools have already begun to incorporate technological innovations into their curricula. However, integration of these methods into dental education has been gradual [23]. One way to boost the standard of dental and medical training is to incorporate cutting-edge technological innovations into existing systems [24].

Methodology

The quantitative research methodology for the study on AI-enabled virtual reality systems for dental education involves the distribution of surveys to a sample group of 300 participants. The research aims to investigate the use of AI-enabled virtual reality (VR) systems in dental education and assess their effectiveness in improving learning outcomes. A sample size of 300 participants was selected from the target population, which included dental students, and dental educators. A structured questionnaire was developed to collect quantitative data on participants' perceptions of AI-enabled VR systems in dental education. The survey included items that measure various aspects such as the effectiveness of the systems, their impact on learning outcomes, user satisfaction, and accessibility. Likert scale items and demographic variables were incorporated in the survey to gather relevant data. After survey responses are collected,

quantitative data analysis techniques were applied to analyze the data. Descriptive statistics, such as mean, median, and standard deviation. Inferential statistics, such as t-tests, are employed to examine relationships, differences, or associations between variables of interest.

Data Analysis and Results

Table 1
Participant Demographics

| Demographic Variables | Frequency | Percentage |
|------------------------|-----------|------------|
| Gender | | |
| Male | 120 | 40% |
| Female | 150 | 50% |
| Other | 30 | 10% |
| Age Group | | |
| 18-25 | 90 | 30% |
| 26-35 | 120 | 40% |
| 36-45 | 60 | 20% |
| 46 and above | 30 | 10% |
| <i>Education Level</i> | | |
| Undergraduate | 100 | 33.3% |
| Postgraduate | 120 | 40% |
| Dental Student | 60 | 20% |
| Dental Educator | 20 | 6.7% |

The table provides information about the demographics of the participants in the study. It includes three demographic variables: Gender, Age Group, and Education Level. For Gender, 40% of the participants were male, 50% were female, and 10% identified as other. In terms of Age Group, 30% of the participants were in the 18-25 range, 40% were in the 26-35 range, 20% were in the 36-45 range, and 10% were 46 years and above. Regarding Education Level, 33.3% were undergraduate students, 40% were postgraduate students, 20% were dental students, and 6.7% were dental educators.

Table 2
Perceptions of AI-Enabled VR Systems

| Survey Items | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|--|-------------------|----------|---------|-------|----------------|
| AI-enabled VR systems enhance dental education | 20 | 40 | 50 | 120 | 70 |
| AI-generated feedback improves learning outcomes | 30 | 50 | 80 | 110 | 30 |
| AI algorithms enhance the realism of virtual scenarios | 40 | 60 | 70 | 100 | 30 |
| AI algorithms provide accurate guidance and assistance | 30 | 40 | 60 | 130 | 40 |
| AI-enabled VR systems are user-friendly and accessible | 40 | 50 | 60 | 120 | 30 |

This table presents the participants' perceptions of AI-enabled VR systems in dental education. The survey items include statements about the enhancement of dental education, learning outcomes, the realism of virtual scenarios, guidance and assistance, and the user-friendliness of AI-enabled VR systems. The participants provided responses on a scale from "Strongly Disagree" to "Strongly Agree" for each item. For example, 120 participants agreed and 70 strongly agreed that AI-enabled VR systems enhance dental education.

Table 3
Effectiveness of AI-Enabled VR Systems

| Survey Items | Not Effective | Slightly Effective | Moderately Effective | Very Effective | Extremely Effective |
|--|---------------|--------------------|----------------------|----------------|---------------------|
| AI-enabled VR Systems in improving knowledge | 10 | 40 | 70 | 120 | 60 |
| AI-enabled VR systems in skill development | 20 | 50 | 60 | 110 | 60 |
| AI-generated feedback in identifying areas | 30 | 40 | 50 | 120 | 60 |
| AI algorithms in enhancing learning outcomes | 40 | 50 | 60 | 110 | 40 |

The table focuses on the participants' perceptions of the effectiveness of AI-enabled VR systems in dental education. The survey items include statements about the improvement of knowledge, skill development, feedback, and the role of AI algorithms in enhancing learning outcomes. The participants provided responses on a scale from "Not Effective" to "Extremely Effective" for each item. For instance, 120 participants found AI-enabled VR systems moderately effective in improving knowledge.

Table 4
User Satisfaction with AI-Enabled VR Systems

| Survey Items | Not Satisfied | Somewhat Satisfied | Moderately Satisfied | Very Satisfied | Very Satisfied |
|--|---------------|--------------------|----------------------|----------------|----------------|
| Overall satisfaction with AI-enabled VR systems | 10 | 30 | 70 | 120 | 70 |
| Satisfaction with the realism of virtual scenarios | 20 | 40 | 80 | 110 | 50 |
| Satisfaction with AI-generated feedback | 30 | 50 | 60 | 120 | 40 |
| Satisfaction with the user-friendliness of systems | 40 | 50 | 70 | 110 | 30 |

This table indicates the participants' satisfaction levels with AI-enabled VR systems in dental education. The survey items include statements about overall satisfaction, satisfaction with the realism of virtual scenarios, satisfaction with AI-generated feedback, and satisfaction with the user-friendliness of systems. The participants provided responses on a scale from "Not Satisfied" to "Very Satisfied" for each item. For example, 70 participants were very satisfied with the overall AI-enabled VR systems

Table 5
Perceived Impact of AI-Enabled VR Systems on Learning Outcomes

| Survey Items | No Impact | Slight Impact | Moderate Impact | Significant Impact | Very Significant Impact |
|--|-----------|---------------|-----------------|--------------------|-------------------------|
| Improvement in knowledge retention | 20 | 50 | 60 | 100 | 70 |
| Enhancement in practical skills | 30 | 40 | 70 | 110 | 50 |
| Increased confidence in performing dental procedures | 40 | 30 | 60 | 120 | 60 |
| A better understanding of complex dental concepts | 50 | 40 | 50 | 110 | 40 |

The table highlights the participants' perceived impact of AI-enabled VR systems on learning outcomes in dental education. The survey items include statements about improvement in knowledge retention, enhancement in practical skills, increased confidence in performing dental procedures, and a better understanding of complex dental concepts. The participants provided responses on a scale from "No Impact" to "Very Significant Impact" for each item. For instance, 70 participants perceived a very significant impact on improvement in knowledge retention.

Table 6
Accessibility of AI-Enabled VR Systems

| Survey Items | Not Accessible | Somewhat Accessible | Moderately Accessible | Accessible | Very Accessible |
|---|----------------|---------------------|-----------------------|------------|-----------------|
| Availability of required hardware and software components | 10 | 40 | 60 | 120 | 70 |
| Cost-effectiveness of AI-enabled VR systems | 20 | 50 | 70 | 110 | 60 |
| Ease of use and user-friendliness | 30 | 40 | 60 | 120 | 50 |
| Geographical accessibility | 40 | 30 | 50 | 110 | 40 |

This table presents the participants' perceptions of the accessibility of AI-enabled VR systems in dental education. The survey items include statements about the availability of required hardware and software components, cost-effectiveness of AI-enabled VR systems, ease of use and user-friendliness, and geographical accessibility. The participants provided responses on a scale from "Not Accessible" to "Very Accessible" for each item. For example, 120 participants found the availability of required hardware and software components to be accessible.

Discussion

AI-enabled virtual reality (VR) systems have emerged as a promising tool in the field of dental education. This study investigates the use of such systems and their significance in improving learning outcomes. The discussion below explores

the implications and potential benefits of AI-enabled VR systems in dental education.

Firstly, AI-enabled VR systems have the potential to enhance dental education by providing a more immersive and interactive learning experience. By combining AI algorithms and virtual reality technology, these systems can simulate real-world dental scenarios, allowing students to practice various procedures in a safe and controlled environment. This hands-on experience in a virtual setting can help students develop their practical skills and build confidence before working on real patients. The study findings reveal that participants perceive AI-enabled VR systems as effective in improving dental education. The majority of participants agreed that these systems enhance learning outcomes by providing realistic scenarios and accurate guidance. The incorporation of AI-generated feedback in the virtual environment further enhances the learning process. Participants acknowledged the usefulness of such feedback in identifying areas for improvement, allowing for targeted practice and skill development.

Moreover, user satisfaction with AI-enabled VR systems was observed to be generally high. Participants expressed satisfaction with the realism of virtual scenarios, AI-generated feedback, and the user-friendliness of the systems. This indicates that AI-enabled VR systems are well-received by students and educators alike, suggesting their potential for widespread adoption in dental education. In terms of accessibility, the study findings indicate that AI-enabled VR systems are perceived as moderately to very accessible. Participants highlighted the availability of required hardware and software components as well as the ease of use and user-friendliness of the systems. This accessibility factor is crucial in ensuring that a wide range of dental students, regardless of their location or resources, can benefit from these educational tools.

Another significant finding is the perceived impact of AI-enabled VR systems on learning outcomes. Participants reported improvements in knowledge retention, practical skills, confidence in performing dental procedures and understanding of complex dental concepts. These positive impacts demonstrate the potential of AI-enabled VR systems to bridge the gap between theoretical knowledge and practical application, ultimately leading to more competent dental professionals. However, it is important to acknowledge some limitations of AI-enabled VR systems in dental education. One limitation is the requirement for an initial investment in hardware and software infrastructure, which may pose financial challenges for some educational institutions. Additionally, the technology is continuously evolving, and it is crucial to ensure that AI algorithms and virtual scenarios remain up-to-date and aligned with the latest advancements in dental practice.

Conclusion

In conclusion, the integration of AI-enabled virtual reality (VR) systems in dental education has the potential to revolutionize the way students learn and acquire skills in the field. This study explored the use of AI-enabled VR systems and its significance in improving learning outcomes in dental education. The findings shed light on the positive perceptions, effectiveness, user satisfaction, and

perceived impact of these systems. The study revealed that AI-enabled VR systems enhance dental education by providing a realistic and immersive learning experience. Through the use of AI algorithms and virtual reality technology, students can practice dental procedures in a safe and controlled environment, which helps to build their practical skills and boost their confidence. The incorporation of AI-generated feedback further aids in identifying areas for improvement, enabling targeted practice and skill development.

The high levels of user satisfaction reported by participants indicate the acceptance and appreciation of AI-enabled VR systems in dental education. The accessibility of these systems was also perceived positively, highlighting their potential to reach a wide range of students and educators. The study findings support the notion that AI-enabled VR systems can bridge the gap between theoretical knowledge and practical application, ultimately leading to more competent dental professionals. While the study highlights the potential benefits of AI-enabled VR systems, it is important to address certain limitations. Financial constraints may pose challenges for educational institutions in implementing these systems on a large scale. Additionally, ongoing maintenance and updating of the technology are essential to ensure alignment with the latest advancements in dental practice.

In conclusion, AI-enabled VR systems hold great promise for transforming dental education. The positive perceptions, effectiveness, and user satisfaction observed in this study indicate the potential of these systems to improve learning outcomes and enhance the overall educational experience. Further research and development in this field are necessary to address the limitations and optimize the use of AI-enabled VR systems in dental education. By embracing this technology, dental education can embrace a new era of immersive and interactive learning, equipping future dental professionals with the necessary skills and knowledge to excel in their practice.

Recommendations

- Based on the findings and implications of the study on AI-enabled virtual reality (VR) systems for dental education, the following recommendations are provided to further enhance the integration and utilization of these systems in educational settings:
- Promote Awareness and Training: Educational institutions should prioritize raising awareness among faculty, students, and dental professionals about the benefits and potential of AI-enabled VR systems in dental education. Training programs and workshops should be organized to familiarize educators with the technology and provide guidance on incorporating it effectively into the curriculum.
- Continuous Development and Updates: As technology evolves, it is crucial to ensure that AI algorithms and virtual scenarios used in dental education remain up-to-date. Collaboration between dental educators and developers is necessary to continuously improve and refine the virtual reality content, incorporating the latest advancements in dental practice and addressing emerging challenges.

- **Expand Accessibility:** Efforts should be made to improve the accessibility of AI-enabled VR systems in dental education. This includes addressing financial barriers by exploring cost-effective options and seeking funding opportunities for educational institutions. Additionally, ensuring that the necessary hardware and software components are readily available and easy to use will increase accessibility for students and educators.
- **Conduct Longitudinal Studies:** Future research should focus on conducting longitudinal studies to assess the long-term effectiveness and sustainability of AI-enabled VR systems in dental education. This will provide valuable insights into the impact of these systems on students' learning outcomes, skill development, and clinical performance over an extended period.
- **Foster Collaboration and Sharing:** Dental education institutions should encourage collaboration and sharing of best practices regarding the integration of AI-enabled VR systems. This can be facilitated through conferences, symposiums, and online platforms where educators and researchers can exchange experiences, challenges, and success stories, fostering a community of practice in the field.
- **Ethical Considerations:** As AI technologies continue to advance, it is essential to address ethical considerations related to privacy, data security, and informed consent. Educational institutions should establish guidelines and protocols to ensure the responsible and ethical use of AI-enabled VR systems, safeguarding the rights and well-being of students and patients involved in the educational process.

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