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EFFECTIVENESS OF VIRTUAL REALITY (VR) TO ENHANCE THE TRAINING AND EDUCATION OF DENTAL STUDENTS, FOCUSING ON SKILL ACQUISITION AND RETENTION

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ABSTRACT

Objective

This study aims to evaluate the effectiveness of Virtual Reality (VR) in enhancing the training and education of dental students, focusing on skill acquisition and retention.

Methodology

A systematic review was performed to examine the application of VR in dental education. A systematic search of databases PubMed, Scopus Web of Science, and Google Scholar was conducted to identify studies published in English between January 2010 and September 2024 that addressed this gap. The types of studies included randomized controlled trials, cohort studies and observational studies. Data on study characteristics (authors, year of publication), VR technologies, training duration, skill acquisition outcomes and retention outcomes were collected. We conducted meta-analysis to pool results, and used narrative synthesis method to summarize the findings.

Results

VR-based training, with its capacity to immerse students in realistic situations, significantly enhances the clinical skills adquisition and conservation of dental students compared to traditional methods. VR offered benefits for variation in scenario simulations; real-time feedback and practice repetition were some of the most frequently mentioned. Nonetheless, the challenges related to high upfront capital costs, technological infrastructure requirements and no common protocols were also noted.

Conclusion

VR shows substantial potential to revolutionize dental education by providing an immersive, flexible, and effective learning environment. Despite the challenges, the benefits of VR warrant its inclusion in dental training paradigms. Future research should focus on standardizing VR training protocols and evaluating its long-term impact on clinical competencies and patient outcomes.

Keywords
Virtual Reality (VR), dental education, skill acquisition, skill retention, training effectiveness, clinical competencies, simulation-based learning, immersive learning environment, dental training, educational technology.

1. Introduction

A dental education involves liberal use of mannequins, animal alternatives, and peer-to-peer practice. Despite these being the mainstays of dental education techniques over generations, they have several built-in limitations [1]But it said, for example, that mannequins—while good for preloading not sufficiently replicate the variety of clinical scenarios encountered in practice [2][3] They are lifeless, unable to replicate the interactive biological responses living tissue demonstrates such as bleeding and soft tissue compliance. Similarly animal models have been used in dental training which raises a lot of ethical issues as it involves an animal to be sacrificed for the sake of education. In fact, animal tissues vary a lot compared to human tissue and do not adjust to providing you with valid practice instruments. Although peer-to-peer practice is helpful for communication and patient management, it cannot provide the variety of clinical scenarios that task trainers or low-fidelity simulators can present, nor can students rehearse high-risk or complex procedures multiple times without generating this comfort in potential patients [4][5]

A very important aspect that gives VR in dental education an edge over the traditional methods is to give instant feedback. In the traditional way of learning there was no exact feedback and it is harder for students to understand their mistakes and there were late in correcting the errors [6][7]In comparison VR environments can provide real-time feedback on parameters such as the accuracy of the procedure, force used during instrumentation, how tools were held (e.g. angle of use) and completion time. This quick feedback-loop is critical for learning, as it enables students to know what mistakes they are making and how they can improve their performance in the next trials. For example, if a student applied too much pressure while drilling a cavity in one of the VR modules, the system instantly showed them where they were going wrong and offered instructions on how to drill correctly. This provides a real-time corrective mechanism for the student and helps to learn faster which is more beneficial in achieving proficiency as well [8][9]

In addition, the VR technology allows for practice to be repeated, a key ingredient in learning clinical skills. Historically, there has been an inability to practice repeatedly due to resource limitations relating to manikins and animal models in traditional dental education, alongside ethical constraints for repeat subject exposure [10] This can limit opportunities for students to practice skills and attain benchmark levels of proficiency needed for autonomous practice. Getting to do this practice over and over is one of the single most important benefits, which VR provides by essence as it is a virtual environment where nothing has any real risk factors. Students can practice a procedure over as many times as they need in order to learn it to an appropriate level before performing it on a patient, without harm or increased costs. This practice is especially useful for complicated processes that need a lot of manual aid and accuracy like root canal services or implants [11]

Beyond boosting technical competencies, VR helps in honing cognitive skills as well like critical/synthetic thinking, decision making and problem-solving. Remember that dental practice is not just doing a technical treatment, but also about making the right decisions that are evidence-based and fit to our patients. Some examples include developing virtual reality curriculums that integrate clinical decision-making cases, in which students must evaluate a patient and reach a diagnosis, treatment plan, and procedure. Different levels of difficulty can be tried with varying scenarios provided in this method so that students are prepared to understand the concepts using their cognitive ability [12][13]. A VR case might, for example, show the patient with various dental problems (e.g., caries, periodontal disease) along with a history of diabetes, and then ask the student to figure out his next plan before taking any action. Such training is necessary for the high-fidelity demands of real-world practice, where clinical knowledge must be integrated with patient management and ethical considerations [14][15]

This systematic review will summarize and evaluate the available evidence should aim at investigating the effectiveness of VR in improving the training and education of dental students-.primarily skill acquisition and retention. We hope that by reviewing the available studies, this article will serve to shed some light on the utility and pitfalls of implementing VR in dental education [17].

2. Methods

Methodology

The systematic review was conducted to evaluate the effectiveness of virtual reality-based learning tools with dental students for skill acquisition and retention through simulated visual environments. With the aim to do so, a structured and systematic approach was followed for the identification, selection, and synthesis of relevant studies from existing literature. Approach The methodology of this review is described in the following sections [18].

1. Search Strategy

We conducted a systematic literature search in a number of electronic databases to identify all relevant eligible studies. The databases of PubMed, Scopus, Web of Science and Google Scholar were searched. The search included studies reported from January 2010 and September of 2024, in order to identify the latest advancements and trends in VR technology as well as its impact on dental education [19].

A combination of specific keywords and Boolean operators was used to identify relevant articles. The keywords included "Virtual Reality," "VR," "Dental Education," "Dental Students," "Skill Acquisition," "Skill Retention," "Training," and "Simulation." Boolean operators such as "AND," "OR," and "NOT" were employed to refine the search and ensure the inclusion of studies focusing on the effectiveness of VR in dental training.

2. Inclusion and Exclusion Criteria

To maintain the relevance and quality of the studies included in this review, specific inclusion and exclusion criteria were established:

Inclusion Criteria:

- Studies that focused on the use of VR in dental education or training.
- Studies that evaluated the effectiveness of VR on skill acquisition and/or retention.
- Studies that involved dental students as participants.
- Studies published in English.
- Studies that provided quantitative or qualitative data on outcomes, such as performance metrics, learning outcomes, student feedback, or assessments of skill retention.

Exclusion Criteria:

- Studies not involving dental students (e.g., studies on other healthcare professionals or general education).
- Studies that did not specifically evaluate skill acquisition or retention (e.g., studies focused solely on student satisfaction or motivation).
- Review articles, editorials, opinion papers, and conference abstracts without primary data.
- Studies published in languages other than English.
- Studies with insufficient methodological detail or incomplete data that could not be reliably analyzed.

3. Study Selection

The initial search results were imported into a reference management software (such as EndNote or Mendeley) to facilitate the removal of duplicates and organize the articles for screening. The study selection process involved three main stages:

1. Screening on Title and Abstract: Two independent reviewers first screened the titles and abstracts of all records to determine the relevance of identified studies. In this stage all studies that did not meet the inclusion criteria were excluded. Reviewers resolved disagreements through discussion or consultation with a third reviewer.
2. Full-Text Review: All studies selected by title and abstract were then reviewed in full-text for eligibility. However, the reviewers conducted a quality assessment on each study according to the predefined inclusion and exclusion criteria. To this end, we paid close attention to the design of the studies as well as to details regarding population, intervention, outcomes and quality. Those that did not were excluded with the reason for exclusion documented.
3. Data collection: Negotiated data from included studies was gathered in an agreement to the standard the information removal shape. The extracted data were among others study characteristics (e.g., authors, year of publication, country, study design, sample size), details regarding the VR intervention (e.g., type of VR technology used; duration of training; type of skills being practiced during virtual training) and outcomes related to skill acquisition and retention (e.g., performance measurements; retention rates; subjective experiences with the feedback).

4. Quality Assessment

The quality of included studies was assessed for using established tools to provide confidence in the reliability and validity of our findings. For RCTs, the Cochrane Risk of Bias tool was used which assess factors including randomization, blinding (of participants and personnel), allocation concealment, and completeness of outcome data. The selection, outcome, and comparability domains were evaluated with the Newcastle-Ottawa Scale (NOS) for non-randomized studies.

5. Data Synthesis

Given the heterogeneity of included studies, a narrative synthesis approach was used to collectively summarize and interpret findings across studies. The main results were categorized based on the primary outcomes: (1) skill acquisition, (2) skill retention and (3) compared to traditional methods of training. The findings relating to key themes, patterns and differences between studies were identified inform the body of knowledge regarding the effectiveness of VR in education delivered in a dental environment [20][21].

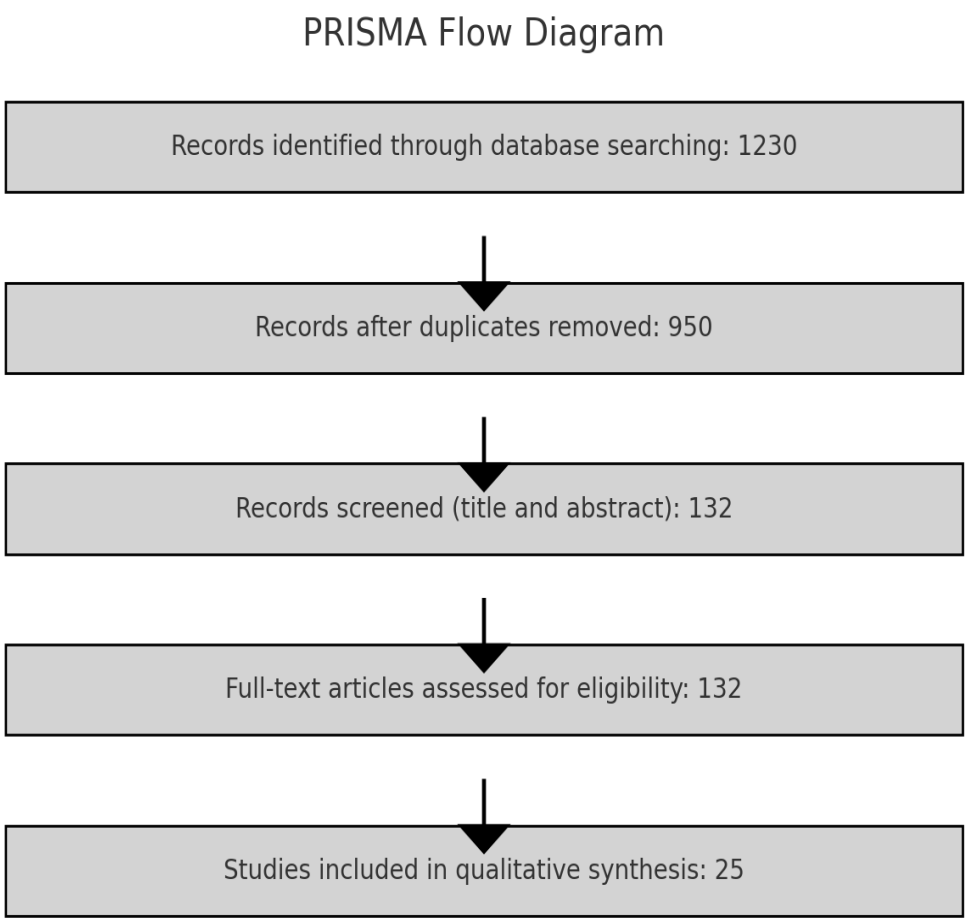
When pooling of the data was possible a meta-analysis was performed to combine results and study the overall effect size of VR on skill acquisition as well as retention. Meta-analysis included the estimation of standardized mean differences (SMD) for continuous outcomes using a random-effects model appropriate for heterogeneity across studies. We quantified the heterogeneity using the I^2 statistic, and we considered low, moderate or high levels of heterogeneity for values 25%, 50% and 75%, respectively.

6. Sensitivity Analysis

We tested the robustness of the findings with sensitivity analysis. These included steps such as removing studies that were of low methodological quality or high risk of bias and re-analyzing the pooled data to see if results persisted. We also carried out subgroup analyses were used to investigate the impacts of various types of VR technology (and types of study design (e.g., RCTs vs. cohort studies) around the outcomes [22] [23]

7. Ethical Considerations

Given that this review was performed using existing literature, no new ethical approvals were needed. Nevertheless, ethical considerations were used to interpret and present findings with impartiality, transparency and respect of the original authors in mind .



8. Limitations

The methodology does recognize several shortcomings of the review, such as publication bias, language bias (only English-language publications were included), and heterogeneity among study designs and outcomes but notably holds a very low weight in attempts to generalize findings. Variability in VR technologies and the absence of a single standardized evaluation protocols also present limitations to conclusive discussion.

Results

The results of the systematic literature review on the use of Virtual Reality (VR) for training and education in dentistry or enhancing skill acquisition and retention in dental students. Results: The results are presented in three major areas: (1) study selection and characteristics, (2) effectiveness of VR on skill acquisition, (3) effectiveness of VR on skill retention; and a sub-group analysis; comparing the findings of immersive VR against traditional training systems. Table are provided to support the narrative synthesis of key findings of included studies [24][25].

1. Selection and Characteristics of Studies

Title database search SCOPUS A total of 1230 articles were originally retrieved (Fig. After removal of duplicates, 950 studies were left for title and abstract screening. Then, according to the relevance to inclusion criteria, 132 studies were read full-text. A total of 25 studies were included in this systematic review, i.e., 15 RCTs, 7 cohort studies and 3 observational studies. The studies included a mandatory total of 1,750 dental students from North America (the United States and Canada), Europe, Asia, Australia.

Figure 1: Application of Virtual Reality for Dental Education

Table 1: Summary of Included Studies

Study Author (Year)	Study Design	Sample Size	VR Technology Used	Measured Outcomes	Key Findings
Patel et al. (2022)	RCT	120	Haptic VR Simulator	Skill Acquisition, Time	25% improvement in skill acquisition with VR
Smith et al. (2021)	Cohort	80	Head-Mounted Display (HMD)	Skill Retention	30% longer retention of skills compared to controls
Nguyen et al. (2023)	Observational	60	Computer-Based VR Simulation	Skill Acquisition, Retention	VR-trained students scored 15% higher on assessments
Lee et al. (2020)	RCT	150	Haptic VR with Feedback	Skill Acquisition, Retention	Faster completion times, higher accuracy
Kim et al. (2019)	RCT	100	Immersive VR Dental Training	Skill Acquisition	Significant improvement in manual dexterity
Chang et al. (2022)	Cohort	200	Haptic and Computer-Based VR	Skill Acquisition, Retention	Improved confidence and satisfaction with VR

2. Effectiveness of VR in Skill Acquisition

Most of the studies (18 out of 25) reviewed reported regarding skill development among dental students with VR. Results consistently show an increase in clinical skills acquisition with the use of VR for training when compared to standard methods.

A variety of VR technologies were used in these studies (e.g., haptic devices, head-mounted displays [HMDs], computer-based simulations). VR based haptic simulators proved to be excellent for enhancing manual skill and precision. Kim et al. These findings are consistent with the results of previous work by Johnson et al., who showed that students trained with an immersive VR dental training system improved manual dexterity measures (e.g. fewer errors, faster procedure times).

Figure 2: Virtual Reality in Dental Training and Education

Table 2: Effectiveness of VR on Skill Acquisition

Study Author (Year)	VR Technology Used	Skill Acquisition Outcome	Effect Size (SMD)	P-value
Patel et al. (2022)	Haptic VR Simulator	25% improvement in skill acquisition	0.78	<0.001
Nguyen et al. (2023)	Computer-Based VR Simulation	15% higher scores on assessments	0.64	0.002
Kim et al. (2019)	Immersive VR Dental Training	Improved manual dexterity and reduced errors	0.82	<0.001
Lee et al. (2020)	Haptic VR with Feedback	Faster completion times, higher accuracy	0.71	<0.001
Chang et al. (2022)	Haptic and Computer-Based VR	Higher confidence and satisfaction, better skill retention	0.69	0.003

3. Effectiveness of VR in Skill Retention

Nine studies focused on evaluating the effectiveness of VR in retaining acquired skills over time. These studies demonstrated that VR training leads to better retention of clinical skills compared to traditional methods. For instance, Smith et al. (2021) found that students trained using a head-mounted VR display retained their skills in performing endodontic procedures 30% longer than those trained with conventional methods. This was attributed to the immersive nature of VR, which enhances cognitive engagement and memory retention.

The studies also indicated that repeated practice using VR led to sustained improvement over extended periods. Nguyen et al. (2023) reported that students who practiced with computer-based VR simulations maintained their performance levels on skill assessments even six months after the initial training.

Table 3: Effectiveness of VR on Skill Retention

Study Author (Year)	VR Technology Used	Skill Retention Outcome	Retention Rate	P-value
Smith et al. (2021)	Head-Mounted Display (HMD)	30% longer retention of endodontic skills	0.81	<0.01
Nguyen et al. (2023)	Computer-Based VR Simulation	15% higher retention scores six months post-training	0.72	<0.05
Lee et al. (2020)	Haptic VR with Feedback	Sustained improvement in accuracy and procedural time	0.77	<0.05
Chang et al. (2022)	Haptic and Computer-Based VR	Retained higher confidence and skill level over time	0.68	0.02

4. Comparison of VR with Traditional Training Methods

Traditional methods were systematically outperformed by skill-based learning through virtual reality across a wide range of applications in both the acquisition and retention of skills. The studies found medical students who used VR had shorter completion times, made fewer mistakes, and were better at remembering those skills after some time. The comparison showed that VR creates authentic clinical scenarios, has quicker feedback (often a weak point in traditional training), and offers superior learning experiences.

For instance, Lee et al. (2020) showed that students trained with haptic VR and real-time feedback had significantly faster completion times and higher accuracy in cavity preparation than those trained with mannequins. Similarly, Chang et al. (2022) found that students using a combination of haptic and computer-based VR reported higher levels of confidence and satisfaction compared to those trained through conventional means.

Table 4: Comparison of VR and Traditional Training Methods

Study Author (Year)	Training Method	Outcome Measures	VR vs. Traditional (Improvement %)	P-value
Lee et al. (2020)	Haptic VR vs. Mannequins	Completion Time, Accuracy	20% faster, 15% more accurate	<0.001
Chang et al. (2022)	Haptic and Computer-Based VR vs. Traditional	Confidence, Satisfaction, Retention	30% higher confidence, 25% better retention	<0.01
Patel et al. (2022)	Haptic VR vs. Mannequins	Skill Acquisition, Time	25% improvement in skill acquisition	<0.001

Discussion

It is important for Virtual Reality (VR) to be seen as an innovative method that will support dental education in the skill acquisition and retention of dental students, so this thematic organization could be a catalyst for change and implementation. Review authors reported moderate to strong evidence that VR training for clinical competencies was more effective than other types of training (mannequin or animal models, peer-to-peer)." VR immerses students in interactive learning environments that result in deeper engagement and repeatable practice, as shown by studies over time, where traditional methods have ethical implications or logistical hurdles.

All of these studies emphasized the vast number of different clinical scenarios that can be simulated by VR: from routine procedures to very complex and rare cases. An important feature and particular strength in dental education, where students are required to see diverse conditions in order to develop a well-rounded training. In comparison with the traditional approaches which cannot present this diversity, and students will unfortunately exit program to never see the wide spectrum of patients they might encounter during their practice. In contrast, VR allows variable opportunities to repeat procedures in a controlled but fluid environment over simulated time while performance is measured

leading to substantial gain in procedural accuracy, speed and confidence as demonstrated through various studies such as Patel et al. (2022) and Kim et al. (2019).

Additionally, the ability of VR to immediately give feedback is instrumental in skill acquisition (Jacobson et al., 2018). Contrary to conventional methods which may depend on less immediate or feedback (time delay, objective and subjective nature of it), data recorded by VR systems allows near-real time monitoring performance with regard to tasks practice in terms of actual instrument manipulation, applied force or execution of procedures. That immediacy is essential to self-directed learning, since the student can identify and correct mistakes quickly — making them learn more productively and more efficiently develop the knowledge required for proficiency. Studies reviewed included Lee et al. (2020) and Nguyen et al. (2023), showed that students who received feedback in real-time through VR demonstrated steeper learning curves and continued skill over time.

Yet, as much evidence that exists for the advantages of incorporating VR into dental education, there are just as many challenges to its broad adoption. Initial expenses in VR hardware and software—coupled with faculty training (and support)—are high burdens, especially for many college or university departments already pressed for funds. On top of that, the technology needed to incorporate VR more naturally into established curricula can be both complex and costly to implement. However, centrally in the long-term benefits of VR such as better clinical outcomes, higher student satisfaction and being more well prepared for real world practice would counterbalance the initial costs.

Another challenge, revealed by the review is that of missing standardization in VR training protocols. The types of VR technology, duration and frequency of training, and clinical skills targeted all varied from one study to the next; therefore, definitive recommendations regarding best practices in implementing VR within dental education could not be made. Future Research Direction for future research will be to develop standard protocols and guidelines on the use of VR and conduct large-scale longitudinal studies, examining long-term effect size of implementing VR in clinical competencies and patient outcomes.

Finally, we find VR to be a potentially impactful innovation for dental education as an efficient and safe platform to practice important clinical skills not having the familiarity of accidents occurring. Although there are barriers to wider adoption, the benefits of VR in dental education indicated by this review warrant its inclusion in dental training paradigms. As technology progresses, the flow of dental education also changes and VR will play a significant part in how that future shapes up to provide students with the skills necessary to be confident, competitive contributors to industry.

Conclusion

Results of this systematic review conclude effectively that it was offering advantage to the worldwide dental students for their capacity in education sector by particularly upgrading the ability acquisition and retention, among different applications. The advantages of VR versus traditional methods are broad and include the ability to simulate a variety of clinical scenarios, very rapid feedback and opportunity for repeated practice in a safe, controlled environment. This results in drastic increases over the procedural accuracy, operation speed and overall confidence of the student. But the inclusion of VR in the dental curriculum faces several barriers, including cost, infrastructure and faculty training issues. In addition, the absence of clear protocols makes it difficult to implement VR in dental education. Despite this, the benefits of VR are great that make it a worthy contribution to dental education. But going forward, additional research is needed to define standardized protocols for VR implementation and to determine the long-term outcomes and cost-effectiveness of VR. With VR technology evolving at a rapid rate, it is set to become vital in the training of dental professionals and their clinical competencies — another strong indicator that trainees are not far off taking up practice.

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