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THE EFFECTIVENESS OF AUGMENTED REALITY IN DENTAL EDUCATION: A SYSTEMATIC REVIEW

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ABSTRACT

Augmented Reality (AR) is an innovative technology that overlays virtual objects onto the real world, allowing both to coexist within the same space. In dental education, AR has the potential to improve learning outcomes by providing immersive and interactive experiences. This review aims to identify the extent of AR utilization in dental education and explore its effects based on existing studies. A systematic review was conducted using PICO (Population, Intervention, Comparison, and Outcome) search strategy. Relevant studies published from 2016 until October 2024 were identified from the Web of Science (WoS), Ovid, Cumulated Index in Nursing and Allied Health Literature (CINAHL) and Scopus databases. Inclusion criteria were limited to English-language articles focused on AR in dental education. A total of 1,754 articles were found, and 13 articles were eligible for review based on inclusion and exclusion criteria. In dental education, AR studies were predominant in restorative dentistry (n=4 studies), as well as, local anaesthesia training (n=4 studies), followed by dental anatomy subject (n=3 studies, dental charting practice (n=1 study) and orthodontic technique dental education (n=1 study). AR has shown the greatest impact on skill proficiency enhancement in restorative dentistry, followed by local anaesthesia and dental anatomy. In conclusion, AR presents a promising tool to revolutionize dental education by providing engaging, cost-effective and efficient learning platform. While it is not a substitute for traditional methods, it can complement them and support skill development. Further research is needed to optimize AR's integration into dental curricula and evaluate its long-term impact on students' clinical competence.

Keywords: AR; augmented reality; curriculum; dental training; virtual reality

Abstrak

Realiti Terimbuh (RT) ialah teknologi inovatif yang membolehkan pertindihan objek maya ke

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atas dunia nyata, seterusnya membolehkan kedua-duanya wujud bersama dalam ruang yan g sama. Dalam pendidikan pergigian, RT berpotensi meningkatkan hasil pembelajaran melal ui pengalaman imersif dan interaktif. Ulasan ini bertujuan mengenal pasti sejauh mana peng gunaan RT dalam pendidikan pergigian serta meneroka kesannya berdasarkan kajian sedia ada. Suatu ulasan sistematik telah dijalankan menggunakan strategi carian *PICO (Populatio n, Intervention, Comparison, Outcome*). Kajian berkaitan yang diterbitkan dari tahun 2016 hin gga Oktober 2024 telah dikenal pasti daripada pangkalan data Web of Science (WoS), Ovid, Cumulated Index in Nursing and Allied Health Literature (CINAHL) dan Scopus. Pemilihan ar tikel dihadkan kepada artikel berbahasa Inggeris yang memfokuskan penggunaan RT dalam pendidikan pergigian. Sebanyak 1,754 artikel telah ditemui, dan 13 artikel telah dipilih berdas arkan kriteria-kriteria yang telah ditetapkan untuk ulasan ini. Dalam pendidikan pergigian, kaj ian RT paling banyak dijalankan dalam bidang pergigian restoratif (n=4 kajian) serta latihan a nestesia setempat (n=4 kajian), diikuti subjek anatomi pergigian (n=3 kajian), amalan mereko d status gigi di dalam carta pergigian (n=1 kajian) dan pendidikan teknik ortodontik (n=1 kajia n). RT menunjukkan impak terbesar dalam meningkatkan kecekapan kemahiran pergigian re storatif, diikuti anestesia setempat dan anatomi pergigian. Kesimpulannya, RT merupakan al at berpotensi untuk merevolusikan pendidikan pergigian dengan mengetengahkan kaedah p embelajaran yang menarik, kos efektif dan efisien. Ianya berperanan sebagai pelengkap ata u sokongan kepada kaedah tradisional bagi pembangunan kemahiran tertentu. Penyelidikan lanjut diperlukan untuk mengoptimumkan integrasi RT dalam kurikulum pergigian serta menil ai kesan jangka panjangnya terhadap kompetensi klinikal pelajar.

Kata kunci: AR; kurikulum; latihan pergigian; reality maya; realiti terimbuh

1.0 INTRODUCTION

Augmented Reality (AR) is a technology that superimposes virtual objects onto the real world, effectively blending virtual and physical realities. This integration enhances users' interactions with their surroundings by providing more immersive, informative, and interactive experiences. Contrasting to virtual reality (VR) technology that completely immerse a user inside a synthetic environment, where, the user cannot see the real world around him, an AR system is characterized by three principle features which include the combination of real and virtual content, ability for real-time interaction, and alignment of virtual elements with the real environment in three dimensions (Azuma 1997). In recent years, AR has seen significant growth in various sectors, particularly in education and healthcare. By enabling the visualization of complex concepts and fostering active student participation, AR helps bridge the gap between theoretical knowledge and practical application. One notable advantage of

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AR in educational settings is its capacity to create realistic simulations, allowing learners to practice real-world tasks within safe, controlled environments. Moreover, AR does not rely on head-mounted or haptic devices, as VR does, making it more accessible for use in various settings. As AR technology continues to advance, its applications are expanding, offering transformative possibilities for how learners access and interact with knowledge.

Dental education needs hands-on exercises based on the theoretical knowledge. A key challenge in dental training is fostering spatial imagination to master the practical skills and theoretical knowledge in dentistry. Traditional dental education combines theoretical instruction, textbook learning, and practical experience with real teeth, models, or simulations (Mahrous et al. 2021). Despite their effectiveness, these techniques have certain drawbacks, such as high material costs, moral dilemmas surrounding the use of cadavers, and limited opportunities for repeated practice. AR solves these issues by offering a creative and affordable way for students to see intricate anatomical structures with three-dimensional models and practice procedures in a virtual setting at any time (Dalanon 2023). Therefore, the utilization of AR may be an effective solution to improving the quality of dental education. Reviewing the existing studies systematically is essential to assess its effectiveness since AR is gradually playing a role in dental education.

Previous reviews have addressed the role of immersive technologies in dentistry, but their scope differs substantially from the focus of the current work. Farronato et al. (2019) discussed applications of AR in dentistry in a broad context, emphasizing its use for image visualization, accuracy enhancement, and support during surgical procedures. However, their review did not specifically evaluate the effectiveness of AR for educational purposes, particularly in relation to knowledge enhancement, skill acquisition, or student engagement. A systematic review by Joda et al. (2019) included nine studies within dental education, but only one pertained to AR technology; the remaining studies focused on VR applications. As a result, their findings primarily reflect the impact of VR rather than AR on dental teaching and learning. Given the increasing accessibility and practicality of AR systems in educational settings that often requiring less specialized hardware than VR, an updated and focused review on AR in dental education is warranted. Therefore, this systematic review aims to (1) identify the extent of AR utilization in dental education, (2) investigate its effectiveness in terms of knowledge enhancement, skill acquisition and student engagement in dental education, as well as, (3) provide insights into the strengths and limitations of AR as a teaching tool.

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2.0 MATERIALS AND METHODS

2.1 Search strategy

The systematic review was carried out on electronic databases, including Web of Science (WoS), Ovid, Cumulated Index in Nursing and Allied Health Literature (CINAHL) and Scopus. The date parameter of the paper collation was set from January 2016 to October 2024. The following terms and their combinations were searched: (augmented reality) OR (AR) AND (oral) OR (Dent*) AND (education) OR (training), to which “Boolean operators” were applied. The keywords were selected to gather and register as much relevant data as possible.

The search string used was (“augmented reality”) OR (“AR”) AND (“oral” OR “dent*”) AND (“education” OR “training”) AND (date: [1 January 2016 TO 31 October 2024]). The following focus question was developed, according to the population, intervention, comparison, and outcome (PICO) study design: “Does the use of AR (I) increase the effectiveness (O) of dental education (P) compared to traditional methods (C)?”

2.2 Eligibility Criteria

The full texts of all possibly relevant research papers were chosen, considering the following inclusion criteria:

- Original articles (randomised controlled trial, stratified sampling, convenience sampling) which are delivered in English language.
- Studies must be related with the utilization of AR and dental education
- The study population involves dental community members (dental students/ dental practitioners).

The exclusion criteria applied in this study included review articles, letter to editor, proceeding papers, technical and case reports. In addition, articles without the full text being available or articles that are not in English language were also excluded.

2.3 Study Selection and Data Extraction

All records identified from the databases were managed using the software EndNote 2.0, and any duplicate articles were removed prior to the screening process. These articles were screened in four stages to get sufficient information that was related to research objectives. The first stage of screening was performed to exclude the title of articles that did not match the inclusion criteria. Next, the second stage of screening excluded the abstracts of the

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remaining paper that did not meet the inclusion criteria. These two stages of screening process were performed by two dental students.

In the final stage of screening, there were two reviewers that are experts in the field of research interest who evaluated the full text papers using the Data Extraction Form (DEF). To minimize bias, the authors' names in each article were concealed prior to distributing the articles to the expert reviewers. Full articles that did not meet any inclusion criteria were removed in this stage. Next, both reviewers agreed that articles selected should be included in the review. However, when there were differences in opinion, it was resolved by discussion between the reviewers. Data extraction form was used as a primary tool to extract the essential contents of the article for systematic reviews. It contains all variables of interest for each study and other data needed to assess the quality of the study. The following variables were defined in this investigation: title of article, author, methodology, results, comment or conclusion.

3.0 RESULTS AND DISCUSSION

3.1 Search results

The initial search on scientific search engines yielded 1,754 results. Duplicate research and studies published were excluded, resulting in a total of 1391 studies. Out of these, 1,029 articles were excluded as they were reviews, meta-analyses, case reports and congress papers. After the initial selection, 21 studies underwent a full-text examination. Among these, 8 articles were discarded because six of the articles are not related to the utilization of AR, while the remaining two articles are about AR and its utilization for clinical management, not in dental training or dental education. Figure 1 shows the PRISMA flow chart that shows the selection process and the reasons for the excluded articles. In total, 13 studies were included in this review.

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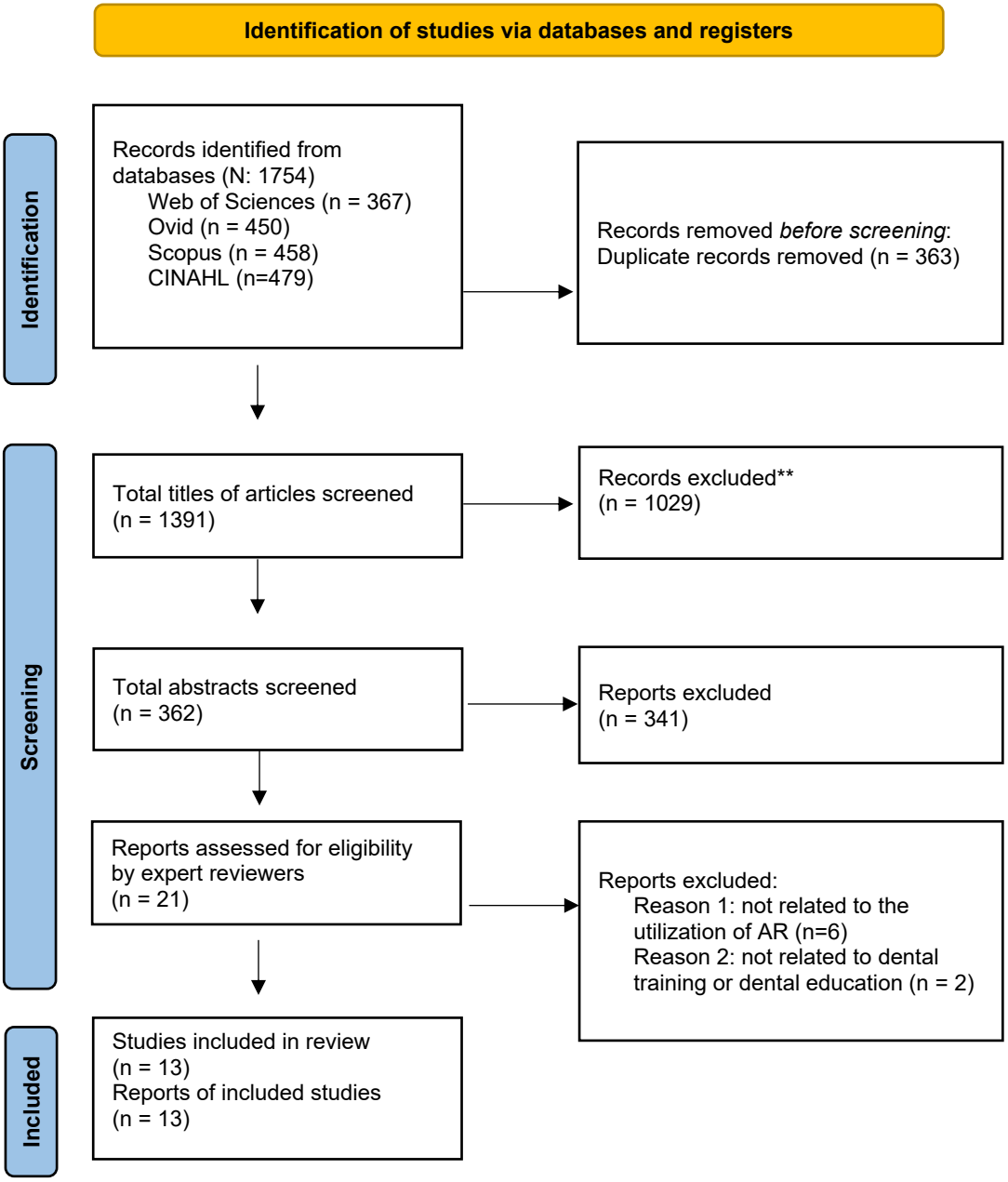

Figure 1: Study selection process according to the PRISMA guideline

3.2 Descriptive Analysis

Out of the 13 selected studies in this review, the utilization of AR technology in dental education was most profound in restorative dentistry (n=4 studies), and local anaesthesia training (n=4 studies), followed by dental anatomy (n=3 studies), dental charting practice (n=1 study) and orthodontic technique dental education (n=1 study). All of the studies were further analysed to investigate the effectiveness of AR in terms of knowledge enhancement, skill

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acquisition and student engagement in these five dental education categories namely restorative dentistry, local anaesthesia training, dental anatomy, dental charting practice, and orthodontics.

Figure 2 illustrates the number of studies that reported the effects of AR utilization in terms of knowledge enhancement, skill proficiency, and student engagement across five categories of dental education: restorative dentistry, local anaesthesia training, dental anatomy, dental charting, and orthodontic. The greatest increase in skill proficiency following utilization of AR was observed in restorative dentistry, with four studies reporting notable improvements. This was followed by local anaesthesia training, where three studies reported enhanced technical performance, and dental anatomy training, supported by two studies reporting similar improvements. In addition to skill development, the use of AR in restorative dentistry and local anaesthesia training also contributed to better knowledge acquisition, with three studies in each category reporting positive outcomes. Overall, the integration of AR consistently enhanced knowledge acquisition and student engagement, supporting its value as a beneficial tool in dental education. The specific effects of AR, along with its strengths and limitations in each of these dental educational categories are summarized in Table 1.

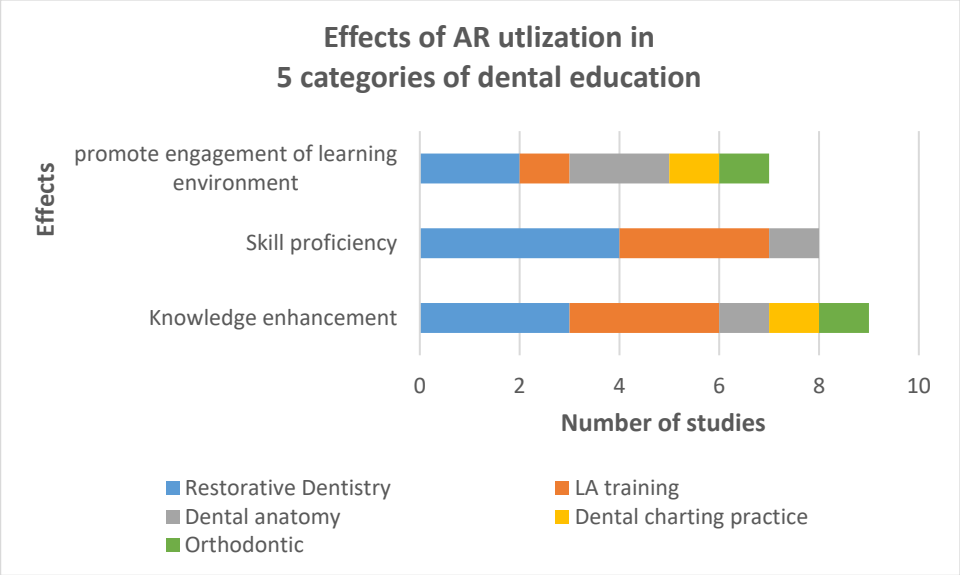

Figure 2: Total studies exhibit knowledge enhancement, skill proficiency and engaging learning environment with AR tools

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Table 1: *Summary data of the 13 selected studies*

Author and Year	Field of interest	Study design	Participants	Characteristics of AR and other methods (if present)	Key findings (Impact/ Strength / Limitation of the AR used in the study)
Dalanon (2023)	Restorative	Cross-sectional study	Preclinical dental students	• A cost-effective AR model was developed for students to learn line and point angles in restorative dentistry	• **Impact:** Learners consistently rated their experiences with AR tools as favourable for learning line and point angles, with a strong interest in continued use • **Strength:** AR is a valuable educational tool that facilitates the achievement of learning outcomes in restorative dentistry, while potentially reducing associated costs • **Limitation:** Some technical limitations of the AR technology had been issued related to the software flexibility and device compatibility
Mai et al. (2024)	Restorative	Cross-sectional study	61 fourth-year dental students and an educator with more than 10 years of experience in prosthodontic teaching and clinical practice	• An automated scoring and augmented reality visualization (ASAR) software program was compared with student self-assessment and expert assessment (conventional visual inspection methods) in the evaluation of tooth preparations	• **Impact**: Auto-assessment with ASAR showed comparable accuracy to expert assessment, significantly higher scores and faster evaluation times than student self-assessment, and consistent evaluation times across tooth types • **Strength:** This software program can serve as an effective self-directed learning aid for students by providing reliable and real-time evaluation of tooth preparation

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Llena et al. (2018)	Restorative	Quasi-experimental study compared the effectiveness of AR technology in learning operative dentistry	41 third-year dental students	• In addition to traditional resources (lectures, guide, audiovisuals, teacher instructions) used by the control group, the experimental group utilized AR cavity models on computers and mobile devices	• **Impact**: Students whom utilized the AR cavity models to learn cavity preparation (the experimental group) performed better in most of the assessed cavity preparation skills, with the significant improvements were seen in specific aspects of Class I and Class II cavity preparations
Lai et al. (2024)	Restorative	Feasibility study to evaluate the accuracy of dental restorations designed using AR dental training simulator	A prosthodontist and a dental technician	• Integrated AR simulator (SimEx Plus – EPCAD) is utilized for tooth preparation and digital restoration fabrication	• **Impact**: The integrated AR simulator demonstrated the ability to design dental restorations with internal gap accuracy suitable for clinical use, thereby enabling students to develop competencies in both tooth preparation and digital restoration fabrication
Mladenovic et al. (2019)	Local anaesthesia	Prospective study with a control and an experimental group	41 fourth- and fifth-year dental students	• The experimental group used the AR simulator for inferior alveolar nerve block training, in addition to theoretical instruction and exercises	• **Impact**: The experimental group performed the inferior alveolar nerve block (IANB) faster and higher anaesthesia success rate. They also scored higher on the post-clinical questionnaire reflecting better knowledge and skills acquisition • **Limitation:** The experimental group had AR as an additional learning method, but despite this, they still experienced the same increase in heart rate as the control group when performing IANB

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Mladenovic et al. (2020)	Local anaesthesia	Randomized control study	21 fourth- and fifth-year dental students	• The study group received conventional training supplemented with AR simulation sessions	• **Impact**: Students using the AR technique performed local anaesthesia (LA) significantly faster compared to the control group • **Limitation:** The utilization of AR did not reduce acute stress levels during the procedure
Mladenovic et al. (2021)	Local anaesthesia	Prospective study to evaluate students' perception of AR as method of distance learning for LA training	Final year students who had no clinical experience administrating local anaesthesia	• Students use their mobile phones/tablets to practice local anaesthesia techniques in an AR environment	• **Impact and strength**: The AR used for LA training is a valuable distance learning tool, effectively capturing students' interest and enabling self-paced learning at any location
Mladenovic et al. (2022a)	Local anaesthesia	Correlational study to determine students' perceptions of the mobile simulator application	19 fourth-year dental students	• A mobile simulator application consisting of simulation videos, 3D atlas and AR mode for local anaesthesia practice	• **Impact**: This learning device has the potential to significantly improve participants' knowledge and skills in performing local anaesthesia, which are essential for a wide range of dental procedures
Kim-Berman et al. (2019)	Dental anatomy	An experimental study to evaluate the validity of an AR virtual tooth identification test	109 first-year dental students	An AR-based virtual tooth identification test was developed, and students used their smartphones to access the AR application,	• **Limitation**: Students preferred real teeth for tooth identification test due to several issues with the AR when performing the tooth identification test such as issues with

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				identify virtual tooth models, and record their answers	viewing, handling, time limits, and technical problems with the AR
Mahrous et al. (2021)	Dental anatomy	Cross-sectional study	80 first year dental students	Students learned the anatomy of first mandibular molar using four methods (extracted teeth, standard 3D anatomical models, 3D printed tooth replicas, AR-viewed virtual 3D teeth overlaid in real space)	• **Impact**: Although students perceived natural extracted teeth offering the greatest educational value, and 3D printed models were the most user-friendly, the AR-viewed virtual 3D teeth were considered the most engaging in learning tooth anatomy
Alsalleeh et al. (2024)	Dental anatomy	A comparative experimental study design to assess the effectiveness of AR in teaching root canal anatomy.	43 third-year dental students	• Two modalities for learning root canal systems were compared: CBCT image analysis of root canal anatomy, and AR-based tooth model exploration • The AR-based tooth model exploration allows students to visualize and manipulate the anatomy in real time	• **Impacts**: In the tests which assess students' understanding of root canal anatomy, the AR group showed significantly better performance The AR group completed tasks faster and with greater accuracy, indicating improved learning efficiency Students in the AR group reported higher engagement and satisfaction with the learning process
Mladenovic et al. (2022b)	Dental charting practice	Pilot study	13 dental students	• Students use the Immersify Dental mobile application, which allows users to perform virtual dental charting using a simulated dental mirror	• **Impact**: All the students confirmed that the application effectively facilitated their understanding of how to complete a dental chart

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					• **Strength**: Most users agreed that the application was easy to use and free from technical challenges, enabling students to practice the dental charting procedural task, in a realistic and user-friendly environment. The immersive and interactive design of the AR-based tool helped bridge the gap between theoretical knowledge and hands-on practice, highlighting AR's strength as a dental charting training tool
Gredes et al. (2022)	Orthodontic	Cross-sectional study	Dental students enrolled in their first orthodontic technical course	• Students utilized the "AR-Demonstrator-App," which provided step-by-step visual instructions for manufacturing a removable orthodontic device	• **Impact**: Most students found the app was helpful and engaging for learning complex procedures • **Limitation**: Ongoing scepticism persists among students regarding the replacement of plaster models with the AR-Demonstrator-App for demonstration, although the proportion disagreeing with such replacement declined from 69% in 2017 to 30% in 2020

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3.3 The research trends in AR within Dental Education

The trends in AR within dental education show a growing focus on strengthening foundational learning while improving accessibility for students. Many studies emphasise the use of AR to teach essential dental skills and anatomical knowledge, including root canal morphology, tooth identification, restorative concepts such as line and point angles, tooth preparation, and local anaesthesia techniques. Recent research demonstrates a clear movement towards more immersive and interactive learning environments, where AR is used to create three-dimensional visualisations and dynamic simulations that enhance student understanding (Alsalleeh et al. 2024, Mahrous et al. 2021, Mladenovic et al. 2022a, Gredes et al. 2022, Kim-Berman et al. 2019, Dalanon et al. 2023; Llena et al. 2018, Mai et al. 2024). Several studies highlight the use of AR applications on mobile devices such as smartphones and tablets for accessibility and flexibility in learning, allowing students to practice and study in various environments, including at home. Apart from teaching tool, AR is also being explored for assessment, with several studies developing automated scoring systems and visualisation tools for assessment of tooth preparation and tooth identification test (Kim-Berman et al. 2019, Mai et al. 2024). Recent work also highlights an interest in creating cost-effective AR models through the use of free software (Dalanon et al. 2023), which can help make AR-based education more accessible to institutions with limited resources.

3.4 Discussion

The findings of this systematic review highlight the growing integration of AR in dental education. From an initial pool of 1,754 articles, only 13 met the inclusion and exclusion criteria, indicating that while AR in dental education is a developing field, the study of its utilization in various aspects of dental education remains limited. However, the studies that were included demonstrate a promising trend in the application of AR technologies to enhance both theoretical and clinical components of dental training.

In dental education, the predominant use of AR is not only in the teaching of restorative dentistry, but also in the local anaesthesia training as evidenced by four studies in each of the subjects. Restorative dentistry provides students with the clinical foundation to restore oral health and serves as the basis for specialties such as prosthodontics, endodontics, and periodontology, which may draw attention to the use of AR tools in this field. Meanwhile, the emphasis in the utilization of AR in local anaesthesia training is likely attributable to the importance of the procedure in many clinical situations and the risks associated with nerve block administration. Complications such as nerve injury and hematoma formation can arise

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from inaccurate technique or inadequate anatomical knowledge. By enabling interactive, three-dimensional visualization of anatomical structures and simulating injection pathways in real time, AR provides a safer and more effective platform for trainees to practice and refine their skills, thereby reducing the likelihood of such adverse outcomes in clinical practice.

Vast majority of studies expressed the belief that AR should be incorporated into dental education (Dalanon 2023, Alsalleeh et al. 2024, Mladenovic et al. 2022a), highlighting strong support for the integration of immersive technologies into advanced dental training programs. It has been shown to improve technical skills such as tooth preparation precision and syringe manipulation for local anaesthetic procedures. AR models, such as mobile simulators and 3D printed models, are perceived as user-friendly, engaging, and effective in improving both knowledge and practical skills.

Students have reported positive attitudes towards AR tools, appreciating their ability to visualize complex dental anatomy, simulate procedures step-by-step, and engage with interactive educational content. AR also serves as a valuable supplementary tool during times when traditional methods, such as clinical training or in-person teaching are limited for example, during the COVID-19 pandemic. Additionally, AR platforms developed with free software offer a cost-effective and expandable option for broader educational access. Systems like auto-assessment tools and AR simulators have demonstrated consistent, reliable evaluation results, saving time and providing objective feedback compared to traditional assessment methods (Lai et al. 2024, Mai et al. 2024). Hence, it can serve as a reliable and effective aid, facilitating both self-assessment by learners and assessment by educators for evaluation of an operative procedure such cavity preparation of a tooth.

Despite the perceived benefits of AR, a study found that students favoured real teeth for tooth identification tests, highlighting the limitations of AR, including difficulties with viewing and handling particularly under restrictive time constraints (Kim-Berman et al. 2019). A similar trend was found in orthodontic subject, where in 2017 the majority of students (69%) disagreed with replacing the traditional demonstration method with the AR-Demonstrator-App for constructing a removable appliance in their first orthodontic technical course (Gredes et al. 2022). Although the percentage of disagreement has decreased to 30% by 2020, the doubt for complete replacement of traditional teaching method in the first orthodontic technical course still persist. Hence, AR is still viewed as a complementary rather than a complete replacement of the traditional teaching methods.

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In addition, technical challenges, such as device compatibility, Internet dependency, and software glitches, can impact usability and accessibility of AR in dental education. Moreover, although AR enhances procedural practice, it does not fully replicate the tactile feedback and complexity of real clinical experiences (Mladenovic et al. 2019). Studies also indicate that AR may not significantly reduce stress during real procedures, and its effects on emotional readiness remain uncertain (Gredes et al. 2022). Therefore, while AR can support learning, it is unlikely to fully replace traditional methods, instead best serving as an adjunct to hands-on practice and conventional teaching frameworks. Additionally, successful integration of AR in the subject curriculum requires clear alignment with educational objectives to avoid AR becoming a novelty rather than a genuinely effective tool. Without proper instructional design, AR tools might fail to maintain student attention in the competitive digital environment.

Future research should focus on improving student acceptance by developing AR tools that more closely simulate real clinical experiences, including enhanced tactile feedback and more intuitive object manipulation. Longitudinal studies are needed to explore how student perceptions evolve as technology advances and as AR becomes more familiar in routine training. Technical refinement is essential, particularly the development of more stable, platform-independent systems that function reliably without heavy internet dependency. Another important direction involves investigating the emotional and cognitive impacts of AR, particularly its role in reducing procedural anxiety and improving learner confidence in clinical settings. To prevent AR from being used superficially, future work should emphasise evidence-based instructional design, ensuring that AR applications are explicitly linked to learning objectives and assessment requirements. Collaboration between educators, software developers, and curriculum planners will be crucial for creating AR platforms that are pedagogically robust, scalable, and adaptable across different dental disciplines.

3.5 Limitations of the present systematic review

One key limitation identified in this systematic review was the considerable variation in study design, sample size, intervention (AR) types and outcome measures across the included studies. This level of heterogeneity made meaningful comparison challenging and restricted the ability to combine data. The review was also constrained by language and database restrictions, as only studies published in English and those indexed in selected databases were considered. This may have resulted in the exclusion of relevant research and reduced the overall comprehensiveness of the search. Another limitation relates to the rapid pace of

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technological development in fields such as digital dentistry and augmented reality. Because these technologies evolve quickly, earlier studies may no longer reflect current capabilities, which affects the relevance of some evidence. Additionally, many of the included studies reported only short-term outcomes, with limited data available on long-term performance and sustainability. The absence of extended follow-up restricts understanding of the lasting effectiveness of the interventions evaluated.

4.0 CONCLUSION

Despite the growing interest in digital technology integration in dental education, the identification of only 13 studies over nearly nine years suggests that research on augmented reality in this field remains limited, particularly in less explored areas such as dental charting and orthodontics. In dental training, AR enhances skill proficiency with the greatest impact in restorative dentistry, followed by local anaesthesia and dental anatomy. Several studies across these three areas also demonstrate improved knowledge acquisition. Overall, AR implementation in dental education consistently supports positive learning outcomes and increased student engagement.

AR shows promise in dental education by enhancing students' knowledge and practical skills through engaging, cost-effective, and efficient learning and assessment methods. However, several challenges persist with its utilization in dental education, such as, its limitation to completely replicate tactile feedback and the uncertainty of its effect on emotional readiness to perform clinical procedure on a real patient. These limitations highlight that AR should serve as an adjunct rather than a replacement for traditional teaching in dental education. Nevertheless, future efforts focussing on refining AR technologies and addressing their technical barriers will be useful to optimize their integration into dental curricula.

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