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SYSTEMATIC REVIEW

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Contemporary educational methods in periodontology

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Abstract

Aim: The 1st European Workshop on Periodontal Education in 2009 made recommendations regarding the scope of periodontal education at undergraduate (UG), postgraduate (PG) and continuing professional development (CPD) levels, defining competencies and learning outcomes that were instrumental at the time in helping to define periodontal teaching curricula. The 19th European Workshop on Periodontology and 2nd European Consensus Workshop on Education in Periodontology (*Education in Periodontology in Europe*) was held in 2023 to identify changes and future developments in periodontal education (including those informed by the COVID-19 pandemic) and embracing methods and formats of periodontal teaching and training. The aim of this review was to assess current knowledge regarding education methods in periodontology, including traditional face-to-face (F2F) teaching and the move to student-centred methods, virtual learning methods and use of digital technology, as well as blended teaching and learning (including teaching delivery and assessment) at UG, PG and CPD levels.

Materials and Methods: Systematic searches were conducted to identify relevant studies from the literature. Data were extracted and descriptive summaries collated.

Results: The pandemic was a major disruptor of traditional F2F teaching but provided opportunities for rapid implementation of alternative and supplementary teaching methods. Although online learning has become an integral part of periodontal education, teachers and learners alike favour some form of F2F teaching. Blended teaching and learning are feasible in many areas of periodontal education, both for knowledge and skills acquisition as well as in assessment. Student-centred methods and blended approaches such as the flipped classroom seem highly effective, and online/virtual classrooms with both synchronous and asynchronous lectures are highly valued. Learning with haptic methods and virtual reality (VR) enhances the educational experience, especially when VR is integrated with traditional methods. The quality of the teacher continues to be decisive for the best knowledge transfer in all its forms.

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Conclusions: Live F2F teaching continues to be highly trusted; however, all types of student-centred and interactive forms of knowledge transfer are embraced as enhancements. While digital methods offer innovation in education, blended approaches integrating both virtual and traditional methods appear optimal to maximize the achievement of learning outcomes. All areas of periodontal education (UG, PG and CPD) can benefit from such approaches; however, more research is needed to evaluate their benefits, both for knowledge transfer and skills development, as well as in assessment.

KEYWORDS
continuing professional development, dental education, periodontology, postgraduate education, teaching and learning

Clinical Relevance

Scientific rationale for study: Adaptations and adjuncts to traditional face-to-face (F2F) teaching, such as virtual and blended methods, are increasingly used in dental education. This review explored current and future developments in teaching and learning methods for periodontal education.

Principal findings: Traditional F2F teaching continues to be a trusted form of education but can be enhanced by virtual and blended methods. Student-centred, virtual and blended approaches are highly effective, and online/virtual teaching is appreciated by both learners and teachers. The quality of the lecturer continues to be a major factor.

Practical implications: Educators should continue to develop educational innovations in periodontology that incorporate adjunctive, virtual and blended approaches for both knowledge and skills teaching as well as assessment.

1 | INTRODUCTION

In 2009, the European Federation of Periodontology (EFP), in collaboration with representatives from the Association for Dental Education in Europe (ADEE), held the first European Workshop on Periodontal Education, with the outputs published in the *Journal of Dental Education* in 2010. This workshop represented a landmark event in periodontal education, which reviewed the current status of and trends in periodontology, made recommendations regarding the scope of periodontal education at undergraduate (UG), postgraduate (PG) and continuing professional development (CPD) levels and defined competencies and learning outcomes in teaching and assessment (Sanz & Chapple, 2010). Since then, the competencies have been instrumental in helping to define periodontal teaching curricula at dental schools across Europe and beyond. Given the changes that have occurred since 2009, the EFP held the 19th European Workshop on Periodontology and 2nd European Consensus Workshop on Education in Periodontology (*Education in Periodontology in Europe*) in 2023, with the general objective to update and expand the conclusions of the first workshop. As before, this was undertaken in collaboration with representatives from ADEE, and included four working groups that addressed topics relating to (i) UG periodontal education, (ii) PG periodontal education, (iii) CPD and (iv) education methods. This paper represents the findings from the 4th working group that focused on education methods.

Periodontal education draws on an extensive body of scientific evidence, including pre-clinical and clinical research, to ensure that dental professionals are well equipped to manage patients with periodontal diseases. However, this approach brings its own challenges. The complexity of pre-clinical and clinical training requires a comprehensive understanding of periodontal biology and pathology, a high level of hands-on experience and the ability to translate these skills into patient-centred care. Furthermore, the rapidly evolving landscape of dentistry, characterized by technological advances and changing patient demographics and expectations, requires a dental curriculum that is both dynamic and responsive. At its core, however, periodontal education requires a holistic approach to patient care, recognizing that periodontal health is not only central to oral health but also intrinsically linked to systemic health and overall wellbeing.

It is timely to revisit the guidance published in 2010, particularly in the context of recovery from the SARS-CoV-2 (COVID-19) pandemic as well as the great number of technological advances that have occurred over the last decade, including those driven by the pandemic. Whereas traditional in-person learning (face-to-face, F2F) has long been considered the cornerstone for knowledge transfer (Figure 1) and is highly trusted by both educators and students, the potentially limited student attention span during passive F2F teaching and limited learner retention rate may possibly limit development of critical thinking skills (Chandrasekharan Nair et al., 2022; Jeffries, 2014; Nickson & Cadogan, 2014). On the other hand, student attention spans and retention rates may also be associated with teaching quality (Bradbury, 2016).

Dental educators have long been active in developing online teaching and learning resources, pre-dating the pandemic by many

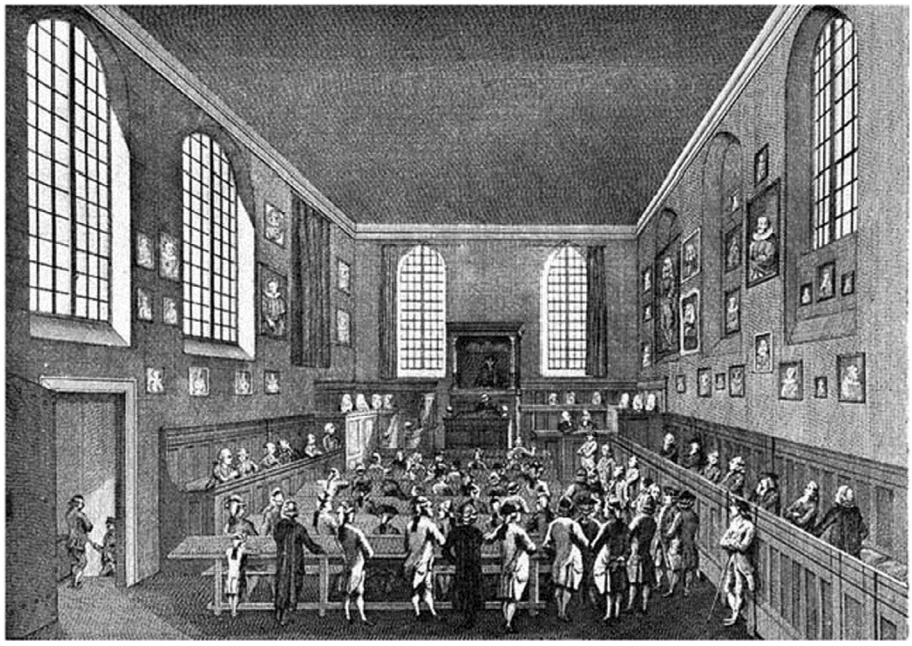

FIGURE 1 Illustration to depict face-to-face (F2F) lectures at the newly built University of Amsterdam (1632). In January 1632, the first F2F lectures were presented at the newly built University of Amsterdam (initially called *Athenaeum Illustre*). The inaugural lectures were delivered by the newly appointed professors Gerardus Vossius and Caspar Barlaeus. The first lecture by Prof. Vossius was on the topic "On the usefulness of history." *Source*: https://www.amsterdamsebinnenstad.nl/binnenstad/192/agnietenkapel2.html; https://en.wikipedia.org/wiki/Athenaeum_Illustre_of_Amsterdam.

years. Blended teaching methods utilizing electronic forms of teaching in addition to traditional F2F teaching have become increasingly relevant in education in general, and also in dentistry and periodontology (Walinski et al., 2023). Furthermore, the integration of artificial intelligence (AI) into dentistry has opened up a new era of precision care, efficiency and innovation. AI algorithms are now being used to assist in diagnosis, treatment planning and even prediction of treatment outcomes in various areas of dentistry, from operative dentistry to periodontology (Noor, 2023). One of the most promising future areas of AI and dentistry is in education, and AI-powered virtual reality (VR) systems are being explored for their potential to transform dental education. These systems use AI algorithms to simulate realistic dental procedures, offer interactive training modules and provide immediate feedback, creating immersive and realistic learning environments. In a recent survey, dental students reported positive experiences and expectations with such AI-based VR simulations, highlighting their interactive nature and the ability to practise procedures in a controlled environment (Adnan et al., 2023).

Blended and virtual methods present the opportunity to combine the advantages of online and F2F teaching while overcoming some of the disadvantages of focusing solely on either conventional or electronic methods. Reported concerns among educators regarding purely online teaching relate to the quality of the experience (for both faculty and students), the degree of student engagement, challenges of providing skills teaching remotely, social isolation, lack of interaction, impacts on mental health and wellbeing as well as lack of peer-to-peer learning (Antoniadou et al., 2022). Furthermore, advantages and disadvantages of using blended methods may vary between UG, PG, and CPD courses. Definitions of various terms relevant to this manuscript are presented in Table 1.

The COVID-19 pandemic has perhaps been greater than any other force in driving the development and introduction of online, blended and virtual teaching methods, as well as more student-centred approaches and teaching delivery, tailored to individual learning styles, preferences and pace. Electronic resources are now employed more widely than ever before, creating potential for greater efficiencies in delivery of teaching between different but complementary subject areas. As the field continues to evolve, the fusion of AI with virtual education tools promises to redefine the contours of the dental education landscape, making it more adaptable, personalized and potentially more effective.

Therefore, the overall aim of this working group was to focus on current knowledge on education methods in periodontology, including traditional F2F methods, the move to student-centred approaches, virtual teaching methods and blended teaching and learning in periodontal education.

2 | A SCOPING REVIEW EVALUATING TRADITIONAL FACE-TO-FACE TEACHING METHODS AND THE MOVE TO STUDENT-CENTRED METHODS IN PERIODONTOLOGY

2.1 | Aim of review

The COVID-19 pandemic was a sudden all-encompassing disruptive moment, where all F2F was abandoned globally because of social distancing requirements (Di Carvalho Melo et al., 2023). This could be regarded as a natural experiment forcing academic institutions to immediately re-evaluate traditional F2F teaching and investigate alternative methods. The objective of this scoping review was to identify current attitudes and adjuncts to traditional lecturing methods (F2F) in undergraduate education, postgraduate education leading to specialization and CPD (also known as continuing education [CE]) in dentistry. Specifically, the field of periodontology was included. We considered reports from 2017 up to June 2023, covering a period of 3 years before and after the COVID-19 outbreak.

TABLE 1 Definitions of key terms as used in this paper.

Term	Definition
Asynchronous teaching[a]	Activities that engage a cohort of learners separately and/or at different times to one another (most online teaching is asynchronous, for example, students watch a pre-recorded lecture at some time after the teacher has recorded it).
Blended teaching and learning[a]	A combination of remote and F2F, synchronous and asynchronous teaching methods to facilitate learning.
Continuing professional development[a]	Engagement in activities that update and broaden knowledge, skills and experience, throughout an oral health professional's career (also known as Continuing Education).
Flipped learning[a]	An approach where students acquire knowledge before a synchronous teaching event, and use formal teaching time to discuss, evaluate and apply concepts through interaction with each other and a teacher (the flipped classroom can be a type of blended learning in which learners access educational resources (such as online materials/videos/audio files, etc.) prior to attending class, and then during a F2F classroom session actively participate in learning under the guidance of the teacher).
Online teaching and learning	Teaching and learning that is delivered electronically, for example, via phone apps, PC-based activities, the internet and various multimedia applications. Teaching can be delivered synchronously or asynchronously.
Postgraduate education leading to specialization	Education conducted to achieve academic or professional degrees, certificates, diplomas or other qualifications by students who have already obtained an undergraduate dental degree. In the context of dentistry, specialization indicates postgraduate education (including accredited training programmes) that allows students who successfully complete the training to be registered as specialists in their chosen specialty.
Synchronous teaching[a]	Activities that engage a cohort of learners together, at the same time (i.e., a live teaching event) (this can include F2F classes or live online classes).
Traditional teaching and learning	F2F teaching and learning that takes place in a classroom context or clinical environment.
Undergraduate education	Education conducted to enable students to achieve their first professional degree.

[a]Definition taken from ADEE glossary of terms (Davies et al., 2023).
Abbreviation: F2F, face-to-face.

2.2 | Methods

Medical subject headings (MeSH) terms and keywords were used in a systematic search strategy of the relevant literature in Medline/PubMed and the Cochrane Database of Systematic Reviews from 2017 up to 13 June 2023 (Figure 2). Bibliographies of review articles and other texts were also searched. Relevant articles were selected based on the PRISMA flow diagram (Moher et al., 2009) with an inclusive approach to selecting papers relevant to the topic. Given the explorative aim of this review and the heterogeneity of identified study types, we could not apply stringent criteria for selecting studies, but adopted broad inclusion/exclusion criteria.

Inclusion criteria:

- Studies or reports in which F2F teaching in dentistry and periodontology was evaluated (including relevant studies from the medical literature)
- Studies or reports where F2F teaching was supplemented, adapted or replaced with other methods
- Teaching and learning at the levels of undergraduate, postgraduate or CPD
- Full text available.

Exclusion criteria:

- Studies where F2F teaching was compared specifically with blended teaching and learning approaches or new (online) technological platforms or virtual learning tools (such as AI or VR), as these are covered in Sections 3 and 4
- Reviews, although these were nonetheless obtained to permit additional information and/or review of reference lists
- Education methods to non-dental and non-medical students and professionals
- Editorials/commentaries/letters/conference abstracts
- Articles not in English language.

Titles and abstracts derived from the searches were screened by three authors (B.G.L., E.E.V., P.M.P.) to assess potential relevance and eligibility. Following this, full-text articles were obtained and assessed for inclusion, with any disagreements resolved by discussion. Given the explorative and scoping nature of the paper, neither a PRISMA statement nor a focused (PICOS) question for review was adopted, nor certain quality assessments. Relevant data were abstracted from the identified papers by three authors (B.G.L., E.E.V., P.M.P.), which considered a range of outcomes including factors such as examination grades and assessment outcomes, student and teacher perceptions and preferences and student satisfaction.

2.3 | Results

The identification and selection of articles through the literature search process is shown in Figure 3. Table 2 presents a list of teaching methods presented and discussed in this manuscript. Database and reference list searches found a total of 310 papers, of which 218 were

MeSH Terms:
Education, dental OR Education, dental, graduate OR Education, dental, continuing OR Periodontics, education OR Students, dental OR Dental student OR Teaching OR Education OR Learning

AND
All fields:
Periodontal disease$ OR Periodontal OR Periodontitis OR Periodontology OR Periodontic$ OR Dental OR Dentistry

AND
All fields:
Undergraduate OR Postgraduate OR Continuing Education OR Continuing {adj1} education OR Clinical {adj1} teaching OR Clinical {adj1} learning OR Pre-clinical {adj1} teaching OR Pre-clinical {adj1} learning OR Non-clinical {adj1} teaching OR Non-clinical {adj1} learning OR Outcome$ OR Result$ OR Grade$ OR Student {adj1} satisfaction OR Student {adj1} wellbeing OR Student {adj1} well-being OR Self-perceived {adj1} learning OR Self-perceived {adj1} efficacy OR Effectiveness OR Confidence OR Attitude OR Competence OR Marks OR Assessment OR Performance OR Student {adj1} performance OR Student {adj1} experience OR Employment OR Employment {adj1} outcome$ OR Employer {adj1} feedback

AND
All fields:
In-Person OR In {adj1} person OR Face-to-face OR Synchronous OR Classroom {adj1} learning OR Classroom {adj1} teaching OR Classroom {adj1} education OR Traditional {adj1} learning OR Traditional {adj1} teaching OR Traditional {adj1} education OR On-site {adj1} learning OR On-site {adj1} teaching OR Onsite {adj1} learning OR Onsite {adj1} teaching OR Live {adj1} lecture$ OR Lecture$

Limits: English language

FIGURE 2 Search strategy to evaluate traditional face-to-face teaching methods and the move to student-centred methods (Section 2).

excluded following title/abstract screening. Full texts of 92 manuscripts were obtained, of which 40 were rejected, leaving 52 papers which were included in the core results of this scoping review. Reasons for exclusion of papers at each stage are also shown in Figure 3.

2.3.1 | (Inter)active student-centred methods additional to or replacing F2F teaching

To promote active student-centred learning, several educational approaches have proven useful (Table 3). Central to these approaches is the change from teachers and teaching to a learner and learning pedagogy.

The active learning classroom or technology-enabled learning classroom

Certain aspects of dentistry are well suited to learning in the active learning classroom (ALC) and technology-enabled learning classroom (TELC) modes and may provide greater effectiveness than traditional F2F teaching for knowledge transfer; for example, teaching dental radiology. TELCs are equipped with technology, movable furniture, multiple screens to allow connectivity, flexibility and 360° visibility; the teachers walk in between and around. The concept is to deliver basic course content by asynchronous lectures via the web, while in ALC time is devoted to difficult problems with hands-on learning. In general, ALC and TELC result in improved problem solving and conceptual understanding of the course, with students securing higher grades than in traditional F2F teaching (Gordy et al., 2019).

Problem-based learning

Problem-based learning (PBL) is an experiential and student-centred approach that emphasizes critical skills such as inquiry, problem solving, critical thinking, clinical reasoning skills and collaboration through pair and group work. With PBL, a realistic problem is employed to challenge the students (as a group) to identify their own learning objectives (Wood, 2003). Self-directed study is followed by group discussion to enhance individual knowledge. PBL aims to stimulate learners to *construct* knowledge rather than *acquire* it. Various studies have shown its

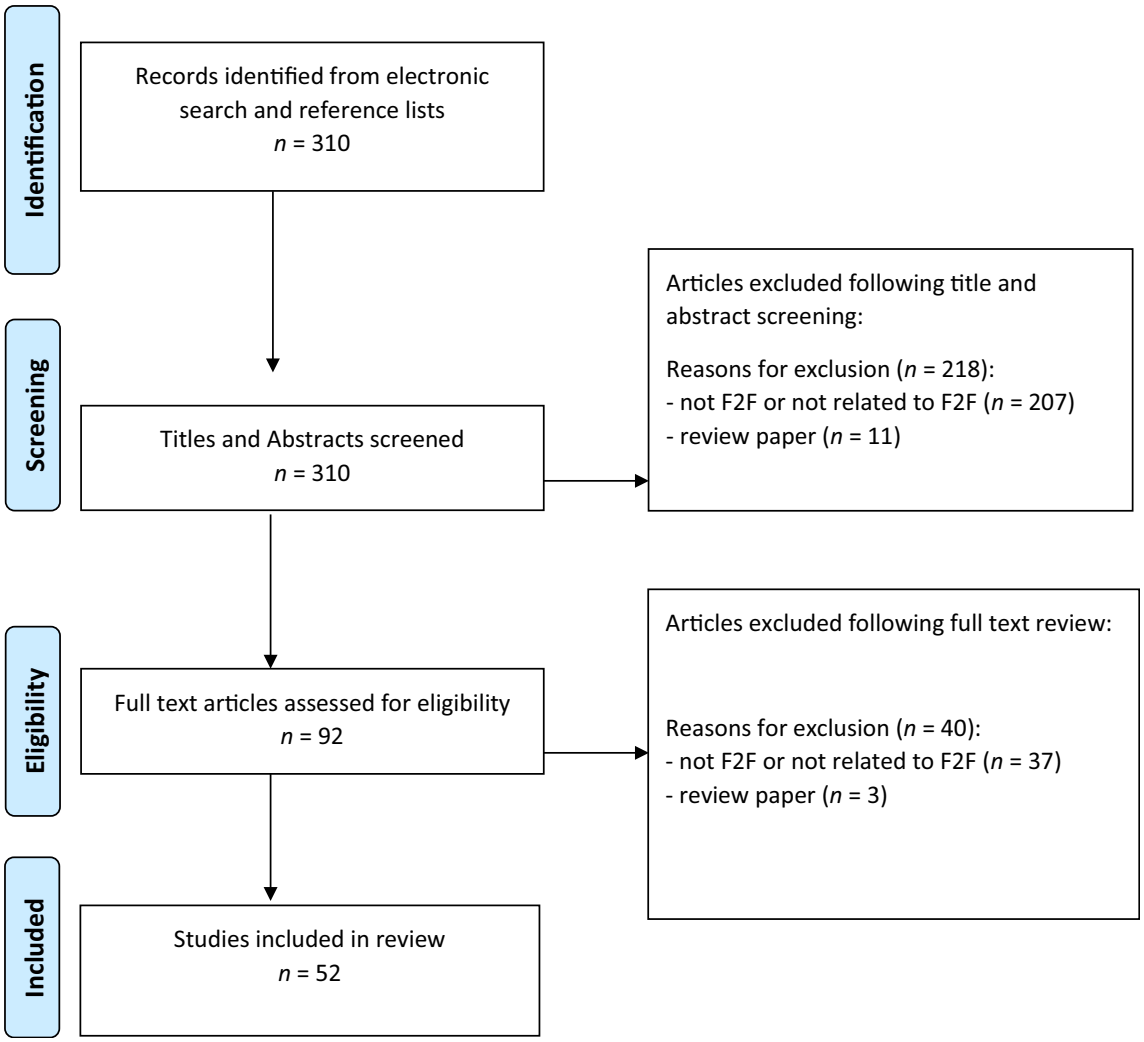

FIGURE 3 Identification of articles (based on the PRISMA checklist) to evaluate traditional face-to-face (F2F) teaching methods and the move to student-centred methods (Section 2).

effectiveness, student satisfaction and improved preparedness for clinical practice (Bai et al., 2017; Oderinu et al., 2020; Paudel et al., 2021; Sekhon et al., 2022). With this method, the pivotal role of tutors/facilitators in stimulating self-directed, active, collaborative and contextual learning is crucial, without their reverting to traditional one-way knowledge transfer. Yet, in one study on PBL—and seemingly in contrast to the favourable results for PBL—99% of students rated 'listening to lecture and taking notes' also as '(very) useful' (Sekhon et al., 2022).

Case-based learning

Case-based learning (CBL) is a learning method in which during class, clinical context, cases and examples are employed to enhance foundational knowledge. Two studies reported that CBL had a positive effect on learning outcomes and student confidence (Chowaniec et al., 2018; Persky et al., 2017).

Peer-assisted learning

Peer-assisted learning (PAL) refers to students learning with and from each other as fellow learners, thereby enhancing overall learning, long-term memory and team spirit. In a study with final year dental students in a class on orthodontics, PAL by classmates was not shown to be superior compared to traditional F2F (Ehsan, 2020).

Team-based learning

Team-based learning (TBL) is an educational approach increasingly adopted in health-professional schools. It fosters problem solving, critical thinking, active learning and communication skills among students. TBL addresses the growing need for a student-centred, interactive and collaborative approach in dental education. TBL comprises three steps: self-preparation (material accessible via school servers or teaching platforms [e.g., BlackBoard, Canvas]); an in-class readiness assurance test (RAT); and in-class subject-, case- or application-based discussions and/or application-focused exercises. The lecturer is the facilitator rather than the presenter of the course content. TBL emphasizes student accountability by requiring them to prepare beforehand, contributing to team discussions and participating in the class. TBL gives higher scores on assessments (Nishigawa et al., 2017; Park et al., 2019). Moreover, TBL encourages communication skills,

TABLE 2 Various teaching methods and classroom types presented and discussed.

Teaching method	Abbreviation used
Traditional face-to-face lecturing, also known as conventional (classroom, theatre) lecture-based learning	F2F, LBL
Active learning classroom	ALC
Audience response system	ARS
Case-based learning	CBL
Enhanced video-based learning	EVBL
Expert-assisted learning	EAL
Flipped classroom	FC
Jigsaw learning	JSL
Live demonstration	LD
Lecture F2F plus workshop	LW
Peer-assisted learning	PAL
Presentation–assimilation–discussion learning	PAD
Problem-based learning	PBL
Research-based learning	RBL
Staged self-directed learning model	SSDL
Step-by-step teaching	SBS
Team-based learning	TBL
Technology-enabled learning classroom	TELC
Think–pair–share including story telling	TPS-S
Virtual classroom	VC

application of knowledge and PAL. The students also believe that TBL encourages self-directed learning and improved critical thinking skills compared to learning in the F2F mode.

Think–pair–share

Think–pair–share (TPS) is a didactic method in which active and collaborative learning is encouraged to improve learning, problem solving and critical thinking. Using this method, students individually think about a question posted by a lecturer. Next, students pair up to discuss and challenge their thoughts, and finally share their thoughts with the lecturer and other student pairs. Students rated the TPS learning strategy including storytelling (TPS-S) superior to their experiences with traditional lectures and perceived the method effective in improving clinical learning (Ganatra et al., 2021).

Jigsaw learning

Jigsaw learning (JSL) is a cooperative learning method. Students with different characteristics work in heterogeneously formed groups consisting of 2–6 individuals, and study topics are distributed to each group. When generating the groups, the teacher considers the characteristics of each student (success, economic, cultural factors, etc.). In one study, no significant difference could be found between JSL and F2F in a pre-test or a post-test; however, in the retention test, success with the Jigsaw method was significantly higher (Sagsoz et al., 2017).

The flipped classroom

Flipped classroom (FC) has been proposed as an alternative to conventional lectures (McLaughlin et al., 2014; Tolks et al., 2016). In an FC (also known as reverse, inverse or backwards classroom), students are introduced to new content before coming to class. This can be done at the students' own pace and schedule (asynchronous), through various analogue and/or online sources (pre-recorded lectures [video, online/stream], book chapters, readings, video clips [YouTube], podcasts) that they access on their own, possibly different from their classmates. The learning materials can be uploaded by the course director, or students can be encouraged to find materials on their own, or both. Students come to class prepared with the foundational knowledge from their pre-class learning, and subsequently the classroom time is dedicated to active learning and engagement. Instructors guide discussions and help students to apply their knowledge and encourage critical thinking and problem solving. FC allows for more personalized learning experiences and peer collaboration. Also, active assessments and feedback can be integrated into the learning process. FC yielded better test results in a removable prosthodontics course (Z. Wang et al., 2021). Interestingly, students in FC engaged more regularly with the online learning materials. A positive result for FC was also reported on the teaching of the new periodontitis classification, with a high level of student satisfaction with FC (Crome et al., 2021). On the other hand, for teaching a dental skill (orthodontic wire-bending), the FC approach demonstrated efficacy in acquiring practical skills equal to that of live teacher demonstrations (Sivarajan et al., 2021).

2.3.2 | The virtual classroom as alternative to the traditional 'live' F2F lecture

The virtual classroom at the undergraduate level

The COVID-19 pandemic imposed significant constraints on dental education. The social distancing protocol forced teachers and students to the virtual classroom (VC) (also known as synchronized distance [e-]learning or online learning) (Table 4). Nevertheless, the VC was already in place in some schools before the pandemic (Libby et al., 2017; Zheng et al., 2017). One study showed that >75% of students concurred that they had missed out on valuable educational experiences because of the pandemic. Over half of them expressed reduced motivation to engage with the VC and expressed doubts about the efficacy of online assessments (Hattar et al., 2021). But, particularly among fifth-year students, a large majority (79%) acknowledged that quarantine had boosted PAL. The data indicated that students held a mixed view of the VC: they appreciated certain aspects, but the VC was considered inadequate as a substitute for hands-on clinical practice and students felt insecure about their future ability to practise dentistry independently after graduation (Hattar et al., 2021). Almost 75% considered restorative dentistry the most negatively affected, followed by prosthodontics (69%), while orthodontics and oral diagnosis were perceived as the least negatively affected subspecialties (by 18% and 21%, respectively). Periodontics was reported to

TABLE 3 (Inter)active and student-centred methods supplementing or replacing traditional face-to-face (F2F) teaching.

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Bai et al. (2017)	PBL	Fourth-year dental students, $n = 90$; (PBL group $n = 42$, traditional F2F $n = 48$) and follow-up survey 3 years after graduation, $n = 69$ (original PBL group $n = 32$, original traditional F2F $n = 37$) (China)	PBL implemented course dental alveolar surgery, effect on preparedness for clinical practice. Randomized clinical trial, theoretical exam and a clinical case analysis. 3 years later, follow-up survey.	No differences between the two groups, either in examination scores (78% for PBL; 78% for F2F, $p = .843$) or case analysis (7.1 for PBL; 6.8 for F2F, $p = .195$). But higher study interest in PBL and collaboration motivation (both $p < .001$). 3 years after graduation, preparedness for dental alveolar surgery in practice higher for the group that received PBL (7.15) than the F2F group (6.66; $p = .044$).	PBL did not improve exam scores and case analysis scores. But PBL improved preparedness for dental alveolar surgery in clinical practice 3 years into dental practice. PBL helped students to develop the desire to collaborate.	PBL did not give immediate better results, but apparently in the longer term is an advantage. Authors claim PBL group is more likely to consult with professionals while in practice. No differences in lifelong learning attitudes for both groups.
Chowaniec et al. (2018)	CBL	Second-year dental students, $n = 52$ (USA)	Course: 'Basic concepts in paediatric dentistry' (stainless steel crowns, pulp therapy, space maintenance). Cross-over design, student performance in a quiz was tested in three modalities (timing of the case-discussions): a 60-min case-based discussion before or after a 90-min lecture, versus no CBL.	Timing of CBL has positive outcome for quiz scores after a lecture compared to before (means and SD): 6.0 ± 1.0 versus 5.5 ± 1.3 at a maximum score of 7; $p = .008$ including no CBL in ANOVA; for student confidence (12.7 ± 2.3 vs. 11.6 ± 2.0 at a maximum confidence score of 20 points; $p < .001$ including no CBL in ANOVA); and student preference (33 vs. 14; $p = .01$).	CBL after a lecture contributes to learning outcomes.	The effectiveness of learning might depend on the educational situation of students (being not prepared for CBL). When using a type of flipped classroom concept, wherein students prepare for in-class activities, the case presentation beforehand could be more effective.
Crome et al. (2021)	FC	Final-year (10th semester) dental students, $n = 55$ (Germany)	Teaching the periodontology module on the new classification; 33 digitized periodontitis patient cases. Mixed data collection: questionnaire and correct case classifications: before (T0) and after (T1) module in a flipped classroom (online). 11 diagnostic/	High level of student satisfaction with the periodontology module (mean ± SD): 14 ± 1 points out of maximum score of 15. 89% of participants felt confident to classify a periodontitis patient. The module showed a significant reduction in case-classification error	FC-based teaching concept might be superior to conventional F2F lectures, especially when complex topics are covered.	F2F lectures on periodontology and the periodontitis classification were provided in previous semesters, before COVID-19. Out of the 11 diagnostic decisions required, only 4 parameters (extent, grading, percentage of bone loss per age,

TABLE 3 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
			classification decisions tested.	rates: T0 error rate = 28.3%; mean ± SD of errors 3.12 ± 1.67 versus T1 error rate = 18.7%; 2.06 ± 1.81; Δ = 9.6%, $p = .002$.		phenotype) showed significant improvements, with effect sizes ranging from small to medium. The paper was not comparative in design, so the learning effect of FC compared to another teaching technique could not be evaluated.
Ehsan (2020)	PAL	Final-year dental students, $n = 58$ (Pakistan)	Two PAL sessions on the subject of orthodontics, by peers of the same class/level as adjunct to two traditional F2F, compared to four traditional F2F lectures (expert-assisted learning, EAL [faculty]); assessments through 10 multiple choice questions pre- and post-teaching sessions.	After the traditional lectures (EAL) on four occasions, test scores were always significantly higher than scores before the lectures ($p < .05$ for all four), while after the two PAL sessions, test scores were not significantly higher after the sessions compared to before the sessions ($p > .1$).	PAL was shown to be as effective as traditional F2F	Relatively small study. Authors speculate that the level of PAL can be enhanced. PAL fits well with the concept of 'flipped classroom'.
Ganatra et al. (2021)	TPS-S	Third- and fourth-year dental students, $n = 55$ (Canada)	Tested TPS-S in an oral pathology seminar of 1.5 h with clinical case-based questions related to diagnosis and management. Data were obtained through rating and the SEEQ questionnaire (mixed method).	Students rated the TPS-S seminar for all but aspects between 4 and 5 (range 1–5) ($p = .05$). The overall value of the seminar was rated (mean ± SD) at 4.62 ± 0.52, $p = .028$ and the instructor performance was rated at 4.73 ± 0.45, $p = .016$.	Students rated the TPS-S seminar as superior to traditional lectures on most domains and perceived the method effective to improve clinical learning.	Fourth-year students had more knowledge and often led discussions (unequal participation). Some students were unhappy with the pairing. Sometimes the instructor took over.
Gordy et al. (2019)	ALC versus traditional F2F. ALC here is TELC.	Dental hygiene students, $n = 32$ (USA)	Dental radiology courses. Questionnaires, qualitative and quantitative data analyses.	63% preferred ALC over F2F. ALC scored higher over F2F in all qualitative aspects (5) ($p < .001$–$.05$). Course grades for F2F were significantly influenced by incoming GPA and ATC, while grades for ALC were less dependent on GPA and ATC.	ALC is a suitable alternative for dental radiology courses for dental hygiene students.	There were some sensory limitations (from teacher) and some technical challenges in applying the ALC (a.k.a. TELC, Technology-enabled learning classroom).

(Continues)

TABLE 3 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Nishigawa et al. (2017)	TBL versus FC	Dental students, $n = 41$ (Japan)	Course on fixed prosthodontics. First six lessons were FC and the next eight were TBL lessons. Comparisons of test results in final exam for curriculum material covered by FC versus TBL. A referential examination with the same questions was conducted to 8 faculty members who had not attended any of the classes.	TBL classes had slightly higher examination scores than FC classes (70 ± 30% vs. 66 ± 17%, respectively), but differences were not significant. Referential examination results showed slightly higher scores for the same curriculum.	Analysis revealed no noticeable difference in the effectiveness of the TBL or FC class format. Both styles are highly effective.	In a previous study of the same group, it was reported that TBL had higher efficiency than traditional F2F lecture style. In combination with the current results, it can be concluded that student-centred teaching formats in general yield higher efficiency.
Oderinu et al. (2020)	PBL	Fourth-year dental students, $n = 72$ (Nigeria)	Learn about cariology through PBL compared to other dental topics by traditional F2F. Questionnaires and students' perception were on a 5-point Likert scale.	Higher student preference for PBL (3.75 ± 0.50) versus F2F (3.42 ± 0.56) ($p = .005$). The highest score with PBL versus F2F for 'able to provide intellectual stimulation with peers' (4.11 ± 0.75 vs. 3.04 ± 1.14; $p < .001$). The lowest mean score for PBL and F2F was 'interaction with tutors' (2.80 ± 0.58 vs. 2.52 ± 0.51, respectively; $p = .002$).	PBL was preferred over F2F for the course on cariology	PBL requires a larger number of facilitators than traditional F2F; it is recommended to have 6–10 students per facilitator in the PBL sessions. This study had three facilitators.
Park et al. (2019)	TBL	Dental students, $n = 34$ (USA)	Six teams of 5–6 students were randomly assigned. Total of four TBL classes. TBL classes were mandatory. Pre-reading materials were assigned, and each class began with a readiness assurance test (RAT), first individual, then as team, with team discussions. Subsequently, case-based discussions and review of learning objectives. Individual and team RATs	Students scored on individual RATs with mean scores of 42%–61%, while mean team scores ranged from 71% to 100%. For three out of four RATs, team scores were significantly higher than individual scores ($p < .01$) Students favoured TBL over traditional F2F, with 68% preferring TBL and 23% preferring F2F. Students (strongly) agreed that TBL promoted application of	TBL format gives higher scores on assessments than individual student tests. TBL format encourages communication skills, application of knowledge, and peer-to-peer learning. The students also believed that the TBL format encouraged self-directed learning and critical thinking skills compared to learning in F2F teaching.	The study did not compare TBL to traditional F2F; nevertheless, the study concluded TBL was more efficient and preferred based on surveys with students' experiences in traditional F2F classes. A discrepancy in text and Figure 1 in the paper regarding the number (3/4 or 4/4) of individual versus team test being significantly different.

TABLE 3 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
			were compared. Also, a survey was made on students' experiences and preferences.	knowledge (89%), peer-to-peer learning (82%), communication skills (85%), self-directed learning (83%) and critical thinking skills (73%).		
Paudel et al. (2021)	PBL	Second-year dental students, $n = 22$ (Nepal)	Learn about diabetes through PBL. Learning was evaluated with pre- and post-PBL true/false questions. PBL and tutor performances were evaluated by students' perception on a 5-point Likert scale.	After PBL sessions, in 10 out of 12 test true/false questions, there was an increased frequency of correct answers regarding the knowledge on diabetes. The great majority of students (73%–96%) agreed on the positive influence of the discussions in the tutored group and the importance of the influence of the tutor (91%–100%).	PBL was accepted by the great majority of students. The role of the tutor/facilitator was regarded as important.	PBL sessions were performed online as alternative to planned F2F education due to COVID-19 pandemic and this report was not comparative.
Persky et al. (2017)	CBL	Second-year dental students, $n = 43$ highly engaged; $n = 36$ less engaged (USA)	Uncontrolled design. Class on foundational pharmacology. Medication Minutes were added to class contents as CBL method; further, there was basic science lecture material (Medication Minutes: clinically relevant facts about drug, ranging from drug utilization and prescription to potential drug interactions to Black Box Warnings) Non-graded quizzes ($n = 5$) were available for learning.	Short-term measures of retention: students performed significantly better (~30%) on the Medication Minutes than the traditional basic science lecture material. No difference in examination performance between the Medication Minute and basic science material. Long-term measures of retention: students performed 94% better on the Medication Minutes content than the lecture basic science material. Students performed 15% better when Medication Minute material appeared as knowledge questions compared to application questions ($p < .05$).	Teaching pharmacology in a clinical context yielded better long-term retention than teaching with a non-clinical focus.	Students were able to transfer from a CBL-based instructional method to a knowledge assessment. Increasing the long-term retention of pharmacologic knowledge may help better prepare students for their clinical experiences, especially when treating medically complex patients.

(Continues)

TABLE 3 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Sagsoz et al. (2017)	JSL (cooperative learning) within PBL setting	Dental students, $n = 50$ with similar GPA scores. Randomly assigned into experimental (JSL) and control group (F2F) ($n = 25$ each) (Turkey)	Control group: F2F lectures on restorative dentistry. Within the experimental group: five heterogeneous teams were formed by the teacher, based on the characteristics of each student (like success, economic and cultural backgrounds). Five different subtopics on restorative dentistry were studied per subgroup. Subsequently, by mixing subgroups, all students in experimental group learned about all subtopics.	No significant differences between the JSL and F2F groups (means and SD for test scores) for pre-test (35.8 ± 9.4 vs. 40.4 ± 12.1, $p = .178$) or post-test (57.4 ± 6.6 vs. 54.6 ± 10.3, $p = .259$). But in a retention test 3 weeks later, JSL group scored higher than the control group (57.8 ± 7.9 vs. 51.2 ± 8.9, $p = .012$, respectively).	JSL is as effective as F2F, but better for longer term retention of material.	JSL looks like TBL and PBL, but groups/teams are not formed at random: teachers must maximize heterogeneity within a team on the level of student characteristics. It seems a very cumbersome method and probably not applicable to many dental school environments.
Samuelson et al. (2017)	CBL	Second-year dental students, $n = 82$. Six-month follow-up response rate was $n = 40$ (49%) (USA)	Course pre-clinical removal prosthodontics (RPD). Comparison between CBL and F2F. Half of the class received CBL and F2F instruction in alternating sequence; here the students were their own controls. Perceived RPD treatment planning efficacy, comprehension and instruction method preference were surveyed directly and 6 months later.	81% of students preferred CBL over F2F instruction (9%), directly after the course and the same pattern after 6 months. CBL was associated with higher gains in RPD treatment planning comprehension ($p = .04$) and perceived efficacy ($p = .01$). The advantages of CBL were not different from F2F at 6 months after the course (based on $n = 40$ responders to the survey).	Students preferred CBL over traditional F2F instruction immediately after the course. The findings suggest small educational benefits for CBL.	The findings support the introduction and further testing of CBL in the pre-clinical dental curriculum, in anticipation of possible future benefits evident during clinical training.
Sekhon et al. (2022)	PBL	First- to fourth-year dental students, in two dental colleges, $n = 382$ (India)	Questionnaires on teaching methodologies on a 5-point Likert scale.	100% of students rated PBL and interactive lectures as 'very useful' (76% and 56%, respectively) and 'useful' (24% and 44%, respectively), while they all rated F2F as 'average' (48%), 'not useful' (49%), 'poor' (3%).	PBL and interactive lectures were rated as (very) good, but students like traditional lectures too. A 40-min lecture is preferred.	Not clear when the study was performed, that is, pre-, during, post-COVID-19, so unclear if teaching was online. The study also evaluated the preferred methods of teaching for clinics; 88% rated 'demonstration followed

TABLE 3 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
				Somewhat contrary to this, 68% and 31% rated 'listening to lecture and taking notes' 'very useful' and 'useful', respectively. A 40-min duration of a lecture was rated (the most) useful by 88%.		by practical' as the best option.
Sivarajan et al. (2021)	FC	Third-year dental students, $n = 40$. Study performed from October 2019 to February 2020 (Malaysia)	RCT. Flipped classroom (FC, $n = 20$) and group live demonstrations (LD, $n = 20$) on orthodontic wire-bending, six sessions for six assignments. Data analysis based on wire-bending scores and questionnaires.	For two out of six wire-bending assignments, scores for FC were significantly higher than for LD: for the Adams clasp ($p < .01$), and for the Z-spring ($p = .03$). There was no statistically significant correlation between wire-bending scores and video usage. Students were satisfied with both teaching methods.	For teaching a dental skill, namely orthodontic wire bending, a flipped classroom approach was found to have equivalent or better efficacy in acquiring practical skills when compared to live teacher demonstrations. At the end of the course, students' feedback on the FC method was just as positive as that for LD.	During the course, students initially felt more at ease with LD. The incorporation of continuous formative assessments following each exercise might have contributed to an improved learning experience for students when acquiring orthodontic wire-bending skills. These were feedback moments and could have potentially blurred the distinction between the effectiveness of the FC method and the LD.
Z. Wang et al. (2021)	FC	Fourth-year dental students, $n = 137$ (Japan)	RCT, single blinded, FC versus F2F, in the removable prosthodontics (RPD) course. Trial conducted in 2017, 2018 and 2019. Data on test/exam outcomes, univariate and multivariate analyses.	Test results were higher in the FC group versus the F2F group: (mean ± SD) 36 ± 16 versus 46 ± 18, $p = .001$. The number of online log-in counts (accesses) was higher in FC group than in F2F group: (mean ± SD) 11 ± 10 versus 22 ± 13, $p < .001$.	FC proved more effective than the traditional lecture format in terms of knowledge acquisition. These results suggest FC has the potential to be applied for certain classes to replace traditional lecturing.	The key determinant of effectiveness was not the instructional style itself but rather the frequency of individual learning interactions: students in FC engaged more regularly with the online learning materials.

Abbreviations: ALC, active learning classroom; ANOVA, analysis of variance; ATC, admission test colleges; CBL, case-based learning; EAL, expert-assisted learning; FC, flipped classroom; GPA, grade point average; JSL, Jigsaw learning; LD, live demonstration; PAL, peer-assisted learning; PBL, problem-based learning; RAT, readiness assurance test; RCT, randomized controlled trial; RPD, removable prosthodontics; SEEQ, Student evaluation of educational quality; TBL, team-based learning; TELC, technology-enabled learning classroom; TPS-S, think–pair–share including story telling.

TABLE 4 The virtual classroom (VC) as alternative to live, traditional face-to-face (F2F) teaching.

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Antoniadou et al. (2022)	VC	Dental students from Greece: third-year ($n = 97$, pre-clinical) and fourth-year ($n = 51$, clinical); Denmark: third-year ($n = 39$, pre-clinical). During second lockdown of the COVID-19 pandemic (Greece and Denmark)	Synchronous online lectures in VC (11–12 h/week) were evaluated by mixed data collection: questionnaires and five-point Likert scales. Availability of digitized educational materials (e.g., recorded lectures, slide shows, literature) in a asynchronous e-platform.	94% of third-year Greek students (strongly) agreed that e-learning in the VC is a suitable education method for 'theory in dentistry', while 53% of fourth-year students (strongly) disagreed ($p = .047$). 60% of third-year Greek students and 71% of fourth-year Greek students (strongly) disagreed that VC prepared them well for practical training ($p = .032$). Both Greek and Danish students preferred F2F over VC. Greek versus Danish students: Greeks agreed more that VC is a suitable method for theory ($p = .04$); Danes agreed more that VC prepared for practical training ($p = .011$); Greeks agreed more that they asked questions in the VC ($p = .046$); Danes agreed more that VC is a waste of time ($p = .001$); Nevertheless, Danes agreed more that they wanted to continue with the VC ($p = .006$).	Students reported that VC was a suitable teaching method for theory in dentistry, but they preferred F2F teaching. A minority of students believed that VC prepared them sufficiently for their practical training. Less than half of students believed that VC prepared them for their exams, and more than half preferred blended learning. Less than half desired VC to continue after the pandemic. Nearly half of the participants believed the online exam model to be unreliable. Overall, students considered distance e-learning in VC as an educational method applicable only to theoretical lessons but they lacked physical communication and interaction in the VC.	In the VC with synchronous lectures, the students may encounter technical problems. Study showed that students from Greece and Denmark shared consensus on numerous aspects, but there were also distinct variations that could be attributed to differences in the educational programmes and cultural contexts of the two countries.
Aulakh et al. (2022)	VC	Postgraduate students, trainees in oral and maxillofacial surgery in a training hospital, $n = 14$ (UK)	COVID-19 forced a journal club to move from F2F to the VC mode. Online survey. A mix of 10-point Likert scale and multiple-choice questions, comparing VC with F2F journal club.	Trainees found it easier ($p < .05$) to attend the journal club in VC than F2F; learning through the VC journal club was perceived as more effective and more comfortable than F2F and provided more time to read	Although journal clubs for postgraduate students and specialists in training are typically held in academic institutions, VCs can replace them. Trainees in oral and maxillofacial	The study was very limited in size. Trainees in oral and maxillofacial surgery in a training hospital may not be comparable to postgraduate education in periodontology, paediatric dentistry, endodontology,

TABLE 4 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
				over and critique papers in preparation. 12/14 trainees gave score ≥7 for the VC journal club and significant increase in Likert scale scores for the VC versus F2F. 10/14 trainees felt that journal club would benefit from remaining online. 11/14 reported that for future tutorials and meetings, they preferred a combination VC and F2F.	surgery felt positive about VC.	etc., as these typically take place within academic institutions (dental schools). Live interaction and PAL is not easy in the VC sessions, while for journal clubs at the postgraduate level, these aspects are very important. Reliable technology is important.
Dalal et al. (2022)	VC	First-year dental students, $n = 90$ (USA)	Focus on class 'Human biology', which is a traditional F2F lecture style; experiences before (live lectures) and during lockdown (VC) were surveyed; 22 responses on a 5-point Likert scale.	12 out of 22 items were rated significantly more unfavourably during the VC than before lockdown during live lectures. Items the most decreased ($p < .001$) were Q&A, application activity, self-assessment, PAL and PBL.	First-year students preferred live F2F lectures for the class 'Human biology' because of better opportunities for Q&A, PAL, PBL and self-assessment.	Live interaction with the teacher and with peers is a recurring theme in various studies.
Fuhrmann et al. (2022)	VC for teaching motivational interviewing	Undergraduate dental students in fourth clinical semester, $n = 38$ of which $n = 25$ recorded 40 complete interviews and these were evaluated. Part of a course of the Section Periodontology. Study performed in 2017 (Germany)	Uncontrolled interventional trial, evaluation of the e-course 'Motivational Interviewing'. Patient–student interviews were recorded and evaluated. Students' self-efficacy regarding smoking cessation and oral hygiene motivation and the acceptance of the tool were assessed.	Students showed high levels of MI-adherent behaviour (15.45 ± 6.98), open-ended questions (9.95 ± 6.90) and reflections (10.43 ± 8.85), which were comparable to previous classroom trainings (no statistical testing done). In addition, 90% of the students preferred e-learning over classroom teaching. Furthermore, the students' therapeutic self-efficacies were significantly increased by the programme.	Effectively equipped dental students with fundamental knowledge and MI skills from the e-module 'Motivational Interviewing' in the VC. Students reached 3.9 out of 5 points for overall evaluations in empathy and 4.3 of 5 for 'MI spirit'.	Due to the fact that the completion of the e-MI course had to be done in addition to the normal curriculum, this might be a hint for a high cost–benefit ratio of such a blended learning concept.
Goob et al. (2021)	VC with synchronous and asynchronous (pre-recorded) lectures.	Undergraduate dental students (8th and 10th semester students) in the Dept. of Prosthodontics, on a course on removable	Four lecture types were investigated: (i) conventional live lecture; (ii) asynchronous VC (pre-recorded PPT lecture); (iii)	General technology for VC worked well; 100% of students had the needed hardware and 85% used home internet and the	Students liked the asynchronous VC the best, but for future teaching the combination of conventional lectures and	In a country like Germany, the technological and hardware requirements were not a problem as may exist in some other countries.

(Continues)

TABLE 4 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
		dental prostheses I–III, $n = 102$ (Germany)	synchronous lecture in VC (Zoom-conference); (iv) Synchronous live stream in VC. Survey question scoring by VAS scale (0%–100% agreed) or recording frequencies.	remainder other available sources of connection. Digital learning courses promote learning outside the university. Students rated the transmission and technical functionality of asynchronous VC as the best ($p < .001$). The asynchronous VC scored the highest ($p \leq .007$) compared to the other concepts and was rated the best for future education. Interaction with the teacher was better for conventional lecture and Zoom lecture.	digital teaching concepts had the highest acceptance.	Studying in an environment outside the university and at times of own preference, was rated as highly desirable; with this, the asynchronous VC was adjudged the best. The pandemic circumstances may have contributed to the favourable evaluations for asynchronous lectures.
Hattar et al. (2021)	VC	179 fourth-year and 131 fifth-year students, $n = 310$. Study performed at the end of academic year 2019–2020 (Jordan)	Questionnaire on education impact; 7 questions, 4-point scale (strongly) disagree, (strongly) agree. Survey on their level of preparedness for subspecialties.	54% felt less motivated to follow-up with VC and 56% believed that online assessment was not a good method for evaluation. 66% of the students thought that VC group discussions had a positive value, while 67% preferred online lectures compared to theatre lectures. Periodontics was reported to be negatively affected by almost 50% of fourth-year students and 11% of the fifth-year students. Majority of students, particularly fifth-year students (78.7%) ($p < .001$) stated that the quarantine increased their collaboration with their colleagues. 87% of students reported the practical experience to be most	77% reported missed educational experiences due to the pandemic. Students partially appreciated the VC, whereas they did not consider it a substitute for F2F clinical practice. The overall self-perceived preparedness level was promising; however, students had reservations regarding independent practice following graduation. Interestingly, the fourth- and fifth-year dental students judged that their education in many of the dental subspecialties was negatively affected by the COVID-19-imposed quarantine.	The student population consisted of 77% females. Uncontrolled study results were obtained due to COVID-19 lockdown, and student perceptions were not compared to previous years. Students were not feeling adequately trained in clinical skills of the various subspecialties. In general, dental students' perceptions may be 'coloured' by their need for practical training and their fear of missing out with the VC. Readiness for starting in practice after graduation with considerable amounts of VC teaching is low.

TABLE 4 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
				negatively affected. The fifth-year students showed satisfactory self-perceived preparedness related to a range of attributes and professional skills.		
Jiang et al. (2021)	VC for traditional F2F lectures, PBL, RBL, CBL, TBL.	Undergraduate dental students ($n = 104$), standardized resident physician training students ($n = 57$) (total 161) (China)	A 12-item survey on satisfaction and efficiency. Reporting frequencies for the total study population or separate for dental students and resident physician students. Undergraduate students (96%) had significantly more often ≥5 VCs/week than physician residents (2%); the latter had mainly <5 VCs/week ($p < .001$).	All student responses and preferences: 79% were (very) satisfied with their courses in the VC. Preferences: traditional F2F lectures 42%, CBL 33%, PBL 25%, RBL 0%, TBL 0%. Undergraduate dental students preferred traditional F2F lectures (87%) and TBL (38%) more than standardized residency physician training students (74%, $p < .05$ and 12%, $p < .001$, respectively).	Dental undergraduate and standardized physician resident students showed sufficient satisfaction with VC during the COVID-19 pandemic. Majority of students preferred traditional F2F lectures.	Satisfaction and preferences must be judged at the time of lock-down, where VC was the only alternative to traditional teaching. Cultural and geographical differences between USA and Europe need to be accounted for.
Johnson King et al. (2022)	VC	Postgraduate students in orthodontics in an academic environment, $n = 25$ (15 trainees from UK, 10 international trainees) (UK)	Cross-sectional qualitative study investigating postgraduate students' perceptions of F2F and VC in a 3-year programme in orthodontics. Students had received both F2F and VC between March 2020 and January 2021. In this study, VC was called 'distance learning'.	Students identified six themes to be important for their education in comparing F2F and VC: (i) social support network; (ii) technology; (iii) learning experience; (iv) education environment; (v) interpersonal interactions; and (vi) effective teaching/learning. Students regarded distance teaching more time efficient (more time to prepare for teaching sessions), as they did not need to travel to access that teaching session.	The majority of students wanted the VC to continue for theoretical orthodontic topics; however, they felt strongly that practical skills needed F2F teaching. Students expected an optimal learning experience from a hybrid teaching model, utilizing the benefits of both modes of teaching.	The study was very limited in size. The topics being taught by F2F and VC were not specified in the paper. Live interaction and PAL were not easy in the VC sessions.

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TABLE 4 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Khan et al. (2022)	VC employing Blackboard Collaborate	Dental students (third- to sixth-year levels; $n = 227$) (Saudi Arabia)	Survey, nine-item questionnaire that included questions related to experiences on VC (synchronous online lectures).	75% experienced minimum to moderate technical problems regarding connectivity during the VC, while 2% of the respondents experienced very severe technical problems. 54% supported the continuation of VC after the pandemic.	Although VC was highly appreciated, VC lectures were less interactive; possibilities as well as the desire for posing questions during and after the lectures are limited. The online lectures should last a maximum of 45 min, and students prefer at least a 15-min break between online lectures.	Internet connectivity as well as a decline in the comprehension of the lectures as compared to F2F learning were found to be barriers to online learning. Lack of interactions between students and teachers and peers. Limit VC lectures to 45 min.
Libby et al. (2017)	Synchronous teaching in VC.	Dental hygiene students, two cohorts ($n = 115$): Cohort 1, graduated in 2014 ($n = 54$); Cohort 2, graduated in 2015 ($n = 51$) (USA)	This mixed-methods study utilized a convenience sample. Synchronous teaching in VC versus traditional classroom experiences. Analysed by using pre- and post-programme surveys.	No difference in student perceptions and expectations pre-course versus post-course, although Cohort 2 had a more positive perception of synchronous teaching in VC than did Cohort 1 ($p < .001$). Perceptions of characteristics related to the classroom setting and instructor satisfaction were overall positive ($p < .001$). Technological support and faculty familiarity with VC influenced students' satisfaction. Overall, no difference in satisfaction for synchronous VC compared to their previous live F2F experiences.	No difference in self-reported student satisfaction with synchronous VC when compared to students' previous traditional F2F learning experiences.	Technological issues were a major point of concern for students. If instructors and institutions are not equipped to deal with malfunctions, it can lead to wasted time and student frustration. The results of this study are intended to aid educators in recognizing factors that impact student satisfaction and to improve understanding of VC.
Loset et al. (2022)	VC	Third-, fourth- and fifth-year dental students, $n = 84$ (Norway)	Survey responses in a 5-point Likert scale.	79% (and 92% of fifth-year students) preferred physical lectures over any digital form, 67% rated digital asynchronous video lectures as second best, while only 17% reported enthusiasm about synchronous lectures in the VC (via online platforms, e.g., Zoom).	Students missed their live F2F lectures; they liked recorded lectures for asynchronous learning.	Digital teaching seemed to be less engaging, and the students missed the contact with their fellow students.

TABLE 4 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Nguyen and Patel (2023)	VC	Dental students and dental hygiene students ($n = 290$) 95% of respondents belonged to Generation Y and Z (Generation Y students were born between 1981 and 1996, and Generation Z students were born between 1997 and 2015) (USA)	Online survey. Quantitative and qualitative questions.	There were no significant differences in responses between generations of students. Prior to the pandemic, 96% of dental hygiene students and 70% of dental students preferred regular F2F classroom lectures ($p < .01$). Significantly more dental students than dental hygiene students responded to be more organized, more attentive and less stressed, and perceived transition to VC was easy ($p < .01$).	There was a significant trend that dental students (compared to dental hygiene students) adapted better to VC and for all parameters related to VC, >75% of them agreed. 93% of dental students preferred some classes to stay online, while the corresponding frequency was 62% for dental hygiene students.	There is consensus between dental students and dental hygiene students that laboratory and clinical courses should be taught F2F. It needs to be realized that VC can be improved, and it must be regarded as a truly different setting than simply classroom teaching in front of a camera and being synchronously broadcasted.
Salman et al. (2022)	VC	First- and second-year medical ($n = 200$) and dental ($n = 100$) students, total $n = 300$ (Pakistan)	Multiple-choice questionnaire and feedback on VC for teaching human anatomy. Students had already (pre-COVID) experienced the 'normal' on-campus anatomy classes; this allowed them to compare traditional versus VC anatomy during lock-down.	80% of the students wished for their traditional anatomy learning, that is, live dissection courses and didactic lectures, interaction and motivation from their mentors and peers. 80% complained about technical issues (no laptop/computer/poor internet). 76% of students felt not confident with human anatomy and embryology without interactive sessions and 3D models.	For teaching human anatomy and embryology, VC seems less suitable. For successful VC, good hardware is needed and a robust internet.	81% of students used smartphones and did not have availability for laptops/tablets. Internet reliability was poor. Success of VC is obviously also dependent on the technical possibilities, which may differ per country around the globe.
Shrivastava et al. (2022)	VC	Dental students across India, from first to final year, $n = 533$ (India)	Online survey, self-designed questionnaire on conduct, quality, difficulties, suggestions, regarding VC; descriptive.	49% of students faced difficulties understanding lecture material. 56% grasped <50% of the taught knowledge. Internet connectivity was reported as a problem. 86% preferred traditional F2F. 76% reported that the quality of education was adversely affected.	The quality of VC should be enhanced and must be more student-centred to meet education requirements. Internet connectivity must be at high level before VC is widely applied in the post-COVID era.	78% of respondents were female. 488 out of 533 students (92%) reported that VC was applied in their schools. Poor internet connectivity is in part responsible for higher preference for traditional F2F.

(Continues)

TABLE 4 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
S. Wu et al. (2022)	VC + CBL	Fourth-year dental students, $n = 60$ (China)	Randomized controlled trial, VC + CBL group ($n = 30$), traditional F2F group ($n = 30$). Course: 'Oral Medicine'. The VC + CBL group previewed study material and watched the lecture through video in VC as part of the first preparatory phase and analysed clinical cases; next, in class, team presentations and Q&A. Evaluation through a closed-book knowledge test. Feedback questionnaire (12 questions) in VC + CBL group with 5-point Likert scale.	The VC + CBL group had better results in professional knowledge test than control group (38 ± 4 vs. 34 ± 5, $p < .05$). The students' feedback on VC + CBL via the questionnaire was very favourable; range of scores per question 4.41–4.66.	The VC + CBL mode can increase the effectiveness of a course on Oral Medicine. Students are highly satisfied with VC + CBL; it can mobilize their learning enthusiasm and promote their engagement, interaction and peer-to-peer cooperation.	For both groups, elements of TBL and PAL were also included: before any 'intervention', students were required to preview study material, and in-class team presentations were included. Good internet is needed. Perhaps VC + CBL may cost students more time.
Zheng et al. (2017)	Interactive, synchronous teaching in VC.	Second-year students, class of 2014, $n = 124$ answered self-assessment test. $N = 116$ answered the yearly ADEA survey on the course Evidenced-Based Dentistry (EBD) (USA)	Course on EBD in VC with use of Voicethread, an interactive technological tool. It allows students to make comments directly on slides and to ask questions to teachers and peers. Student-level participation and satisfaction were collected via their use of Voicethread and via an ADEA survey.	The test score on the EBD course was 7.3 out of 8. 45.2% of students responded to the ADEA survey that they were 'well prepared' for EBD compared with the national average of 31.2% (compare also to responses to this question for the Classes of 2013 and 2015, 35.2% and 34.6%, respectively).	Students perceived interactive (Voicethread tool), synchronous teaching in VC to be more effective than other delivery approaches and reported that it made learning more active and engaging.	Interactivity during synchronous VC lectures is advantageous. Limitations: no control group; no pre- and post-test design; study in one single dental school; co-instructors were also the researchers, introducing potential bias.

Abbreviations: CBL, case-based learning; MI, motivational interviewing; PAL, peer-assisted learning; PBL, problem-based learning; PPT, PowerPoint; Q&A, questions and answers; RBL, research-based learning; TBL, team-based learning; VAS, visual analogue scale.

be negatively affected by almost 50% of fourth-year students and by 11% of the fifth-year students. The report clearly corroborates other studies that students accept VC and/or e-learning modules in lieu of F2F lectures, but live interaction with teachers and instructors is greatly needed for learning clinical skills and gaining general self-confidence (Hattar et al., 2021).

A Chinese study investigated the levels of satisfaction for various teaching methods in the VC: F2F (lecture-based learning [LBL]), CBL, PBL, TBL and RBL (Jiang et al., 2021). Undergraduate dental students and standardized physician resident students reported higher satisfaction levels with F2F and CBL compared to PBL, RBL and TBL—all within the VC. In Germany, students were surveyed for their satisfaction with the use of synchronous VC Zoom lectures, synchronous VC livestream sessions and asynchronous (prerecorded) PowerPoint (PPT) presentations, all in comparison with conventional F2F mode (Goob et al., 2021). Students showed a clear preference for the asynchronous VC teaching concept over synchronous methods, although they reported reduced interaction with the teachers. The students showed a vision of future teaching of dentistry, in which online teaching should complement conventional lectures. The excellent technical facilities in Germany may have contributed to the favourable evaluations for asynchronous VC lectures (Goob et al., 2021). Also, the learning of motivational interviewing (MI) in the VC appeared to boost the self-efficacy of German dental students in smoking cessation and oral hygiene promotion (Fuhrmann et al., 2022); here the students displayed a strong preference for VC, indicating high acceptance compared to traditional F2F, without losing efficacy and positively scoring on 'empathy' and 'MI-spirit'. Third- and fourth-year dental students from Greece and Denmark adapted well to the VC during the second lockdown with synchronous lectures and e-exams; nevertheless, they indicated that they preferred live F2F teaching rather than the VC (Antoniadou et al., 2022). Interestingly, in this report, students from the Greek dental school (considered Southern Europe) and the Danish dental school (considered Northern Europe) shared consensus on numerous aspects, but there were also distinct variations that could be attributed to differences in the educational programmes and cultural contexts of the two countries (Antoniadou et al., 2022).

Notably, the Asian studies (Hattar et al., 2021; Jiang et al., 2021; Shrivastava et al., 2022) reported that students expressed a preference for traditional F2F mode in various educational contexts, while in Europe and the United States students were more inclined towards blended or asynchronous e-learning modules (Goob et al., 2021). Internet connectivity was reported to be problematic for both students and professors (Khan et al., 2022; Shrivastava et al., 2022). The success of the VC is obviously also dependent on the course being taught; a course on human anatomy and embryology in the VC was not evaluated well among first-year medical and dental students (Salman et al., 2022).

The VC + CBL showed an increase in the effectiveness of a course on oral medicine (S. Wu et al., 2022). In general, students have reported asynchronous and synchronous VC lectures to be less interactive and with limited possibilities for posing questions during and after the lectures (Dalal et al., 2022; Khan et al., 2022; Loset et al., 2022). Thus, increasing interaction with certain web-based tools will be helpful (Zheng et al., 2017).

There was a significant finding that dental students (when compared to dental hygiene students) adapted better for several parameters related to the VC (e.g., staying organized, having reduced stress levels, ease of transitioning to online learning), and 93% of dental students preferred some classes to stay online, as compared to 62% of dental hygiene students (Nguyen & Patel, 2023).

VC at the postgraduate level

Postgraduate trainees found it easier to attend the VC setting for a journal club for discussion of selected papers (Aulakh et al., 2022) and even considered that VC journal clubs could replace the traditional F2F mode. However, live interaction and PAL are not easy in the VC, particularly for journal clubs at the postgraduate level, and these aspects are considered very important. A preference for a blended learning approach was suggested, in which practical skills are taught in person, while theoretical aspects could be covered remotely (Johnson King et al., 2022).

2.3.3 | Pre-clinical and clinical educational teaching methods for dental skills additional to or replacing F2F method

Teaching (pre-)clinical dental procedures may not benefit from traditional classroom teaching, compared to more basic or fundamental theoretical subjects such as biochemistry and microbiology. Additional types of instructions and methods are needed, and even demanded by dental students, such as (individual) practical training/workshops/hands-on materials and/or step-by-step teaching approaches (Alhamed et al., 2023; De Souza et al., 2018; Faust et al., 2021; Liu et al., 2019; Rayyan et al., 2017; Savoldi et al., 2021; Signori et al., 2019) (Table 5). An effective approach may be to supplement F2F with an audience response system (ARS); this is a tool for interactive audience participation via wireless keypads (Anamali et al., 2022; de Oliveira-Santos et al., 2018). Also, procedural videos and enhanced video-based learning (EVBL) have proven to be valuable learning aids in supplementing F2F for (pre-)clinical skills teaching (Abd-Shukor et al., 2021; Kruse et al., 2022; Rayyan et al., 2017).

Adjuncts, additions and other extras to improve conventional F2F teaching— student and educator perspectives

Difficult subjects for dental students can be tackled by adjunctive measures to traditional F2F teaching, for example, complementing with the utilization of 'adaptive learning', which holds the promise of tailoring the educational experience to individual students based on their responses (Yakin & Linden, 2021) (Table 6). With this innovative method, student engagement, motivation and performance are supposed to be enhanced. An example of an adaptive learning platform is Smart Sparrow, and its successful use has been shown across a spectrum of undergraduate disciplines. Another supplementary method might be 'guided reflection' for improved learning outcomes in

TABLE 5 Pre-clinical and clinical educational teaching methods additional to or replacing face-to-face (F2F).

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Abd-Shukor et al. (2021)	F2F plus EVBL	Third-year dental students, $n = 54$ (Malaysia)	Two groups (random allocation) for a class on partial denture course: control group received lecture plus regular online video, and experimental group received lecture plus online EVBL with video content playback and pause, rewind/forward possibilities; procedures in computer rooms in the school. Pre-and post-intervention test and a delayed test 4 weeks after the teachings. Questionnaire 4-point Likert scale. Practical assessment on denture design.	No difference between the two groups for pre-test ($p = .79$). Experimental group performed better on post-test ($p = .04$). No differences between the two groups on the delayed test ($p = .44$). Experimental group had larger difference between pre-test and delayed-test results ($p = .02$), while this difference was not significant for the control group ($p = .06$). There was no significant difference found in relation to practical skills for denture design ($p = .79$). 70% of students in EVBL group were more likely to accept the enhanced video as a replacement of the existing teaching method rather than a teaching supplement versus 41% in control group.	The application of enhanced video demonstration resulted in a better theoretical knowledge retention but not practical performance. More students also preferred the EVBL method to using conventional learning methods.	Small study. Although some differences were significant, the differences between groups were marginal.
Alhamed et al. (2023)	Video demonstrations during lectures, plus small group hands-on workshops and individual instructions.	Dental students from 17 dental schools across USA, $n = 357$. 67% first- and second-year students, 33% from third and fourth years (USA)	Survey, cross-sectional design of the study, on the subject: computer-aided design/computer-aided manufacturing (CAD/CAM) education.	CAD/CAM-related classroom-based education was likely to happen in traditional F2F lectures (87%) combined with simulated exercises (87%). The pre-clinical education included video demonstrations (82%), demonstrations during a lecture (76%) or instructions to small groups of students (69%), hands-on workshops	Students' education in CAD/CAM needs less or no F2F, more teaching or supplementation with hands-on activities in pre-clinical and clinical settings.	The study was not designed to evaluate F2F teaching CAD/CAM, but rather to evaluate current teaching methods and teaching practices for CAD/CAM within USA. It can be speculated that the education in CAD-CAM needs an alternative student-centred approach fully in the clinical setting, and perhaps utilizing the FC and PAL approaches.

TABLE 5 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
				(66%), as well as individual instructions (50%).		
Anamali et al. (2022)	ARS	Second-year dental students, $n = 83$ (USA)	Controlled cross-over study, two groups of students, group A received one lecture, group B the ARS; after cross-over, the other way around. Course on detecting and staging radiographic caries per ICDAS. Evaluation of ARS by two quizzes, quiz 1 before the cross-over, quiz 2 after the cross-over (each quiz five questions) and survey (two questions).	No difference for the quiz 1 before cross-over: scores of two groups (Lecture first 4.17 ± 1.02 and ARS first 4.12 ± 0.88, $p = .61$). No significant difference for the quiz 2 after cross-over: scores of two groups (Lecture first 2.78 ± 0.88 and ARS first 3.23 ± 0.97, $p = .07$). Survey results showed that most participants preferred either the ARS alone (49%) or a combination of the ARS and a traditional lecture (41%). 80% found the ARS (very) helpful.	In training students in practical skills of detection and staging radiographic presence of dental caries per ICDAS, the hands-on learning tool ARS complements traditional lectures.	ARS seems very promising, but is highly dependent on hardware/tablets/devices and also on teachers' ability to facilitate the sessions. With ARS, teaching radiographic caries diagnosis per ICDAS becomes more interactive and student-centred.
Bak et al. (2023)	VC with asynchronous lectures, synchronous virtual workshops and in-person simulated laboratory exercises.	Second-year dental students, $n = 81$ (USA)	'Complete denture' course in the 2020 fall-term. Web-based survey. Assessments made using a 5-point scale, where 1 denoted the most helpful category.	The mean ratings were: 2.96 ± 0.83 for background lectures, 2.67 ± 0.78 for clinical material and 2.33 ± 0.72 for lab content; values were statistically significantly different from each other ($p < .001$).	The participants' ratings indicated a clear hierarchy in terms of helpfulness, with background lectures receiving the lowest rating, clinical material being deemed more helpful and lab content ranking as the most helpful.	Not a comparative study; VC was installed because of the pandemic. Background lectures were not considered as helpful as lab work.
de Oliveira-Santos et al. (2018)	F2F plus ARS	Third-year dental students, $n = 74$ (Brazil)	Controlled cross-over study; two groups of students, each receiving two F2F lectures with ARS and two F2F lectures with HR. Course on OMR. SP, questionnaires and evaluation of FES.	Mean SP in F2F + ARS and F2F + HR classes was 98% and 47%, respectively ($p < .05$). Mean FES for the F2F + ARS group was 77%, for the F2F + HR group 75% (not statistically different). Frequencies of students reporting on F2F + ARS for attention 92%, participation 96%, classmates' participation 83%, interest 75%,	ARS significantly increased participation in OMR lectures. Higher participation correlated with higher FES scores. ARS is well accepted, and students believed that the method with devices for active ARS positively influenced their performance.	The L + ARS seems very promising but highly dependent on hardware/tablets/devices and also on teachers' ability to facilitate the sessions. Anonymity of students for professors was experienced relatively low: 68%; also, anonymity of students for classmates was relatively low: 76%, while the anonymity is

(Continues)

TABLE 5 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
				learning 87%, dynamic lecture 95%, active participation 97%, anonymity 68%–76%, immediate results 96%.		considered one of the major advantages of ARS.
De Souza et al. (2018)	F2F alone, F2F plus '7 steps Tips', F2F plus Tips plus hands-on simulator training.	First- ($n = 66$) and Third-year ($n = 99$) dental students, $n = 66$. 12 months later, $n = 39$ second-year dental students agreed to participate again (Canada)	Student performances on light-curing. Measurement of the time taken to irradiate composite restorations.	For first-year students, Tips and hands-on simulator helped to increase skills on light-curing technique. For students beyond first year, time in dental school improved performance rather than instruction method.	A significant effect of training method on light-curing technique immediately after training for the first-year students. However, time in dental school improved skills irrespective of initial training method.	The results failed to show significant benefits of training students with a hands-on simulator method. However, authors believed that the simulator training had a positive effect on student skills.
Faust et al. (2021)	F2F plus individualized instructions.	First-year dental students, $n = 83$ (USA)	Randomized case–control study. Course in Ergonomics. A didactic lecture along with a pre-clinical practice session with peer patients. During the clinical practice session, students in the case group received 10 min of one-on-one individualized instruction. 2 weeks later, all students were assessed using a rubric on operator and patient positioning, while simulating restorative work.	4 out of 8 ergonomic scores showed significant (2 with $p < .05$) or trends (2 with $p < .07$) higher scores in case group (operator shoulder abduction position at $p = .029$, the lateral flexion of the spinal column at $p = .021$). The composite scores for ergonomic compliance were significantly better for case students versus control students (1.49 ± 0.24 vs. 1.22 ± 0.22, $p = .005$).	Hands-on individualized instruction improves ergonomic compliance.	For certain aspects of dentistry, perhaps a single lecture can be provided, but the education, for example, in ergonomics, needs individualized instructions and perhaps an alternative student-centred approach fully in the (pre-)clinical setting, utilizing the FC and PAL approaches.
Kruse et al. (2022)	F2F plus video	Third-year dental students, $n = 46$. Study performed in 2019 (Denmark)	Lecture/class on Rubber Dam Application. Randomized, double-blind, parallel arm design. Seven-item, 5-point Likert-scale questionnaire, at baseline (t1), after the video-based or control (PowerPoint) lecture (t2) and after hands-on training (t3). Assessment of judgement on benefits of rubber dam, motivation to use rubber	The lecture plus video and the lecture plus PowerPoint yielded comparable significant improvements in the students' Likert-scale ratings from t1 to t2 (all items $p < .05$), and from t2 to t3 (most items $p < .05$). No significant differences between the video and PowerPoint groups were found in the students'	In this study, the procedural video did not prove to be an enhanced learning aid over PowerPoint-based lecture on rubber dam.	Procedural videos have proven to be a valuable learning aid in a variety of teaching formats. The PowerPoint slides were still shots from the video. The video may be very useful in a TBL or FC setting rather than the traditional lecture.

TABLE 5 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
			dam, self-efficacy and expected use of teaching material.	ratings or in the qualitative analysis.		
Liu et al. (2019)	SBS in dental skill training.	First-year dental postgraduate students (residents, mean age 27 years), from 23 dental institutions, $n = 40$ (China)	Prospective, double-blind and randomized controlled trial. All-in-one group (control group, $n = 20$) or SBS group (experimental group, $n = 20$). Crown preparation on a plastic tooth. For SBS, each step consisted of a 3-min teacher-delivered lecture and 2-min practical demonstration. The training outcome was evaluated by the students (VAS scale), and the quality of outcome was assessed by two experts (per rubric) and by a digital system.	For the outcomes of the all-in-one group and the SBS group, the students' assessments were 6.15 ± 1.98 and 8.10 ± 1.41 ($p = .001$), the experts' assessments were 7.00 ± 1.75 and 8.40 ± 1.10 ($p = .005$), and the digital assessments were 6.43 ± 1.20 and 7.62 ± 0.51 ($p < .001$), respectively. Higher quality of crown preparation was attained in the SBS group.	The SBS teaching method can improve the learner's achievement in dental skill training.	By breaking down the tasks, learners' interest is stimulated, and theoretical and practical understanding is integrated more optimally. Unclear student population: the course seemed very basic, while the authors report recruiting postgraduate students. Also unclear of the setting (23 dental schools).
Rayyan et al. (2017)	Asynchronous Instructional video.	Dental students, $n = 145$ (Saudi Arabia)	Pre-clinical courses of fixed prosthodontics. Survey. Descriptive analyses.	63% of students considered the recorded video demonstrations to be the most convenient. 67% of students regarded live demonstrations to be the least convenient. 88% of students agreed that watching the video before the session made it easier for them to perform the pre-clinical procedure.	Majority of students watched and preferred recorded instructional videos for pre-clinical demonstrations over live F2F demonstrations or synchronous broadcasting.	Students like to watch instructional videos at their own pace. This makes it easier for lecturers, who may have a pre-recorded instructional video without the need to spend time in F2F or synchronous demonstrational video. The best videos can be repeated for several years.
Savoldi et al. (2021)	LW plus workshop with CBCT and dry skulls.	First-year dental students, $n = 64$ (China)	Teaching orofacial bone anatomy. Lecture alone or lecture plus workshop employing CBCT and/or dry skulls in various sequences. Students randomly assigned to four groups. Multiple-choice questions to assess learning outcome and Likert scales for subjective outcome.	Standard lecture followed by CBCT workshop showed highest learning outcome compared to other combinations but was not significant. Students' perception of learning was positively influenced by use of dry skulls ($p = .018$).	First-year dental students like to have availability of dry skulls when learning orofacial bone anatomy, but this did not show in enhanced knowledge.	Small number of students per group. Significant differences between groups may have been present if groups had been larger.

(Continues)

TABLE 5 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Signori et al. (2019)	LW	Dental students, $n = 45$ (Brazil)	RCT: F2F alone (lecture) or LW on teaching of diagnostic performance and theoretical knowledge on secondary caries.	The LW group had higher scores for four out of five diagnostic performances ($p < .05$). Multilevel regression analysis showed a positive impact of LW on two out of five diagnostic performances ($p \le .05$). LW group showed greater knowledge retention after 6 months versus F2F group ($p = .027$).	There was improvement in the students' practical skill in diagnosis when a practical training workshop was implemented in addition to a traditional lecture. Also, the LW group had better knowledge retention 6 months after intervention.	The cost effectiveness of conducting LW instead of L alone needs investigation. The applicability of LW in other dental schools also needs further investigation.

Abbreviations: ARS, audience response system; CAD/CAM, computer-aided design/computer-aided manufacturing; CBCT, cone-beam computed tomography; EVBL, enhanced video-based learning; FC, flipped classroom; FES, final examination scores; HR, hand-raising; ICDAS, International Caries Detection and Assessment System; L, lecture; LW, lecture F2F plus workshop; OMR, Oral Maxillofacial Radiology; PAL, peer-assisted learning; RCT, randomized controlled trial; SBS, step-by-step teaching; SP, student participation; TBL, team-based learning; VAS, visual analogue scale; VC, virtual classroom.

education of basic sciences (Mussarat et al., 2022). By reflective writing, students can be motivated towards deep learning and increased responsiveness of knowledge. In the presentation–assimilation–discussion (PAD) method, a classroom session is split into two segments. During the first half, instructors deliver presentations, whereas the second half is dedicated to students independently absorbing the material and subsequently engaging in group discussions. The PAD method not only highlights the guiding role of instructors but also fosters an environment that empowers students and enhances their motivation and enthusiasm for learning (Zhai et al., 2022). The PAD method can also be considered a student-centred method. Finally, 'co-teaching' is a strategy to boost student engagement. Co-teaching involves two instructors, each with complementary expertise, for example, a basic scientist and a clinician who jointly deliver both foundational knowledge and relevance to clinical dentistry (R. Zhao et al., 2023).

2.3.4 | Evaluations and preferences from lecturers regarding conventional F2F before, during and after the COVID-19 pandemic

A study performed among dental teachers ($n = 101$) representing 18 dental schools in Germany aimed to assess faculty members' perspectives on digital teaching methods and the associated workload for creating digital lectures (Nold et al., 2022) (Table 6). Prior to the pandemic, only a quarter of them engaged in digital teaching and almost two-thirds lacked prior experience. Respondents' attitudes towards online teaching improved during the pandemic, indicating a positive shift for more online teaching in the future (Nold et al., 2022). A successful effort was the implementation of an inter-university course (six schools) on Health Policy in the VC environment, which also employed a form of FC and PBL/CBL (Kennedy et al., 2021). The collaborative approach to virtual teaching and learning was proposed as not only highly engaging for students but also cost effective and efficient, and the authors proposed that the model should continue beyond the constraints of the COVID-19 pandemic (Kennedy et al., 2021).

2.3.5 | Reasons for students to skip or appear late in class

Ensuring consistent attendance in dental classrooms is an ongoing challenge for most dental schools. A cross-sectional survey showed that 44% of students occasionally skipped ≤2 classes per month (Alamoudi et al., 2021) (Table 7). Notably, male students and underachievers skipped classes more often. Students also tended to skip non-dental basic science classes more often. The top three reasons cited by students for missing classes were (i) early morning classes, (ii) their perceived need for exam preparation and (iii) lectures from teachers considered by the students to have below-average presentation skills. Notably, lecture attendance of dental students in an oral pathology course was a significant predictor of final grades (Shumway et al., 2018).

TABLE 6 Adjuncts, additions and other extras to improve conventional face-to-face (F2F) teaching: student and educator perspectives.

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Kennedy et al. (2021)	A synchronous, multi-university, virtual course, in VC, employing aspects of FC, PBL and CBL, here designated as 'SSDL'.	Two course directors, 7 lead instructors, 28 students (seven programmes: predoctoral, graduate, resident) across six dental schools in five states, in different time zones (USA)	Course on 'Health Policy'. Course evaluation performed by each of the six dental schools in their own formats/systems. Evaluations were shared among course directors and lead instructors. Open-ended questions and commentaries.	Course faculty received feedback for the next years' inter-university course: create smaller groups in the break-out sessions, improve email communication, design favourable scheduling of the synchronous sessions to accommodate students in the different time zones, use a single learning/course management system, add a variety of pre-class activities, add more case-based discussions earlier in the course.	The pandemic was instrumental to initiate a multi-university ($n = 6$) virtual oral health policy course in five states and various levels of learners. The VC and student-centred advances of the SSDL model provided the opportunity for delivering this virtual multi-site course.	Six schools leveraged their faculty and shared costs to supply an ongoing learning experience for students who were enriched beyond any single school's ability. This improved the quality through expanded faculty input and participation. Students responded with positive feedback at all schools, and many took steps to engage in learning opportunities in public policy after the course ended.
Mussarat et al. (2022)	Guided reflection, using reflective writing, following the Gibbs reflective cycle.	Second-year dental students, $n = 75$ (Pakistan)	Students randomly assigned to an experimental group 1 ($n = 37$, reflectors) and a control group 2 ($n = 38$, non-reflectors). Basic medical courses. Post intervention, a test of 30 multiple-choice questions on the selected topics was conducted to compare the level of learning between the groups. After 3 weeks, the same activity was repeated with the same groups, but with different topics of lectures.	After Session 1, reflectors scored 23.9 ± 4.8, and non-reflectors scored 23.7 ± 3.8 ($p = .8$). After Session 2, reflectors scored 23.5 ± 4.4, and non-reflectors scored 20.2 ± 5.4 ($p = .018$).	Engaging in reflective practices immediately after teaching of basic sciences courses may serve as a viable approach to enhancing outcome-driven learning in undergraduate dental students.	Pilot trial, small sample size; unclear why guided reflection did not show results after the first session. The better results for reflectors after session 2 could mean that these students had gained experiences after the first session of reflective writing.
Nold et al. (2022)	VC, traditional F2F, asynchronous and asynchronous online lectures.	Dental educators across the country, from 18 dental schools, $n = 101$ (Germany)	Survey with 27 questions, VAS scale, free text, fixed answers, among all German dental faculties, January–April 2021.	64% of lecturers had no experience with the VC before the pandemic. After the pandemic, 88% of lecturers preferred analogue conventional F2F, while 12% preferred online. Nevertheless, 81% of lecturers reported that	Over 80% of lecturers reported offering online lectures and seminars during the pandemic. However, close to 90% of participating teachers still considered F2F teaching their preferred format. Lecturers believed that the	The opinion of the teachers from Germany was rather traditional; nevertheless, they shifted to being more favourable for VC teaching during and after the pandemic. No mention in this paper about student-centred methods.

(Continues)

TABLE 6 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
				VC should be more strongly implemented in dental education in the future. Interestingly, of the teachers preferring conventional F2F, the highest proportion (33%) was in the age group of 30–40 years, while of the teachers preferring online, somewhat more belonged to the age group 51–60 years.	greatest opportunities for interaction existed in traditional analogue teaching, whereas synchronous and asynchronous digital teaching were perceived less favourably.	
Yakin and Linden (2021)	Adaptive learning platform (online)	First-year ($n = 43$) and third-year ($n = 14$) dental students. Study performed in 2018 and 2019 (Australia)	Course on 'Histology of Normal Tissue Architecture'. Mixed-methods analysis: exam scores (for first-year students $n = 43$). Two groups of histology identification questions: the first group on content that was covered in adaptive learning lessons (experimental questions), the second group for which adaptive learning lessons were offered (control questions). All were compared to exam results of regular lessons on other but relevant topics in year 1. Survey on perceptions among the first- and third-year students for their experiences with adaptive learning, 5-point Likert scale (total $n = 57$).	Higher scores were obtained in the experimental (74.3 ± 3.5%) compared to control questions (61.2 ± 6.1%; $p = .04$). Students scored higher in the experimental exam questions compared to the regular lesson questions (74.3 ± 3.5% vs. 59 ± 4%; $p = .01$). A significantly larger number of first-year students perceived that the adaptive lessons improved their knowledge of the subject compared to their knowledge on histology before starting the course ($p < .001$).	The adaptive learning showed potential to improve student engagement, motivation, perceived knowledge and exam performance.	Adaptive learning lessons were self-directed and involved independent learning activities, and they were constructively aligned with their F2F interactive lectures, assessmentsand subject learning outcomes. The report is presented in a somewhat 'biased' mode and the study was not properly controlled.
Zhai et al. (2022)	PAD	Second-year dental students (China)	Course on 'Oral Pathology'. Experimental PAD group, course taught in 2019, $n = 88$.	Distribution of the final theory test scores showed better results for the PAD group than the control	Compared to traditional lecture-based teaching, the PAD class fostered a greater enthusiasm for	The PAD method seems promising and should further be tested in other basic science and 'difficult

TABLE 6 (Continued)

Author, year	Teaching method investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
			Control regular F2F teaching, course taught in 2018, $n = 72$. The two groups' teaching outcomes were compared using final theory tests, biopsy diagnostic tests and questionnaires.	group ($p < .001$). In the biopsy diagnostic tests, the PAD group scored higher than the control group (7.98 ± 0.13 vs. 5.20 ± 0.22, respectively $p < .05$). No difference for the 'enhancing knowledge mastery' item ($p > .05$). The PAD group showed superiority in the remaining nine evaluation items (p-values ranged from 0 to .029).	learning among students and yielded improved educational outcomes.	subject' classes. It should also be tested in other countries.
R. Zhao et al. (2023)	Co-teaching in basic science course (two lecturers, with complementary expertise [fundamental and clinical], presenting the curriculum together)	Second-year dental students, 2020 cohort ($n = 39$), and 2021 cohort ($n = 64$) (New Zealand)	Course on biochemistry. Co-teaching by a biochemist and an oral biologist. Cohort 2020 in VC; cohort 2021 by F2F. Survey by online questionnaire on experiences and engagement levels of students; 10-point interval scale and free-text questions.	Students from both cohorts preferred the co-teaching approach with a mean of 8.74 ± 1.35. In 2020 and 2021, 77% and 76% of participants, respectively, preferred a combined biochemistry and clinical dentistry delivery, either in person (37%), via Zoom (19%) or via video recording (14%). Students experienced enhanced engagement when co-taught and they attributed this to integration of the curriculum, making the content more relevant and stimulating.	Co-teaching established the relevance of theoretical biochemistry to clinical dental sciences and enhanced the students' learning experience. Highest appreciation of students for in-person, two-teacher tutorials.	While effectiveness of teaching biochemistry to dental students may improve, the additional costs of a co-teacher need to be considered when implementing this improvement to traditional lecture-based biochemistry. The study is not controlled, and no comparison. One cohort of students (2020) was taught online (VC).

Abbreviations: CBL, case-based learning; FC, flipped classroom; PAD, presentation–assimilation–discussion learning; PBL, problem-based learning; SSDL, staged self-directed learning model; VAS, visual analogue scale; VC, virtual classroom.

Quality of lecturer

Students think a good teacher is knowledgeable, has good communication skills, is enthusiastic, motivates and inspires (Sekhon et al., 2022) (Table 7). Non-inspiring lecturers with poor communication skills and lack of enthusiasm are also reasons for students to skip classes (see above) (Alamoudi et al., 2021).

2.4 | Discussion

2.4.1 | Aim of review and main outcomes

The current scoping review explored recent literature on the most trusted and most widely applied teaching method, namely F2F. There were very few reports focusing specifically on periodontology.

1. The review identified a wide variety of adaptations to, or alternatives for, F2F teaching methods to promote student-centred knowledge transfer. These educational methods aim to activate students during the learning process (ALC, ARS), to make them owners of the learning process (FC, PAL, TBL) and to promote deeper ways of learning and understanding (e.g., PBL, CBL, TBL). Most papers commented positively about the (inter)active and student-centred approach both in pre-clinical and clinical teaching.
2. The COVID-19 lockdowns forced educators to abolish F2F teaching and forced the introduction of the VCs and online examinations. A diverse global student body has embraced VCs across a wide range of courses, with many students expressing a preference for this format for certain types of courses, although not uniformly and not without exceptions.
3. Conventional F2F seems least suited for teaching clinical procedures. Most educators and students acknowledge that small-group and individual instruction are the most effective, possibly after a plenary introductory lecture enriched with (enhanced) video and cases.

A limitation of this review is that the literature search was restricted to the 3-year period before and after the outbreak of the COVID-19 pandemic. This approach was taken given the major impact that the pandemic had on periodontal and dental education globally. It became clear from papers published prior to this that a great majority of them could not add meaningfully to the findings or conclusions of this review. Hence, we restricted the final search to the period 2017 to June 2023, spanning 3 years on either side of the start of the pandemic.

2.4.2 | Some critical notes regarding (inter)active and student-centred learning

Most papers show positive results for (inter)active and student-centred learning methods. Variations on these methods include PBL, TBL, CBL, PAL and the classroom types ALC, TELC and FC. Nevertheless, in a systematic review of PBL on the acquisition of radiographic interpretation skills among dental students, it was found that no significant differences were found for knowledge scores and satisfaction level (Luke et al., 2021). It must be realized that most likely the advantages and success of PBL are also dependent on the type of course and quality of the lecturer. Thus, how students *perceived* learning versus *actual* learning was examined in large introductory physics courses taught by experienced lecturers using two methods: (i) ALC or (ii) F2F (Deslauriers et al., 2019). Both groups received the same content and materials. Students in ALCs learned more, although they perceived their learning as slightly lower compared to those in passive settings. It is suggested that charismatic lecturers (the superstars) may create an illusion of effective learning, causing students to prefer lectures above active learning (Deslauriers et al., 2019). These findings also highlight that students initially associate the increased cognitive effort of active learning with poorer learning, which can negatively impact their motivation, engagement and self-regulation. Therefore, instructors should implement strategies to improve students' responses to active engagement in the classroom. Interestingly, educators also may resist implementation of (inter)active and student-centred teaching methods. Instructors face numerous challenges in adopting active teaching strategies, including time constraints, limited resources, lack of departmental support, concerns about content coverage and worries about their own teaching evaluations. They also believe that students resist active methods and prefer traditional ones, and they fear student complaints (Deslauriers et al., 2019). Students often may dislike forced interaction and increased responsibility for their learning, and have concerns about the effectiveness of PAL; moreover, the active and student-centred learning methods require obligatory attendance of all students and indeed their equal, active participation: for example, the attendance of half the class in the ALC means a failure of the method. However, when instructors explain and facilitate active learning, student attitudes can improve (Deslauriers et al., 2019). Therefore, notwithstanding the key finding (i) above, adaptations and alternatives to traditional F2F teaching need careful consideration at the level of learning outcomes, educator, institute and country (Neuwirth et al., 2021). There are cultural, geographic, technical and economic differences around the globe, not least in the various levels of hierarchy between students and teachers, the possible peer competition and refusal for peer-to-peer interaction. And with this, it can also be concluded that whatever new and alternative methodology of knowledge transfer is currently presented or proposed (and tried during the pandemic), some form of F2F teaching is here to stay, whether it is traditional live in a classroom or theatre, or in the VC (online) synchronously or asynchronously. This conclusion was also recently brought forward in an opinion paper evaluating the advantages and disadvantages of traditional lectures (Chandrasekharan Nair et al., 2022).

2.4.3 | Some critical notes regarding VC and enriched F2F teaching

A Europe-wide survey questioned 879 dental students in 34 countries on teaching methods and experiences during the COVID-19 pandemic

TABLE 7 Reasons for students to skip face-to-face (F2F) lectures or appear late in class and related test results, and studies on quality of teachers.

Author, year	Class attendance and quality of teacher investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Alamoudi et al. (2021)	Reasons for skipping F2F class	Second- to sixth-year dental students. $n = 678$. Study performed in 2019 (Saudi Arabia)	Cross-sectional validated survey included questions on demographics, average travel time to school, current dental year, most recent GPA and student's perspective towards classroom lectures.	44% occasionally skipped ≤2 classes per month, 30% skipped 3–4 classes and 25% skipped ≥5 classes/month. More than half of female students skipped at most two classes/month, whereas male students showed somewhat lower compliance, with 39% of males and only 14% of females missing >5 classes per month ($p < .001$). Second-year students were more likely to be absent from classroom lectures (31.3%), while third-year dental students were less likely to do so (15.4%). 42% of underachievers were more likely to skip ≥5 lectures per month compared to A-grade (23%) and B-grade students (16%) ($p = .014$). Reported justifications for missing classes included early morning classes (48%), exam preparation (42%) and lecturer's poor presentation skills (42%).	The current data suggests a multi-factorial model for students' attitude towards classroom attendance: early morning classes, other class exams, lecturers' poor performance, the difference between male and female attitude and underachievement. Regarding the benefits of attending classroom lectures, 76% reported that lectures had a positive impact on their academic performance; this sentiment was more pronounced among female students than males (82% vs. 68%, $p < .001$).	Compliance with classroom attendance is a global challenge. Good presentation skills will motivate students to attend F2F classroom lectures. When videos of the lectures were available, 29% of students indicated they would be more likely to skip or be late to lectures while 49% were neutral on the matter, and the rest (23%) committed to remaining punctual even with video recordings available. Students tended to skip non-dental basic science classes more often.
Sekhon et al. (2022)	Students were asked about the qualities of a good teacher.	First- to fourth-year dental students, in two dental colleges, $n = 382$ (India)	Questionnaires on tutor performances on a 5-point Likert scale.	Student ratings for 'strongly agree' on 'knowledgeable', 'communication skills', 'enthusiastic' and 'motivates & inspires' were 80%, 61%, 66% and 94%, respectively.	Students think a good teacher is knowledgeable, has communication skills, is enthusiastic and motivates and inspires.	Not clear when study was performed: before, during or after COVID-19, so unclear if teaching was online.

(Continues)

TABLE 7 (Continued)

Author, year	Class attendance and quality of teacher investigated	Study population and country	Study design, data analysis	Main findings	Conclusion	Remarks
Shumway et al. (2018)	Correlation of lecture attendance with test results.	Second- and third year dental students, $n = 233$. Academic year 2016 (USA)	Course on OP course grades were correlated to % attendance in lectures (Att), to grades in PBS courses, and to AA and TS scores on the Dental Admission Test.	The results of a multiple regression analysis showed that both % Att ($p = .016$) and TS score ($p = .008$) were predictors of OP course grade, while gender, race and age were not. Students' grades in OP were moderately to strongly correlated with their grades in all PBS courses ($p < .001$).	Lecture attendance in OP should be encouraged but % Att was a weaker predictor than TS scores.	Students with lower TS scores and PBS course grades should be encouraged to use additional supports such as attending lectures and ask for tutoring to improve their performance in OP.

Abbreviations: AA, academic average; GPA, grade point average; OP, oral pathology; PBS, prerequisite basic science; TS, total science.

(Coughlan et al., 2022). Nearly 39% of the European dental students thought that the VC had a significant role to play in future dental education, while 47% thought that it only had a small role to play (Coughlan et al., 2022). Students blamed their lack of on-site clinical hours, the postponement of clinical teaching and treatment of patients, as well as the shift towards an online teaching environment, for causing reduced preparedness for their professional future, and as such felt a negative connotation with education in the online environment. However, the students confirmed the value of integrating the VC in the dental school curriculum (Coughlan et al., 2022). The experiences show that students have a stronger preference for synchronous, recorded, live lectures and asynchronous pre-recorded lectures compared to online live but non-recorded lectures (Di Carvalho Melo et al., 2023). Another advantage for asynchronous lectures via the VC was better personal time management and the possibility of revision and making additional notes. A minority of students perceived e-learning as a valuable tool for acquiring clinical knowledge and developing manual skills (Di Carvalho Melo et al., 2023).

From the teachers' perspective, a survey among dental educators showed that while the COVID-19 pandemic brought about numerous challenges for them with the transition to e-learning, it also provided them with valuable experience and increased confidence (Goh et al., 2022). Another paper reported the transitioning of a conventional course on public health issues in one school into a cost-effective, inter-state and six-school-wide synchronous, virtual FC-type learning experience to the great satisfaction of teachers and students (Kennedy et al., 2021). Also, in Germany, a survey among students and lecturers showed that digitization fostered learning independent of time and place and encouraged student autonomy (Hertrampf et al., 2022). However, it was associated with technological challenges and additional work, and the online form brought about a lack of feedback and loss of interaction. Nevertheless, online and offline asynchronous and synchronous teaching has potential (Goh et al., 2022). This is particularly encouraging when dental educators are to embrace a blended approach (Hattar et al., 2021; Mather et al., 2023; Saeed et al., 2020).

Dental undergraduate students, postgraduate dental specialist-students and professionals seeking CPD (also known as CE) have different needs and wishes. For example, there was a surge in traditional CPD for dental professionals after the COVID-19 pandemic; the professionals were longing to go to meetings for live F2F lectures, since these involve peer-to-peer interaction, professional exchange and reflection, adding to the learning effect of 'passive' lectures.

If dental schools adopt e-learning and virtual lectures in the curriculum, or—as many students have suggested—adopt a blended form (Hattar et al., 2021; Mather et al., 2023; Saeed et al., 2020), then it is an absolute prerequisite that there are high-quality technical equipment and internet connections. During the COVID-19 pandemic, internet connectivity was at times poor and online lectures were not always a success (Mahendra et al., 2022; Shrivastava et al., 2022). Also, there are certainly global variations in the availability of the necessary hardware and software; investments in such requirements must be able to be made, and economic and educational priorities

may differ from country to country. On the other hand, the students have pointed to the drawbacks of passive online education: they reported reduced attention spans and diminished communication with peers and instructors.

Methodologies that seem to have great potential to supplement F2F teaching (with or without lecture recordings) include the use of an online and/or a cloud-based tool for better connectivity with the audience; this can be regarded as 'adaptive learning' (e.g., via Smart Sparrow platform, Mentimeter, Kahoot, Socrative) (Yakin & Linden, 2021). The anonymity of responses encourages engagement and empowers presenters to adjust their content delivery on the fly for more effective presentations in larger gatherings. These platforms can also be regarded as an ARS and will counteract the passivity of conventional F2F. Reports in other disciplines and among postgraduate students in paediatric dentistry corroborated the advantages of Mentimeter (Patterson et al., 2020; Pichardo et al., 2021).

2.4.4 | The engaging role of teachers in F2F learning

Some courses seem better suited for F2F. For teaching a class on 'compassion and empathy', some F2F interaction with lecturers has always been deemed necessary (Sukhera & Poleksic, 2021). Further, although students believe F2F lectures will positively impact their academic performance, students also skip classes, more often those who are underperformers. Among the reasons for missing classes were lectures by teachers with below-average presentation skills (Alamoudi et al., 2021). And an exceptional lecturer ('superstar') can generate such a profound sense of enthusiasm for learning that students would opt for their lectures instead of engaging in active learning, although active and student-centred learning is more effective (Deslauriers et al., 2019). Thus, adopting more student-centred teaching with the various methodologies outlined in this review—with skilled teachers and facilitators—may elevate the knowledge base of future dentists.

2.5 | Conclusions

Live F2F teaching will continue to be a highly valued method of dental education by both students and teachers. The recent literature also shows that asynchronous and synchronous F2F lectures in the VC are perceived by students and teachers as good alternatives, and they proved their value during the COVID-19 pandemic. Further, the combinations of conventional live F2F with online synchronous FCs and methodologies such as ALC, PBL, CBL, PAL, TPS and TBL seem the way forward for contemporary dental education. By contrast, although this review presents mainly positive experiences with enhancement of traditional F2F teaching, we should realize that teaching methods themselves for UG, PG and professional learners, as well as student perceptions for additional and non-conventional methods, may differ tremendously by country, continent and culture. Furthermore, a limitation of the available evidence is that relatively few studies focused on periodontology, necessitating a broader view of dental education literature. Finally, whatever teaching methodology is adopted, this review has also highlighted that availability of high-quality teachers (those who are inspiring, enthusiastic and with good communication skills) to facilitate student-centred approaches is critically important for all methods.

3 | THE IMPACT AND FEASIBILITY OF VIRTUAL METHODS AND PROGRAMMES OF EDUCATIONAL PROVISION IN UNDERGRADUATE, POSTGRADUATE AND CONTINUING PROFESSIONAL DEVELOPMENT IN PERIODONTOLOGY: A SCOPING REVIEW

3.1 | Aim of review

The introduction of digital technologies has profoundly changed the landscape of dentistry, offering unparalleled advantages in diagnosis, treatment planning, education and patient care (Srivastava et al., 2023). The COVID-19 pandemic has further highlighted the importance of virtual education, with many dental students expressing satisfaction with online learning platforms and appreciating the flexibility and interactivity they offer (Katebi, 2023). Furthermore, innovations such as digital twins, which are virtual representations of physical objects or processes and have a wide range of applications across different industries, have emerged as potential game changers for distance learning in the dental industry, highlighting the continued evolution and potential of digital education (Maddahi & Chen, 2022). As dental treatments and patient experiences are reshaped by technological advances, including augmented reality (AR) and VR, the integration of these tools into dental education has transitioned from being beneficial to essential (Fahim et al., 2022). Given the growing interest and developments in this area, we conducted a scoping review to assess the extent of research on virtual methods in periodontal education. This approach was particularly relevant in a rapidly emerging field, as there are still a number of ambiguities in the terminology and concepts found in the current literature. In light of the emerging state of research on virtual methods in periodontal education, our scoping review also aimed to identify best practices in virtual periodontal education and assess their relevance, impact and feasibility in dental curricula.

3.2 | Methods

The methodology for this scoping review was based on the framework proposed by Arksey and O'Malley, which provides a structured approach to mapping and categorizing the existing literature on virtual programmes in undergraduate, postgraduate and continuing periodontal education (Arksey & O'Malley, 2005). Arksey and O'Malley's framework included five key stages, which were followed in the

present review: (i) defining the research question, (ii) identifying relevant studies, (iii) selecting the studies, (iv) mapping the data and (v) collating, synthesizing and reporting the findings. By following this framework, we aimed to provide a thorough and transparent exploration of the current state of knowledge on virtual periodontal education and to ensure that our findings were both rigorous and relevant.

3.2.1 | Defining the research question

The key research question that guided our scoping review was, 'What is the current state of knowledge about the use of virtual learning methods and programmes in undergraduate, postgraduate and continuing professional development in periodontology, and what insights can be gained about their relevance, impact and feasibility?'

3.2.2 | Identifying relevant studies

To address our research question, we used a comprehensive search strategy aimed at capturing a wide range of studies discussing virtual learning methods and programmes in periodontal education. Our search was not limited by study design or publication type, allowing for a broad exploration of the topic. We searched the electronic databases PubMed and Embase (via Ovid). Additionally, we reviewed reference lists of included articles, consulted experts in the field and considered grey literature sources to ensure comprehensive coverage.

Our search strategy combined terms related to virtual methods and programmes such as 'online learning', 'e-learning', 'web-based learning', 'distance education', 'haptic', 'simulator', 'virtual reality', 'augmented reality', 'artificial intelligence'; contents such as 'periodontology'; and target groups such as 'undergraduate education', 'graduate education', 'continuing professional education'. The example search string for PubMed was ((virtual method) OR (virtual program) OR (online learning) OR (e-learning) OR (web-based learning) OR (distance education) OR (haptic) OR (simulator) OR (3D) OR (virtual reality) OR (VR) OR (augmented reality) OR (AR) OR (artificial intelligence) OR (AI) OR (ChatGPT)) AND ((periodontology) OR (periodontal) OR (periodontics) OR (perio) OR (gum disease) OR (periodontitis) OR (gingivitis) OR (gingival)) AND ((dental student) OR (undergraduate) OR (postgraduate) OR (continuing education)). The search was limited to articles published in English up until 31 August 2023.

3.2.3 | Study selection

All identified records from the search were imported into EndNote and duplicates were removed (Figure 4). Two reviewers (C.A.R., J.B.E.) independently screened titles and abstracts against the inclusion and exclusion criteria.

Inclusion criteria:

- Studies that focused on virtual learning methods and programmes in undergraduate, postgraduate and continuing periodontal education
- Studies that examined the relevance, impact or feasibility of virtual learning methods and programmes in periodontal education
- Studies that were published in English
- Studies that were published between 2013 and 2023.

Exclusion criteria:

- Studies that did not focus on virtual learning methods and programmes in periodontal education
- Studies that did not examine the relevance, impact or feasibility of virtual learning methods and programmes in periodontal education
- Studies that were not peer-reviewed (e.g., conference abstracts, editorials), or were not relevant to undergraduate, postgraduate or CPD/CE in periodontology.

Discrepancies were resolved through discussion or by consulting a third reviewer. Full-text articles were assessed for eligibility, and reasons for exclusion at this stage were documented. Once the list of relevant studies was finalized, the following information was extracted and incorporated into the evidence tables, including the following:

- Study details: author(s), year of publication, country of origin, study design
- Population: target population (e.g., undergraduate, postgraduate, CPD)
- Study design: description of the virtual learning method/tool, platform and associated technologies studied
- Outcomes: key findings, benefits, challenges and any measures of effectiveness or impact
- Conclusions: brief description of the conclusions drawn by the authors from the respective studies
- Recommendations: suggestions for further research.

Any discrepancies in data extraction between the two reviewers were resolved by discussion or, if necessary, consultation with a third reviewer.

3.2.4 | Data mapping and synthesis

Given the anticipated heterogeneity of the studies included, a meta-analysis was not considered. Instead, the extracted data were mapped and summarized narratively. Data from the studies included were summarized in evidence tables, categorizing studies by the type of virtual learning method, target audience and key outcomes. In addition to the evidence tables, a thematic analysis was conducted to identify common themes, patterns and trends across the studies. This helped us to understand the broader implications of virtual learning in periodontal education and highlight areas of convergence and divergence in the literature.

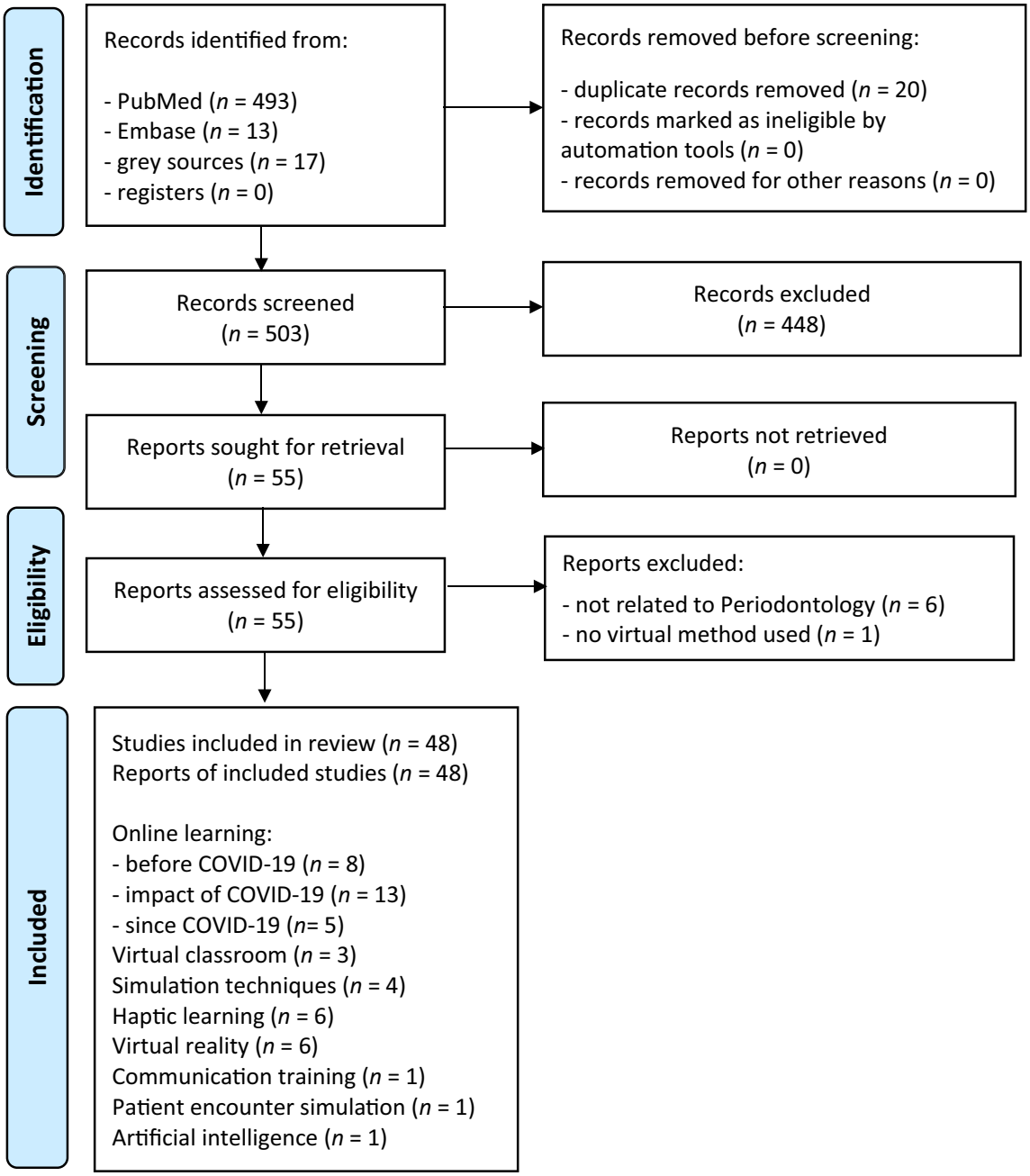

FIGURE 4 Identification of articles (based on the PRISMA checklist) to evaluate impact and feasibility of virtual methods and programmes of educational provision in undergraduate, postgraduate and continuing professional development (Section 3).

3.2.5 | Presentation of findings

The findings of this scoping review are presented in a structured manner according to the objectives of the review. The following structure was used where sufficient evidence was identified in the literature:

- Undergraduate dental education: teaching and assessment of knowledge and skills
- Postgraduate periodontal education: teaching and assessment of knowledge and skills
- Continuing periodontal education: teaching and assessment of knowledge and skills.

The evidence tables aimed to provide a detailed view of each study, while the narrative synthesis provided a holistic understanding of the state of virtual learning in periodontal education.

3.3 | Results

Of the 503 initial records screened, a total of 48 studies were included in the subsequent descriptive analysis: 2 experimental, 2 semi-experimental, 13 cross-sectional, 20 descriptive, 7 survey-based studies, 3 parallel randomized controlled trials and 1 single group study. These studies were grouped into eight areas of virtual

FIGURE 5 Number of publications per country and year on the subject of virtual learning. Smaller bullets represent one publication, larger bullets represent two publications per year. Countries are sorted from top (more publications in total) to bottom (fewer publications in total) (Section 3).

learning as illustrated in Figure 4. A clear finding was that over the last 20 years, the number of publications on virtual learning has increased significantly, especially during the COVID-19 pandemic (Figure 5).

3.3.1 | Online learning

Online learning, characterized by its flexibility and adaptability, has become an integral part of periodontal education. It uses digital technologies and the Internet to deliver educational content and enable remote instruction, providing learners with access to courses and resources, typically from their homes. In the field of UG, PG and CPD, the adoption of online platforms has been driven by both the evolving technological landscape and, more recently, by the COVID-19 pandemic.

Undergraduate education

Online modules and platforms have been used to teach basic periodontal knowledge to undergraduate students. Topics such as pathogenesis and periodontal therapy have been effectively delivered through digital platforms. Interactive elements such as videos, animations and multimedia presentations have enriched the learning experience. The evidence available in the literature on the evaluation of online learning before and after the COVID-19 pandemic and the immediate impact of the pandemic on online learning is presented in Tables 8–10.

The effectiveness of online learning for undergraduate dental students has been evaluated using pre and post tests, quizzes and assignments. Additionally, feedback mechanisms built into the online platforms provide students with insights into their performance and ensure continuous improvement. Overall, the integration of online learning tools in undergraduate periodontal education has not only facilitated a more dynamic and interactive learning experience but also proven effective in enhancing students' understanding and retention of key periodontal concepts.

Postgraduate education

Advanced topics, including advanced periodontal treatments and the content of recent research findings and S3-Level Clinical Practice Guidelines, have been delivered to postgraduate students through online platforms. In particular, webinars, online lectures and discussion fora appear to have facilitated in-depth exploration and peer interaction (Costea et al., 2022) (Table 9). In light of these studies, online platforms appear to offer distinct advantages such as flexibility and accessibility. However, they also pose challenges in terms of student satisfaction, perceived effectiveness and the delivery of practical skills. The move to online education during the COVID-19 pandemic elicited different responses from students in different regions, highlighting the need for continuous improvement and adaptation of virtual learning tools to meet the specific needs of postgraduate dental education.

TABLE 8 Online learning before the COVID-19 pandemic.

Author, year	Population	Methods	Results	Conclusions	Suggestions
France et al. (2021)	One group, total of 90,374 visitors, 16,739 participants (USA)	A review of the development and organization of IDM on the Coursera platform. Analysis of learner statistics, engagement and course feedback from the Coursera platform.	IDM gained 90,374 visitors since its launch, with 16,739 participants. Learners came from six continents and had diverse backgrounds.	IDM provided an opportunity for learners to understand general dental concepts and served as a foundational course for various health professions. The global distribution of learners indicates a strong demand for such courses in dental education.	Future research should focus on the roles of MOOCs in dental medicine, the potential subject matter and structure for expanding MOOCs in dental medicine and offering courses that prepare students for health professions.
Inquimbert et al. (2019)	Not specifically divided into groups in the described content. Total of 165 participants in the survey (France)	The study used a questionnaire survey to identify the type of pedagogical support preferred by dental students. Then, pedagogical videos were developed for the most desired discipline, and satisfaction was assessed.	95.7% of students found online classes and E-learning useful, especially videos.	Digital pedagogical support, especially videos, is highly beneficial in dental education. There is a strong demand for such resources in specific disciplines.	Future work should explore the effectiveness of other digital tools, assess the long-term impact of digital teaching methods and explore the potential of newer technologies like virtual or augmented reality in dental education.
Koole et al. (2012)	Undergraduate dental students in the second and third year of their curriculum (total $n = 119$) (Belgium)	Online periodontal case-based asynchronous discussions were conducted, followed by questionnaires to assess students' and supervisors' opinions. A crossover design was employed to assess the effectiveness of different frequencies of case introduction.	Both students and supervisors highly appreciated the online case-based discussions. On average, students spent 74 min per week on the cases.	Online periodontal-case-based asynchronous discussions are a valuable addition to the dental undergraduate curriculum. They aid in bridging the gap between theoretical courses and clinical practice.	Future research should delve deeper into optimizing the educational approach of online case-based discussions, exploring factors like the structure of presented cases, the frequency of feedback and the compulsory contributions from students.
Kumar et al. (2020)	Three groups based on performance in internal examinations (slow, moderate, advanced learners), 170 students in total (India)	Effectiveness of e-learning in dental education was evaluated through various methods such as continuing dental education, assignments/formative assessments and open discussions through the Edmodo app. The methodology included introducing the technique, designing the course and preparing interactive content.	170 students were categorized into slow, moderate and advanced learners. E-learning had a positive impact on knowledge, skills, attitudes and satisfaction levels.	E-learning can revolutionize dental education by improving both theoretical and clinical aspects. It has shown positive effects on students' knowledge, skills, attitudes and satisfaction compared to traditional methods.	Further research on long-term effects of e-learning in dental education, development of more interactive e-learning platforms, evaluation of different e-learning strategies, assessing scalability and sustainability and understanding perceptions and attitudes towards e-learning are suggested directions.

(Continues)

TABLE 8 (Continued)

Author, year	Population	Methods	Results	Conclusions	Suggestions
Ratka-Kruger et al. (2018)	One group of 50 students (Germany)	The study analysed the structures of a blended learning CPD in periodontology over 7 years. The programme and its instructional design were studied to identify the features of a successful web-based CPD.	Over 7 years, 50 students graduated with a Master of Science degree from the 'MasterOnline Periodontology and Implant Therapy' programme. Qualitative interviews affirmed the learning transfer in a blended learning setting.	Blended learning is an effective approach for CPD in dentistry, specifically periodontology. The MasterOnline programme, with its innovative methods and ICT tools, had positive outcomes in learning transfer and impact on students' dental practices.	Further research should explore the long-term impact of the blended learning CPD programme and sustainability of learning transfer. The effectiveness of specific educational methods and ICT tools should be investigated.
Soltanimehr et al. (2019)	Virtual group ($n = 20$) and traditional group ($n = 19$) (Iran)	Experimental study with 39 dental students with no prior instruction in radiographic interpretation of jaw lesions. Random division into virtual and traditional education groups, matched by GPA.	Virtual education group had higher mean scores in theoretical test, indicating better knowledge acquisition. No significant difference in OSCE scores between groups.	Virtual learning is more effective for knowledge acquisition in radiographic interpretation. No significant difference in clinical reporting skills between virtual and traditional methods.	Conduct larger multi-centre studies to compare virtual and traditional instruction for theoretical and clinical courses. Evaluate efficacy of blended learning for clinical courses in future studies.
Turkyilmaz et al. (2019)	Survey targeted 1130 predoctoral dental students at NYU College of Dentistry, with 255 respondents (USA)	Online survey developed after focus group discussion with experienced predoctoral dental students. A 14-question survey distributed through Qualtrics to second-, third-, and fourth-year dental students over 2 weeks.	48.6% preferred mixed traditional lectures and online learning, and 18% preferred solely traditional lectures.	E-learning positively impacts dental education, as favoured by predoctoral dental students. Many prefer a hybrid of traditional and online learning, with faculty-recommended resources.	Further studies are needed to evaluate e-learning's impact on students' performance, including exam results and clinical competency outcomes.
Woelber et al. (2012)	Two groups: complex-software group ($n = 46$) and easy-software group ($n = 39$) (Germany)	Quasi-experimental design with pre-test and post-test. 85 dental students randomly assigned to the complex-software or easy-software group.	Both groups showed improved knowledge and self-reported behaviours related to periodontal health. Learning time was significantly lower in the easy-software group.	Both complex and easy-to-use software are effective for case-based e-learning in dental education. Easy software achieved comparable or better outcomes in certain areas.	Further exploration of optimal blended learning settings. Evaluation of design elements like animations and multimedia in e-learning.

Abbreviations: CPD, continuing professional development; GPA, grade point average; ICT, information and communication technology; IDM, introduction to dental medicine; MOOC, massive open online course; OSCE, objective structured clinical examination.

TABLE 9 Impact of the COVID-19 pandemic on online learning.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Alam et al. (2023)	98 dental students from Bahria University Dental College (Pakistan)	Quasi-experimental study comparing 2020 online teaching with 2021 F2F and online teaching. Assessed oral biology knowledge and skills, included a perception questionnaire.	Statistically significant grade differences in short answer and viva questions. Online learning stressful and unsatisfactory with no significant difference in knowledge and skills.	Students preferred F2F teaching due to stress and dissatisfaction with online learning. Teaching mode did not impact knowledge/skills.	Conduct studies comparing scores and perception, address challenges in connectivity and costs, explore impact of online sessions on wellbeing, update technology and assess teaching strategies to enhance online learning for dental students.
Amir et al. (2020)	301 dental students (Indonesia)	Online questionnaire assessed student perspectives on DL versus CL in dentistry programme at Universitas Indonesia.	Only 44.2% of students preferred DL over CL, but they agreed that DL provided a more efficient learning method (52.6%), more time to study (87.9%) and more time to review study materials (87.3%).	Despite challenges, students adapted to DL and recognized its efficiency. Pandemic prompted educational transformation and blended learning integration.	Address response bias and non-respondents in future studies. Develop learning strategies based on findings.
Badovinac et al. (2021)	352 undergraduate dental students (Croatia)	Cross-sectional observational design. Electronically distributed survey among undergraduates in the academic year 2019–2020.	Only 36.1% students reported that online teaching fully met their expectations. However, the majority of students (61.9%) agreed that online lectures were as valuable as in-person lectures and that theoretical courses could be carried out online in the future (69.9%).	COVID-19 significantly impacted dental education and rapid switch to online learning. Students reported emotional effects, contact loss and practical course impact.	Implement changes based on study results, addressing challenges. Address students' emotional wellbeing during lockdowns/online learning.
Costea et al. (2022)	Resident doctors from three Romanian dental faculties, divided into junior and senior resident groups (PARO 1 and PARO 2) (Romania)	Cross-sectional multi-centre study. Web-based questionnaire collected resident doctors' perceptions on teaching activity.	Resident doctors were dissatisfied with clinical practice during pandemic but valued online courses. Different perceptions of educational programmes among resident groups.	Residents appreciated teaching strategies, including online theoretical teaching, but raised clinical education and performance concerns. Advocates for systematic online e-learning as part of hybrid teaching approach.	Reorganize and enhance pre-clinical and medical practice to improve residents' proficiency in performing accurate and efficient procedures.
Dong et al. (2022)	65 undergraduate dental students (China)	Implemented blended learning mode: F2F classes and SPOCs on Xfaike online platform. Preparations included optimizing teaching calendar, establishing online platform and integrating online/offline content.	Blended learning was highly accepted; all participants approved. Over 95% believed it improved self-learning ability.	Blended learning mode highly accepted, providing abundant learning materials and improved self-learning ability. Practical and effective for enhancing learning outcomes, especially for medical students meeting higher educational requirements.	Increase proportion of online courses for enhanced inspiration and interest. Incorporate small team collaboration for collaborative learning.

(Continues)

TABLE 9 (Continued)

Author, year	Population	Methods	Results	Conclusions	Suggestions
Hattar et al. (2021)	Two groups based on academic year (fourth- and fifth-year students). Total of 310 participants (Jordan)	A structured questionnaire survey was distributed to dental students to evaluate their experiences and perceptions towards online education and their self-perceived preparedness.	The response rate was 72%. Students partially appreciated the online education system, with 77% feeling they missed educational experiences due to the lockdown.	While students found value in some aspects of online education, they did not consider it a substitute for F2F clinical practice. They expressed reservations about practicing independently after graduation.	There is a need to explore new pedagogic methodologies, improve the online education system and establish collaborations between dental schools. Further research should evaluate the long-term impacts of the pandemic on dental education and seek ways to provide hands-on clinical experiences.
Iqbal et al. (2022)	Two groups (control group A and intervention group B), with 50 undergraduate dental students in total (25 each) from University of Jouf (Saudi Arabia)	Randomized controlled trial evaluating the impact of e-learning-assisted videos on pre-clinical skill competency levels. Students in group A were taught traditionally, while group B used e-learning-assisted videos alongside traditional techniques.	Significant difference was observed in experimental groups post intervention. Group B, which used e-learning-assisted videos, showed enhanced learning and skill competency levels compared to group A, which used only traditional methods.	E-learning-assisted videos, when combined with traditional teaching strategies, can significantly enhance the learning and skill competency levels in undergraduate dental students.	Future studies should delve deeper into the competency levels of students when they restore teeth in clinical practice sessions after engaging with supplemental educational videos.
Kanzow et al. (2021)	Dental undergraduates ($n = 33$) from University Medical Centre Göttingen (Germany)	Assessed distance education efficacy during COVID-19. Online screencasts for theoretical knowledge (11 weeks), on-site practical demos (10 weeks).	On average, each screencast was viewed by 24 students, 5.6 times per user.	Online screencasts effectively delivered theoretical knowledge during COVID. Highly accepted, more accessed than traditional lectures.	Enhance distance education: Longer/better screencasts based on student feedback. Address Periodontology exam performance.
Kaurani et al. (2021)	Dental undergraduates (total $n = 930$) from India, Nepal and Sri Lanka (India)	A cross-sectional study using a web-based survey to assess perceptions of online dental education during COVID-19. The survey included DREEM subscales and the Transferable Skills Questionnaire.	930 valid responses were collected. Sri Lankan students had the most positive perception of online education.	Dental students in the three countries had a generally positive perception of online education during the pandemic. The study emphasized the need for effective online dental education strategies, especially in resource-strained countries.	Recommendations include the development of effective online dental educational interventions, further research to explore areas of improvement in online learning perception, evaluating long-term impacts of online dental education and understanding the factors behind the positive perceptions in countries like Sri Lanka.
Mahendra et al. (2022)	One group, 834 participants (96% dental students, 2% practitioners and 2% academics) (India)	A Google Form questionnaire with 29 dental learning-based questions was distributed to dental students across colleges in Chennai via online platforms.	Approximately 15.5% of the study population were not satisfied with the facilities provided by the online learning platforms. 75% of the study participants did not prefer online learning over	Online-based learning systems can offer vast knowledge but need structured planning for dental curriculum. E-learning is not a full substitute for traditional dentistry	A special curriculum tailored for online dentistry methods should be devised and structured. Virtual demonstrations could augment traditional teaching.

TABLE 9 (Continued)

Author, year	Population	Methods	Results	Conclusions	Suggestions
			traditional learning and reported lower attention span and communication between students and teachers in online classes.	methods unless specially devised.	
Nguyen and Patel (2023)	Two groups (dental and dental hygiene) of 290 students responded from the University of Texas, School of Dentistry (UTSD) (USA)	An electronic survey was administered to all UTSD dental and dental hygiene students via Qualtrics. Information on demographics, pre-pandemic learning preferences and remote learning experiences during the pandemic were collected.	60% response rate ($n = 290$). Over 95% belonged to Generations Y and Z. No significant differences in responses were found between generations.	The pandemic impacted dental education, leading to a shift to remote teaching. Dental students appreciated online flexibility, while dental hygiene students favoured classroom instruction.	Studies can explore the pandemic's impact on dental education, including faculty and curriculum effects. Research can investigate reasons behind different preferences between dental and dental hygiene students.
Sarwar et al. (2020)	One group of 1207 students (Pakistan)	Cross-sectional study using an online survey. Data collected from undergraduate dental students in Pakistan using a pre-tested and validated questionnaire with 31 questions.	Majority of the 1207 students were dissatisfied with the institutional learning management system, quality of resources and teacher training for online classes. Worst ratings were for the effectiveness of online classes.	Dental students in Pakistan showed dissatisfaction with several online teaching aspects. The transition to virtual education needs more time and expertise.	Implement a virtual learning environment (VLE) compatible with smartphones. Dental colleges and universities should provide internet Wi-Fi devices, especially in areas with frequent power outages and average internet connections.
Vrazic et al. (2022)	Dental students from four Croatian universities (Zagreb, Rijeka, Split, Osijek). A total of 504 participants, with 63.5% from University of Zagreb (Croatia)	Anonymous internet-based survey assessing dental students' attitudes towards online learning during COVID-19 pandemic. 29-item questionnaire on demographics, online learning organization and perceptions.	504 participants (85.1% female), mainly from University of Zagreb. Overall student satisfaction was mixed.	Online learning was well regarded for lectures and seminars, and seen as substitute for certain traditional methods. Practical elements of dental education, like clinical clerkship, not effectively replaced by online learning.	Emphasize hybrid approach and improvement of online learning. Integrating well-reviewed formats (lectures, seminars) into curricula.

Abbreviations: CL, classroom learning; DL, distance learning; DREEM, Dundee Ready Education Environment Measure; F2F, face-to-face; SPOC, small private online courses; VLE, virtual learning environment.

TABLE 10 Online learning since the COVID-19 pandemic.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Farid et al. (2022)	Dental students ($n = 232$) and faculty ($n = 35$) at Margalla Institute of Health Sciences, Rawalpindi (Pakistan)	Data collected using the IOLE survey. 4-point Likert scale used to assess perceptions of incivility.	Majority of students reported moderate to serious online incivility, while most faculty reported no to mild problem. Students and faculty agreed that students were more likely to engage in uncivil behaviour than faculty.	Incivility exists in online dental learning, with higher likelihood of student uncivil behaviours. Both students and faculty identified various uncivil behaviours.	Further research needed on the extent and impact of incivility in dentistry's online learning environment. Develop training for students and faculty to reduce incivility.
Kruse et al. (2022)	Single group of undergraduate dental students at University of Freiburg; total 148 participants (Germany)	An online survey was conducted among undergraduate dentistry students, assessing their personal learning strategies, digital media experiences and preferences for different digital learning formats.	Majority of the students had a positive view of digital media for learning, especially for practical exercises. Classical media, such as textbooks, are preferred for basic knowledge while digital formats are favoured for practical training.	Students in the study hold a positive attitude towards digital media in learning, valuing it for practical exercises and the flexibility it offers. They prefer classical media for foundational knowledge but appreciate digital formats for practical training.	Future efforts should focus on creating digital teaching media tailored to student preferences, possibly integrating podcasts and digital patient cases. Further research can delve into the efficacy of varied digital learning strategies and explore the benefits of incorporating more online offerings in dental education.
Liebermann et al. (2022)	Two groups (anterior VR group and posterior VR group) of 82 students from University Hospital, LMU Munich (Germany)	Pre-clinical students were randomly divided into two groups for cross-over testing of tooth morphology knowledge using VR glasses for anterior or posterior tooth morphologies. Tests were conducted after 3 weeks (anterior) and 6 weeks (posterior) of practical course.	No significant differences in test results between the two VR groups. Group using VR glasses for anterior teeth showed better results in the posterior teeth test score.	Using VR for tooth morphology learning did not significantly improve test results. Anterior teeth test scores were better than posterior scores.	Future tests could be held virtually to potentially increase influences. VR dental learning environment holds potential for students despite the current lack of significant improvement in test results.
Veeraiyan et al. (2022)	49 dental undergraduate students from Saveetha Dental College and Hospitals, divided into group I ($n = 24$) attending online classes via Zoom, and group II ($n = 25$) attending offline classes (India)	Interactive teaching method employed for both platforms, teaching periodontics. Teaching plan: three modules per week, each with 12 lectures.	There was no statistically significant difference observed in terms of formative and summative assessment scores between the groups. Overall, the study suggests that interactive teaching methods in both offline and online platforms showed equivalent performance by the undergraduate dental students in periodontics.	Interactive teaching methods, whether online or offline, yielded similar performance by dental undergraduate students. Both groups showed comparable formative and summative assessment scores, suggesting mode of teaching did not significantly impact performance.	Validate findings with larger scale study for broader population. Explore long-term effects on academic performance and knowledge retention.

TABLE 10 (Continued)

Author, year	Population	Methods	Results	Conclusions	Suggestions
Z. Wu et al. (2021)	217 dental students and 134 non-dental students received traditional oral health education. 69 non-dental students attended an e-learning course. All from Sichuan University (China)	Quasi-experimental design with pre- and post-test approach. Questionnaires assessed knowledge, attitudes and behaviours concerning periodontal health.	Both dental and non-dental students improved knowledge and self-reported behaviours after courses. Non-dental students in traditional course achieved/surpassed dental students' pre-course knowledge.	Oral health education improved knowledge and behaviours for dental/non-dental students. E-learning is efficient, especially for non-dental students, surpassing traditional course in some areas.	Improve educational content and address misconceptions about gingival bleeding. Research and develop better oral care education approaches for Chinese students.

Abbreviations: IOLE, Incivility in Online Environment; VR, virtual reality.

For postgraduate students, assessments have focused on advanced clinical procedures, in-depth case studies and more advanced critical evaluation compared to undergraduate dental education. Online platforms have facilitated peer review, expert feedback sessions and detailed analysis of student performance. Despite the benefits of online platforms, studies reveal varying responses from postgraduate students. Although some appreciate the flexibility and accessibility of digital courses, concerns have been raised about the quality of resources and the challenge of effectively replacing hands-on clinical experience.

Continuing professional education

Professionals seeking continuous learning have had access to updated modules, the latest research and expert discussions through online platforms. Virtual conferences, webinars and on-demand lectures have ensured that professionals stay up to date with the evolving landscape of periodontology (France et al., 2021) (Tables 8–10).

Continuing professional education (CPE) assessments have focused on practical applications, recent advances and scenario-based assessments, while numerous online platforms have offered certifications, course completions and credits to ensure that professionals meet their CPD requirements. In essence, the digital shift in CPE has streamlined access to knowledge, enhanced proficiency and met evolving periodontal practice standards.

3.3.2 | Virtual classroom

The virtual classroom bridges the gap between traditional F2F teaching and digital learning platforms. It replicates the dynamics of a physical classroom in a digital space, enabling synchronous interaction, discussion and assessment. The results of the studies identified on virtual classrooms are presented in Table 11.

The early study by Mattheos et al. (2001) evaluated a web-based periodontology course using the virtual classroom approach. Today, it seems noteworthy that in addition to studying periodontology, the students emphasized the improvement of their computer skills, which was significant at the time. Approximately 15 years later and with more advanced information technology, Shi et al. (2015) highlighted students' preference for multimedia coursework in virtual environments, emphasizing the effectiveness of instant messaging forums. Khan et al. (2022) noted a positive reception to online lectures via 'Blackboard Collaborate', although many students felt the need for more interactivity and clarity in content delivery (Table 11).

In summary, the virtual classroom has evolved to enhance students' skills in both curriculum content and technology. Despite the progress, there is still a demand for greater interactivity and clarity to match the effectiveness of the traditional classroom.

3.3.3 | Simulation techniques

The results of the studies identified on simulation techniques are presented in Table 12. A total of five studies were identified that

TABLE 11 Virtual classroom.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Khan et al. (2022)	Single group in cross-sectional study. 245 dental students participated, with 227 completing the survey (Saudi Arabia)	Cross-sectional online survey with 245 dental students from King Khalid University. Survey included demographic data and perceptions of online lectures via Blackboard Collaborate.	77.6% of the respondents found the learning experience with online sessions from home comfortable, although half of this group did not have a better understanding of the lectures. 64.8% of the respondents believed that online lectures should be made more interactive.	Positive view of Blackboard Collaborate for online lectures, but connectivity and comprehension challenges exist. Suggests interactive, shorter lectures.	Improve connectivity, add interactive elements and optimize session durations. Support lower clinical classes.
Mattheos et al. (2001)	Four groups, each with 7 students, totalling 28 from 12 European countries. Web-based periodontology course using PBL (Sweden)	Web-based PBL course with synchronous/asynchronous communication, online libraries, multimedia. Students were grouped, each with a tutor.	82.1% (23) completed; 53% highlighted IT competence and 21% valued PBL exposure.	Virtual PBL classrooms enhance computer skills and tool acceptance. Sync./async. discussions are vital.	Evaluate virtual class impact on knowledge, skills and attitudes. Explore virtual learning effects on individual styles/needs.
Shi et al. (2015)	Cross-sectional study with three groups: medical school undergraduates, dental students and foreign students from three Chinese medical schools. Participants: 708 medical undergraduates, 385 dental students, 366 foreign students (China)	Cross-sectional study using self-administered questionnaire. Forum groups with instant messaging for virtual interaction.	68.81% of the students believed that the current teaching methods need to be improved. Multimedia course work, such as PowerPoint, appeared to be more acceptable to them, especially to the foreign students. More than half of the students thought the internet played an important role during their studies.	Computerized teaching benefits Chinese/foreign medical students. Instant messaging forums are effective and favoured.	Study long-term effects of computerized teaching. Identify aspects enhancing performance.

Abbreviations: IT, information technology; PBL, problem-based learning.

TABLE 12 Simulation techniques.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Dhulipalla et al. (2015)	Two groups: test group (3D animation) and control group (2D video); 40 students in each (total 80 first-year dental students) (India)	Parallel randomized controlled trial with 3D versus 2D videos.	3D group showed significantly better knowledge recall post intervention. Both groups improved clinical parameters after 1 month, with no significant inter-group difference.	3D animations outperform 2D videos in dental education and knowledge recall. Visual comprehension improved, benefiting healthcare outcomes.	Future work: Create regional 3D periodontal videos, and validate cross-culturally. Develop standardized method for periodontal knowledge assessment, ensuring validity.
Graetz et al. (2021)	Students of the 7th semester ($n = 30$) (Germany)	Assessed 30 untrained undergraduates on curettes (GRA) and sonic scalers (AIR) using manikins. 2-h theoretical lesson, 12-week digitized training (45 mins/week).	Initial evaluation showed no RCE-b difference; GRA better in RCE-d. After 12-week training, both groups improved RCE-b with no difference, GRA kept better RCE-d.	Digitized interactive training on manikins benefits inexperienced operators in root surface debridement. Participants achieved >70% biofilm and almost 80% hard deposit removal.	Future research should investigate correlation between direct digital feedback systems and user motivation during training.
Hanisch et al. (2020)	Dental students, 1 year after final examination. Two groups; group 1: typodont ($n = 35$), group 2: 3D-printed ($n = 33$) (Germany)	Used CAD/CAM and PolyJet printing for 3D surgical training model. Real patient data, two materials, sections with soft support.	3D-printed model with varied materials represented anatomical structures effectively. 35 participants rated traditional typodont, 33 rated 3D-printed.	Realistic 3D-printed models from patient data offer dental education alternative to typodonts. Vital for training/examining students.	Enhance gingiva mask for surgical learning. Explore realistic features in 3D-printed models based on real data.
Ren et al. (2017)	Incoming fourth-year undergraduates ($n = 389$) in the fifth-year DDS programme at West China Dental School (China)	Custom questionnaire to 389 West China Dental School students who had digital technology training (2012–2014). Assessed attitudes and efficacy perception; comparisons with conventional methods.	Cross-sectional survey (366 students): positive view of digital simulation. Preference for digital X-ray, microscopes and pathology slides.	Positive student attitude towards digital simulation in dental education. Digital training's stimulating, self-paced nature has transformative potential despite initial costs.	Future research may study effectiveness of digital simulation on learning outcomes.

Abbreviations: CAD, computer-aided design; CAM, computer-aided manufacturing; RCE, relative cleaning efficacy.

evaluated a variety of simulation techniques implemented in undergraduate periodontal education. Dhulipalla et al. (2015) demonstrated that 3D animation in dental education outperformed traditional 2D videos in improving post-intervention knowledge recall. Ren et al. (2017) highlighted positive student perspectives on digital simulations in dental education, highlighting the potential of tools such as digital radiographs and pathology slides. Graetz et al. (2021) further highlighted the benefits of digital interactive training on manikins, noting significant improvements in biofilm and hard deposit removal rates (Table 12).

Overall, simulation techniques in dental education represent a pedagogical advance. Techniques such as 3D animations enhance comprehension and practical application of skill, redefining immersive learning standards.

3.3.4 | Haptic training

Haptic training tools introduce a sensory dimension to dental education. By simulating the tactile sensations associated with dental procedures, these tools provide undergraduate dental students with a sensory-rich training experience that enhances the realism and depth of their learning. The results of the identified haptic training studies are presented in Table 13.

Yamaguchi et al. (2013) used a haptic VR simulator for caries removal and periodontal pocket probing, demonstrating improved skill retention through repeated training, while X. Zhao et al. (2020) introduced an innovative haptic rendering algorithm that skilfully simulated various tool–tissue interactions in dental implantation. More recently, Huang et al. (2023) showed that a multisensory teaching strategy for the training of periodontal instrumentation resulted in shorter treatment times and fewer post-operative complications (Table 13).

In summary, haptic training provides a sensory-rich dental education experience that bridges theory and practice. The tactile feedback from such tools increases students' skills and confidence, preparing them for real-life scenarios.

3.3.5 | Communication training

Effective communication is essential in oral health care, shaping patient trust, ensuring clarity of treatment plans and facilitating interdisciplinary collaboration. Virtual methods have emerged as innovative ways to improve and refine communication skills in dental students, providing them with realistic scenarios and feedback mechanisms. The results of one identified communication training study are presented in Table 14.

Fuhrmann et al. (2022) introduced the 'eMI-med' course for dental students in Germany. After participation, the students' 'patient–student interviews' were recorded and analysed. The results showed that students demonstrated high MI adherence, using open-ended questions and reflection at a level comparable to traditional classroom training. The learning module not only effectively delivered basic MI knowledge and skills but also improved students' therapeutic self-efficacy, particularly in areas such as smoking cessation and oral hygiene. The study suggests the potential benefits of blending e-learning with clinical feedback and highlights the need to assess the long-term impact of such MI-blended programmes (Table 14).

3.3.6 | Patient encounter simulation

'Patient encounter simulations' offer dental students a valuable middle ground between theoretical learning and real-world clinical practice. These simulations often incorporate sophisticated technology to allow students to interact with virtual patients, diagnose conditions and practice treatment protocols in a controlled, risk-free environment. The results of one patient encounter simulation study identified are presented in Table 15.

In an early attempt to simulate patient encounters, Schittek Janda et al. (2004) used a virtual learning environment that allowed dental students to interact with virtual patients through free-text communication. Results indicated that students who interacted with the virtual patient prior to real patient encounters were more communicative and asked more critical and general questions than the control group. The virtual patient proved effective in enhancing students' history-taking skills, with pre-interaction leading to improved communication and professional behaviour (Table 15).

3.3.7 | Virtual reality

VR provides an immersive learning environment that transports dental students into computer-generated worlds where they can practise procedures, interact with virtual patients and collaborate with peers in a simulated space. The results of the studies identified on VR are presented in Table 16.

Introduced by Steinberg et al. in 2007, PerioSim© is a haptic VR dental training simulator. In our experience, it has shown impressive realism in tooth and instrument visualization but fell short in gingival representation. A haptic-based VR periodontal training simulator was the focus of Luciano et al. (2009). This simulator was found to be effective in training both students and professionals, providing a realistic training environment for periodontal procedures. In a survey conducted in 2016, D. Wang et al. (2016) evaluated different dental education systems. Their findings highlighted the discrepancy between system capabilities and clinical training needs. Despite these challenges, they highlighted the potential of VR dental training systems with multisensory feedback. B. Zhang et al. (2020) investigated the benefits of combining virtual simulation with jaw models for implant training. The standout group, which started with the virtual model before moving to the jaw model, demonstrated superior theoretical knowledge and pre-clinical skills. In a subsequent study in 2021, J. Zhang et al. (2021) investigated periodontal training using both VR and jaw models. The results highlighted the benefits of a combined approach, with groups that integrated both methods

TABLE 13 Haptic training.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Huang et al. (2023)	Two groups: MTS group ($n = 50$) and CTP group ($n = 50$) (China)	Multisensory teaching strategy used for pre-clinical training of periodontal scaling in 100 undergraduate dental students. MTS group received haptic/auditory–visual feedback training, and CTP group received conventional training.	MTS group showed reduced treatment time, complications (gingival injury, haemorrhage, root surface roughness) versus CTP group.	Multisensory teaching strategies in pre-clinical periodontal training effectively reduce post-operative complications and enhance patient experience. Decreased treatment time, reduced pain or sensitivity were observed in MTS group.	Explore peri-scopes, virtual reality for immersive training. Investigate the link between sensory experience and scaling results.
Joseph et al. (2014)	60 participants: 40 third-year dental students (novice and simulation groups) and 20 experienced practitioners (France)	Participants were divided into novice and simulation groups. Both received traditional drilling instruction; simulation group also used Virteasy haptic simulator.	Simulation group's haptic simulator training yielded results close to experienced practitioners. Third-year dental students improved drilling accuracy, angulation and depth with practice.	Haptic simulator is beneficial for implant surgery training; simulation group near experienced practitioners. Third-year students outperformed peers, akin to experienced practitioners with simulator training.	Assess haptic simulator's long-term benefits and effectiveness in complex exercises. Explore haptic tech's role in improving fundamental dental procedure proficiency.
D. X. Wang et al. (2012)	Two participant groups: faculty members, dental graduate students. Exact numbers not specified (China)	Evaluated haptics-based dental simulator (iDental) via qualitative and quantitative analysis. Construct validity used to compare faculty and student performance.	iDental fidelity reduced with penetration; Haptic device with six DoF and force/torque feedback is needed. Dentists praised graphics, interface realism.	iDental shows potential, realistic graphics and clinical interface. Need for 6-DoF haptic device with force/torque feedback.	Refine iDental based on preliminary evaluation. Test second-generation simulator's training efficiency.
Welk et al. (2008)	80 dental students (USA)	Assessed DentSim integration/optimization at University of Tennessee. Tests, questionnaires; Likert scale.	Students proficient in Office programs, experienced in computer learning. Majority had home/campus computer access, supporting computer-assisted instruction feasibility.	DentSim enhances dental education via computer-assisted learning and simulation. Progressive integration recommended due to challenges.	Research: Optimal DentSim lab usage/management. Investigate DentSim's long-term impact on education and cognitive motor skills.
Yamaguchi et al. (2013)	CR task: 7 students in three training sessions each. Periodontal pocket probing (PPP) task: 26 students received training (Japan)	Used haptic VR simulator for repetitive training in CR and PPP skills. CR employed multilayered virtual models; scoring based on cut volume, overload instances and time.	Improved scores in CR's second and third sessions, indicating skill progress. Effective repetitive training outcomes in PPP task.	Haptic VR simulator, combined with repetitive training, effectively taught CR and PPP skills in a short time. Scores improved over CR training sessions, also evident in PPP task.	For CR training, incorporate scoring for excessive/insufficient cutting, ensuring complete lesion removal. Explore haptic VR simulator's potential with computerized tooth model for broader dental skill training applications.

(Continues)

TABLE 13 (Continued)

Author, year	Population	Methods	Results	Conclusions	Suggestions
X. Zhao et al. (2020)	N/A (focused on introducing/validating haptic rendering algorithm for dental implantation; no specific participant groups mentioned in the provided summary) (China)	Introduced haptic rendering algorithm simulating tool–tissue contact constraints in dental implantation. State switching framework distinguished high (H-DoF) and low (L-DoF) degree motion.	Algorithm simulated diverse tool–tissue contact constraints for dental implantation, covering H-DoF and L-DoF motions. State-switching framework facilitated seamless transitions between free and constrained motion states.	Introduced haptic rendering algorithm adeptly simulated diverse tool–tissue contact constraints during dental implantation, encompassing H-DoF and L-DoF motions. State-switching framework and virtual constraint method realistically portrayed complete implantation procedure.	Future research avenues were not mentioned in the provided summary.

Abbreviations: CR, caries removal; CTP, conventional training pattern; DoF, degrees of freedom; MTS, multisensory teaching strategy; PPP, periodontal pocket probing; VR, virtual reality.

showing improved theoretical scores and increased professional skill levels (Table 16).

VR in dental education replicates real-world procedures in a safe setting. Despite the challenges such as system–clinical alignment, the evolving VR tools promise an enriched learning experience.

3.3.8 | Artificial intelligence

AI is redefining the boundaries of dental education, introducing intelligent systems that personalize learning, improve diagnostic accuracy and even predict student performance. With the fusion of machine learning, predictive analytics and big data, AI offers a glimpse into the future of periodontal education. The results of the patient simulation studies identified are presented in Table 17.

In a study conducted by Glick et al. (2022), dental students were tasked with examining dental radiographs to identify furcation involvement lesions, with one group receiving AI assistance. Although performance, efficiency and confidence levels remained largely consistent between the two groups, there was a notable tendency for the AI-assisted group to make errors based on AI-generated responses. Despite this, participants in both groups believed that AI could improve clinical decisions. The study suggests that although AI has the potential to improve dental education, it is critical to guard against over-reliance and the biases it may introduce (Table 17).

3.4 | Discussion

3.4.1 | Summary of key findings

Over the past two decades, the field of periodontal education has undergone a profound transformation through the integration of various virtual methods. Online platforms, which have been widely used especially during the challenges of the COVID-19 pandemic, offer flexibility and accommodate learners from undergraduate to postgraduate and CPD levels. Additionally, offline virtual methods such as simulation techniques, with an emphasis on 3D animation and digital replication, provide students with an enriched, immersive learning environment. The development of haptic training tools has been remarkably successful in simulating tactile sensations and greatly enhancing the hands-on training of dental procedures at a pre-clinical level. While recent advances in virtual communication training, exemplified by initiatives such as 'eMI-med', have shown potential for improving students' communication skills, particularly in patient-centred areas such as smoking cessation, more complex patient encounter simulations appear to provide a bridge, allowing students to practise patient interactions in a controlled environment. In addition, the field of VR is opening up new possibilities, especially when combined with traditional learning methods. Finally, the advent of AI appears to offer a technological revolution, introducing adaptive, predictive systems. However, the arrival of AI also serves as a reminder of the need for careful integration to ensure that educational quality is maintained without succumbing to potential AI biases.

TABLE 14 Communication training.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Fuhrmann et al. (2022)	One group: students who underwent the eMI-med ecourse. Total participants: 25 students; 40 interviews analysed (Germany)	Dental students took an 'eMI-med' ecourse. Their patient–student interviews were recorded and assessed using the MITI-d.	Dental students displayed high MI-adherent behaviour, open-ended questions and reflections, comparable to classroom training. Interviews averaged 11 min.	The eMI-med ecourse effectively imparted basic MI knowledge and skills, as reflected in students' high MI-adherent behaviour and interview skills. The programme also bolstered students' therapeutic self-efficacies in smoking cessation and oral hygiene.	Blend e-learning for skill acquisition with clinical feedback. Assess the MI-blended program's long-term impact.

Abbreviation: MI, motivational interviewing.

TABLE 15 Patient encounter simulation.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Schittek Janda et al. (2004)	Experimental group ($n = 16$) of dental students interacted with virtual patient before real patient encounter. Control group ($n = 23$) did so afterwards (Sweden)	Utilized virtual learning environment for dental students to communicate with virtual patients via free text. Interactions were logged.	Virtual patient understood 51% questions in usability test, 37% correct but absent. Experimental group spent more time communicating directly with patients, asked more critical and overall questions than control.	Virtual patient positively impacted dental students' history-taking skills. Pre-interaction led to more critical questions, increased direct communication and improved professional behaviour.	No specific future plans were mentioned, but potential directions include expanding the virtual patient database for improved query responses, exploring virtual patient training's impact on different dental skills, and conducting longitudinal studies for long-term benefits.

3.4.2 | Best practices in virtual periodontal education

The introduction of virtual methods in periodontal education has not only broadened the educational environment but has also introduced a number of best practices that have been instrumental in increasing student engagement, knowledge retention and skill development. Online platforms using elements such as video, animation and multimedia presentations have been shown to be particularly effective in teaching basic periodontal knowledge to undergraduate students, as evidenced by the findings of this scoping review. In the simulation domain, the superiority of 3D animation over traditional 2D visuals in enhancing knowledge recall was reported, highlighting the need to use cutting-edge multimedia tools in periodontal education (Dhulipalla et al., 2015). Similarly, in the haptic/tactile domain, the transformative potential of haptic tools was demonstrated, providing a more vivid and practical training environment for students by mimicking authentic tactile sensations (Yamaguchi et al., 2013; X. Zhao et al., 2020). Furthermore, the blending of traditional teaching with VR was proposed, demonstrating that such an integrated approach promotes improved theoretical understanding and enhanced professional skills, especially when combined with traditional methods (Chapple et al., 2010; B. Zhang et al., 2020; J. Zhang et al., 2021).

In the area of communication training, an innovative 'eMI-med' course skilfully combined e-learning with clinical feedback, highlighting the value of feedback-centred learning approaches (Fuhrmann et al., 2022). However, although the future of AI appears promising, caution was advised against its unchecked embrace, suggesting a harmonious blend with traditional teaching paradigms to avoid potential biases (Glick et al., 2022).

3.4.3 | Gaps and overlaps

The implementation of virtual methods in periodontal education has revealed a landscape characterized by both gaps and overlaps. In

TABLE 16 Virtual reality.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Luciano et al. (2009)	The paper discussed the development and validation of a dental simulator. An experiment was conducted involving faculty members and dental students at the College of Dentistry, University of Illinois at Chicago (UIC), but specific numbers are not mentioned (USA)	A haptics-based virtual reality periodontal training simulator was developed. It allowed users to visualize a 3D virtual mouth and feel tactile sensations while using virtual dental instruments.	The haptics-based virtual reality periodontal training simulator effectively trained dental and hygiene students and professionals in periodontics. It offers a realistic learning environment for periodontal procedures and has potential to be included in the curriculum.	The developed simulator is promising for periodontal training, enhancing traditional methods. It is validated for curriculum integration and offers a valuable instructional tool.	Improvements in user interface, features like performance recording and more comprehensive evaluations are recommended. The simulator's impact on learning outcomes for dental students and professionals should be further explored.
Steinberg et al. (2007)	The study involved 30 experienced clinical dental and dental hygiene faculty who evaluated the dental training simulator system PerioSim© (USA)	PerioSim©, a haptic technology and 3D-virtual reality graphics-based dental training simulator, was used. A PHANToM haptic device and a Dell Xeon 530 workstation were employed.	PerioSim© exhibited high realism in tooth and instrument visuals, but less so in gingiva. Tactile feedback was realistic for teeth, but less so for gingiva.	PerioSim© showed realistic tooth and instrument visuals, with potential for teaching and student evaluations. The system's concept was successful, aiding dental tactile skill development.	Further research should focus on refining gingival tissue representation in PerioSim© and comparing student feedback with traditional training. A comprehensive evaluation of the system is essential.
D. Wang et al. (2016)	Eleven dental training systems were surveyed (China)	A survey of dental training systems was conducted to assess their capabilities and identify gaps in clinical training needs. Components, functions, features, technical challenges and evaluation methods were summarized.	Multiple dental training systems were reviewed, revealing disparities between their capabilities and clinical training requirements. Technical challenges in software, hardware and evaluation methods were noted.	Virtual reality dental training systems with multisensory feedback offer advantages over traditional methods. Yet, challenges persist in developing effective simulators.	Research should concentrate on enhancing multisensory feedback fidelity, refining training platform ergonomics, and devising better evaluation methods. Advancements in haptic feedback, graphic simulation and comprehensive training scenarios are needed for VR dental training systems.
Wierinck et al. (2007)	Eighteen volunteers in operative dentistry, experts in periodontology and novice dental students, each with six participants (Belgium)	Participants used the DentSim virtual reality simulation system for a Class II tooth preparation task. A pre-test, training with feedback and a final test were conducted.	Operative dentistry experts outperformed both novices at pre-test and novices and periodontists during training. Performance levels were consistent 1 min and 1 day after training, and retention was observed.	DentSim is valid and reliable for assessing expert performance in tooth preparation. It distinguishes expertise levels in dentistry, highlighting domain specificity in oral health care.	Future research could assess expert performance in different dental or medical domains using the system. Long-term skill retention and transferability to real patient contexts need exploration.
B. Zhang et al. (2020)	Four groups: Three experimental ($n = 20$ each) and one control group.	80 undergraduates from Lanzhou University were randomly assigned to	Initial theoretical exam scores were similar across groups. V-J (virtual-jaw) and J-V (jaw-virtual) groups	Combining virtual simulation with jaw models enhances implantology training outcomes.	Research the virtual simulation system's long-term impact in oral implant education and

TABLE 16 (Continued)

Author, year	Population	Methods	Results	Conclusions	Suggestions
	Total participants: 80 (China)	experimental or control groups. After theoretical exams, participants received training, followed by an operation test on pig mandibles.	improved in the second theoretical exam.	V-J group outperformed J-V group in theoretical knowledge and pre-clinical skills.	determine the optimal application period for maximum learning outcomes.
J. Zhang et al. (2021)	Four groups: traditional jaw model group (group J), virtual reality group (group V), virtual-jaw group (group V-J) and jaw-virtual group (group J-V) (China) Total participants: 60 (each group, $n = 15$).	Sixty students from Lanzhou University's stomatology department were divided into four groups. They received periodontal training and completed two theoretical assessments.	V-J and J-V groups showed improved second theoretical assessment scores. Operation and scaling process scores were significantly higher in V-J and J-V groups.	Combining VR and a jaw model enhances periodontal training outcomes, boosting grades and professional skills. Optimal learning involves starting with the jaw model before VR.	Investigate VR's long-term teaching effects. Explore VR combined with other methods.

Abbreviation: VR, virtual reality.

TABLE 17 Artificial intelligence.

Author, year	Population	Methods	Results	Conclusions	Suggestions
Glick et al. (2022)	Two groups: control (without AI assistance) and test (with AI assistance). Total participants: 41 (22 third-year dental students and 19 fourth-year dental students) (USA)	Dental students surveyed dental radiographs to detect furcation involvement (FI) lesions. Control group: radiographs without AI.	Performance, efficiency and confidence showed no significant differences between the groups except for one question with a tendency to err with AI-generated answers. Both groups believed AI would improve clinical decisions.	AI integration affects novice dental clinicians' performance, with observed over-reliance on AI for decision making. While AI shows potential for improvement, but caution against over-reliance and biases is necessary.	Conduct larger studies for broader insights. Evaluate AI's impact on various clinical tasks.

Abbreviation: AI, artificial intelligence.

terms of gaps, there is considerable inconsistency in delivery and assessment methods across online platforms, as illustrated by the contents of Tables 8–10 in this review. This lack of standardization calls for consistent guidelines. Addressing these gaps could involve developing clear and universally accepted criteria for evaluating students' performance in virtual environments. Despite the growing presence of both online learning and virtual classrooms, there are areas for improvement to meet students' desire for increased interactivity and clearer content delivery (Khan et al., 2022; Shi et al., 2015). The area of haptic training, although promising, requires tools with advanced capabilities that capture a wider range of tactile sensations relevant to different dental procedures. Current haptic simulators often struggle to faithfully replicate the complex tactile feedback associated with procedures such as periodontal probing or tooth preparation, limiting their effectiveness in providing a truly immersive training experience. Research and development efforts are therefore essential to address these limitations and improve the realism of haptic training for dental students, enabling them to develop the necessary tactile skills with confidence. In addition, the integration of AI, although promising, also presents challenges. As pointed out in a recent study, there is still a notable gap in modules that prepare students for the appropriate use of AI in dental education (Glick et al., 2022). Addressing this gap should include a thorough examination of the ethical considerations surrounding AI in dentistry, including issues of privacy, informed consent and the potential for bias in AI algorithms used for diagnosis and treatment planning. In addition, educators should assess the practicality of seamlessly integrating AI into the curriculum, considering factors such as the availability of AI tools, the need for specialized training and the continuous evolution of AI technologies in dental practice.

In terms of overlap, some redundancies have emerged, particularly in the use of VR and haptic simulators. Several studies have investigated the use of haptic VR simulators for dental education,

potentially leading to overlap in research efforts (Luciano et al., 2009; Steinberg et al., 2007). Another notable overlap is between simulation techniques and haptic training. Both modalities share the common goal of providing a life-like training experience (Dhulipalla et al., 2015; Yamaguchi et al., 2013). A synthesis of their relative strengths could pave the way for an optimized learning environment. Recognizing and addressing these gaps and overlaps is paramount, as it provides the compass for future innovation and ensures a periodontal education landscape that is both efficient and holistically developed.

3.4.4 | Current limitations

The introduction of virtual methods into periodontal education, although full of potential, is fraught with challenges. A prominent limitation lies in the technological requirements; the infusion of virtual classrooms, VR and intricate simulation techniques requires a solid technological backbone, potentially sidelining institutions with limited resources. This technological thrust also introduces a pronounced learning curve for both teachers and learners, particularly when navigating the intricacies of AI and VR platforms.

To ensure greater accessibility of virtual methods in periodontal education, it is imperative to explore cost-effective solutions that can benefit institutions with limited resources. One approach is to develop open-source virtual dental education platforms that are readily available for adoption. Collaborative efforts within the dental education community can help create and share these resources. In addition, partnerships with industry stakeholders can facilitate the provision of affordable haptic devices and software licences, further supporting institutions facing resource constraints.

In addition, the vast digital expanse of online platforms, although offering unparalleled flexibility, presents a challenge in ensuring consistent content quality. It is imperative that content remains evidence-based, up-to-date and aligned with curriculum benchmarks. The proliferation of new virtual tools has resulted in a wide variety of content delivery styles, assessment techniques and feedback strategies, highlighting the urgent need for standardization. However, owing to the great heterogeneity in this specific field today, no specific recommendations for undergraduate, postgraduate and CPD can be made from the current literature.

Finally, although the appeal of virtual methods such as haptic training is undeniable, it is important to remember that they are designed to complement, not replace, hands-on clinical experience. The balance between virtual and real experience is delicate, and tipping the scales too far in favour of virtuality could be detrimental.

3.5 | Future research directions

The dynamics of virtual periodontal education encourage future research efforts. A pressing need is the standardization of virtual platforms to ensure consistent content delivery and assessment across institutions. The role and effectiveness of AI tools, as suggested by Glick et al. (2022), warrant rigorous evaluation to determine their supportive, rather than substitutive, function. Exploration of sophisticated haptic tools, inspired by work such as that of Yamaguchi et al. (2013), can enhance the sensory richness of virtual training. Blended learning models, inspired by studies such as those of B. Zhang et al. (2020) and J. Zhang et al. (2021), could provide a harmonized approach to periodontal education, combining traditional and virtual methods. Emphasis should also be placed on longitudinal evaluations to measure the lasting impact of virtual education on clinical skills and patient care. Once the technology is available, solutions tailored to regions with limited infrastructure resources could democratize access. The potential of virtual patient encounters, as demonstrated by Schittek Janda et al. (2004), requires refinement to better reflect real-world interactions. Finally, as the role of AI grows, ethical considerations in its use become paramount to ensure responsible integration that safeguards both patient welfare and student development.

3.6 | Conclusions

The results of this scoping review suggest an increasing importance of virtual learning in undergraduate periodontal education. While digital methods offer innovative approaches to education, blended approaches integrating both virtual and traditional methods appear optimal to maximize learning outcomes.

4 | BLENDED TEACHING AND LEARNING IN PERIODONTAL EDUCATION

4.1 | Aim of review

A key outcome of the 2009 European Workshop in Dental Education was the articulation of competencies, defined as the blend of knowledge, skills and attitudes appropriate to the individual aspects of the profession, defined at the UG level (Sanz & Meyle, 2010), PG level (Van der Velden & Sanz, 2010) and the CPD level (Chapple et al., 2010). There is recognition that learning styles and requirements differ among these different groups of learners, and the most successful outcomes may be achieved when using a combination of different methodologies (Chapple et al., 2010). The impact of different teaching and learning approaches on the student must also be taken into consideration, and student health and wellbeing, particularly mental health, is recognized as an increasingly important topic. Student satisfaction is also important to evaluate when any teaching innovation is introduced. Accordingly, the aim of this review was to evaluate the impact and feasibility of blended teaching and learning (including teaching delivery and assessment) in periodontology, at the UG, PG and CPD levels.

4.2 | Methods

A systematic search strategy was developed, using medical subject headings (MeSH term) and keywords to search the relevant literature

MeSH Terms:
Education, dental OR Education, dental, graduate OR Education, dental, continuing OR Periodontics, education OR Students, dental OR Dental student OR Teaching OR Education OR Learning

AND
All fields:
Periodontal disease$ OR Periodontal OR Periodontitis OR Periodontology OR Periodontic$ OR Dental OR Dentistry

AND
All fields:
Undergraduate OR Postgraduate OR Continuing Education OR Continuing {adj1} education OR Clinical {adj1} teaching OR Clinical {adj1} learning OR Pre-clinical {adj1} teaching OR Pre-clinical {adj1} learning OR Non-clinical {adj1} teaching OR Non-clinical {adj1} learning OR Outcome$ OR Result$ OR Grade$ OR Student {adj1} satisfaction OR Student {adj1} wellbeing OR Student {adj1} well-being OR Self-perceived {adj1} learning OR Self-perceived {adj1} efficacy OR Effectiveness OR Confidence OR Attitude OR Competence OR Marks OR Assessment OR Performance OR Student {adj1} performance OR Student {adj1} experience OR Employment OR Employment {adj1} outcome$ OR Employer {adj1} feedback

AND
All fields:
Hybrid OR Blended OR Hyflex OR Synchronous OR Asynchronous OR Online {adj1} teaching OR Online {adj1} learning OR Online {adj1} lecture$ OR e-Teaching OR e-Learning OR Blended {adj1} teaching OR Blended {adj1} learning

Limits: English language

FIGURE 6 Search strategy to evaluate blended teaching and learning in periodontal education (Section 4).

electronically in Medline/PubMed and the Cochrane Database of Systematic Reviews up to 6 June 2023. The search strategy and terms are presented in Figure 6. Bibliographies of review articles and texts were also screened. After identification, relevant articles were selected based on the PRISMA flow diagram (Moher et al., 2009), with the aim to be as inclusive as possible during the search to identify relevant literature that would inform this topic. Given the heterogeneous nature of the study types, we adopted broad inclusion/exclusion criteria as shown below.

Inclusion criteria:

- Studies in which blended teaching and learning was evaluated
- Teaching and learning at the levels of UG, PG or CPD.

Exclusion criteria:

- Reviews (although these were also obtained to permit review of reference lists)
- Editorials/commentaries/letters/conference abstracts
- Articles not in English and unable to be translated or unavailable online or by inter-library loans.

Titles derived from the searches were screened to assess relevance and eligibility. Abstracts and titles were independently screened by two authors (P.M.P. and K.D.) for consideration for inclusion. Following this, full-text articles were obtained and assessed for inclusion, with any disagreements resolved by discussion. Given the wide variety of studies identified, it was not possible to adopt the PRISMA statement or develop a focused (PICO [population, intervention, comparator, outcome]) question for review.

4.3 | Results

The flow of articles through the literature search process is shown in Figure 7. The database and reference list search strategies revealed a combined total of 321 titles, of which 252 articles were excluded following title/abstract review, leaving 69 full papers for screening ($\kappa = 0.89$, 96.3% agreement between the two reviewers). The full texts were obtained, of which 17 were rejected, leaving 52 papers ($\kappa = 0.88$, 95.7% agreement between reviewers). The reasons for exclusion of articles at each stage are presented in Figure 7. Three additional papers were identified from reference lists, yielding a total

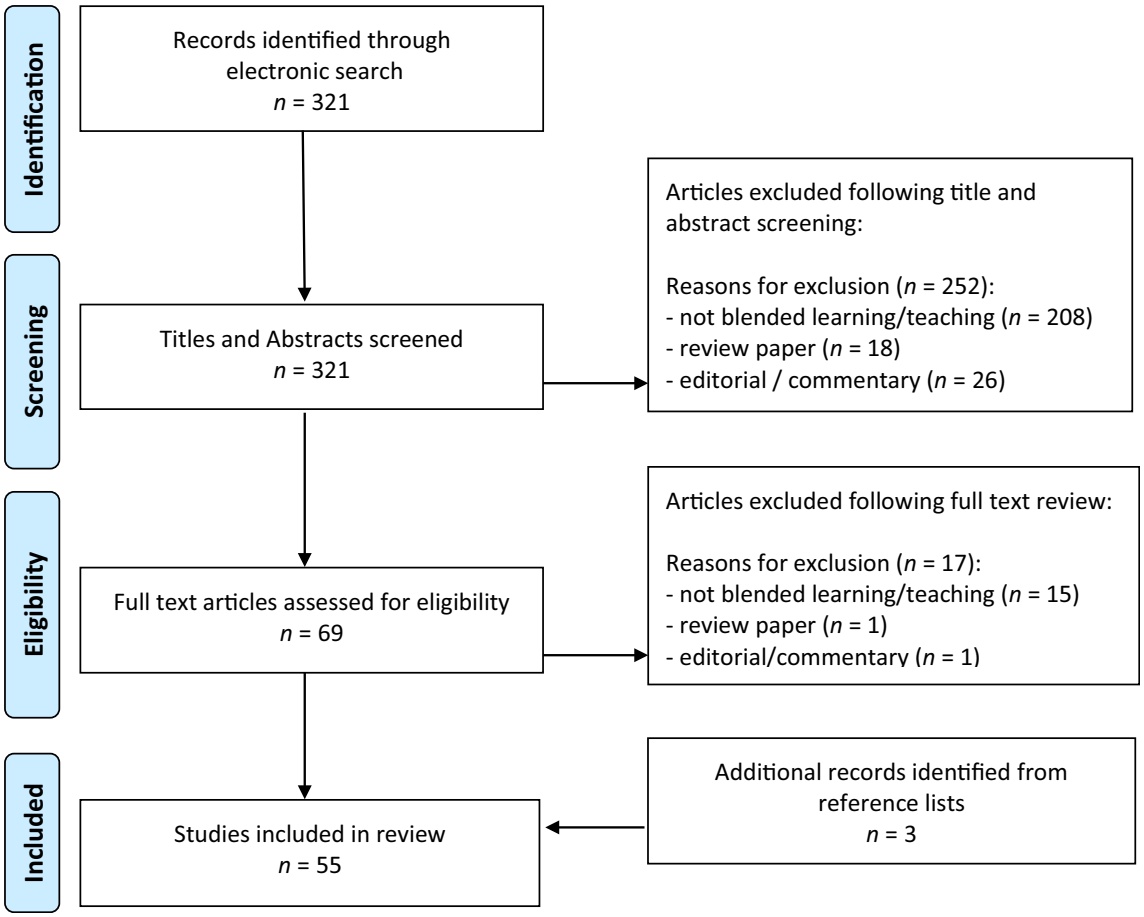

FIGURE 7 Identification of articles (based on the PRISMA checklist) to evaluate blended teaching and learning in periodontal education (Section 4).

of 55 papers for the review. Of these, 49 related to UG teaching and learning (see Table 18), 3 to PG (Costea et al., 2022; Naser-ud-Din, 2015; Varghese et al., 2019) (Table 19), 2 to both UG and PG (Pahinis et al., 2007, 2008) (included in Table 18) and 1 to CPD (Ratka-Kruger et al., 2018) (included in Table 19).

4.3.1 | Undergraduate education

Blended teaching for knowledge: Education methods

Literature shows that blended learning approaches have been widely incorporated into undergraduate dental curricula for teaching knowledge, with the COVID-19 pandemic further accelerating this change (Orozco et al., 2023). In the United Kingdom, the National Health Service (NHS) Health Education England has published specific guidance on using blended learning in undergraduate healthcare programmes (NHS Health Education England, 2022). To date, we identified just two publications relating specifically to the use of blended learning in undergraduate periodontology (Huynh et al., 2022; Lee & Kim, 2018). Significantly more publications have reported the use of blended learning in the broader scope of dentistry, both in terms of the basic sciences and clinical disciplines (Table 18). Owing to the heterogeneous design of these studies, many of which were feasibility studies, it has been possible to make only general statements regarding trends in the literature.

Many studies have reported high levels of student satisfaction with blended learning in undergraduate dental education (Alsharif et al., 2020; Bak et al., 2023; Bock et al., 2020; Bock, Kniha, et al., 2021; Farah-Franco et al., 2021; Kavadella et al., 2012; Quos et al., 2017; Qutieshat et al., 2020; Rohle et al., 2021; Varthis & Anderson, 2018; S. Wu et al., 2022), with some reporting higher levels of satisfaction with blended learning in comparison to traditional lecture-based teaching (Bains et al., 2011; Huynh et al., 2022; Jeganathan & Fleming, 2020; Rocha et al., 2021; Turkyilmaz et al., 2019; Ullah et al., 2021). These findings were, however, not universal, with some studies reporting similar levels of student satisfaction with both blended learning and traditional teaching (Ariana et al., 2016; Eachempati et al., 2016; Orozco et al., 2023). However, Ariana et al. (2016) found that although there were high levels of satisfaction with blended learning and traditional approaches of teaching histopathology, specific aspects of blended learning were found to be significantly better perceived, such as feedback, support and engagement. Other studies similarly reported that blended learning was associated with increased student perception of learning, engagement,

TABLE 18 Key findings from identified studies reporting on use of blended methods in undergraduate teaching and learning.

Author, year	Study population and country	Study design	Main findings	Interpretation
Ab Ghani et al. (2022)	Seventy-two dental students (Malaysia)	Conventional teaching ($n = 36$): F2F (1 h), live demo (1 h), F2F learning time (2 h). Blended Learning ($n = 36$): online recorded lecture, video demonstration, F2F tutorial (1 h), F2F learning time (1 h). Questionnaire provided on learning preferences	No differences between groups in baseline skills or learning preferences, with participants performing equally when using both teaching methods.	The effectiveness of blended learning was similar to conventional teaching. Both teaching approaches did not affect the performance of students. Blended learning can be adopted in pre-clinical fixed prosthodontic teaching without losing any benefits of the conventional approach.
Alsharif et al. (2020)	182 third-year dental students (Saudi Arabia)	Traditional teaching ($n = 97$) and hybrid teaching ($n = 85$) using WhatsApp to send multimedia messages (photos, videos and audio recordings, simple text messages).	The average assignment scores of hybrid learners were statistically significantly higher than those of traditional learners.	Learner achievement was better in hybrid teaching modality. Students demonstrated positive perceptions and high levels of motivation, enthusiasm and responsibility in a hybrid learning setting.
Alwadei et al. (2020)	343 second-year dental students (USA)	Traditional group: non-adaptive fully F2F format ($n = 112$). F-ALP ($n = 48$). Summative Adaptive Learning Platform (S-ALP; $n = 183$) students.	All instructional methods improved students' knowledge based on students' performance on the final exam; S-ALP had the greatest effect.	Formatively and summatively implemented adaptive mediated instructions were more effective than traditional F2F instruction.
Ariana et al. (2016)	194 second-year dental students (Australia)	Two consecutive cohorts. First cohort (control group $n = 90$) traditional teaching in histopathology. Second cohort ($n = 104$) had blended learning. Comparison of assessment outcomes and post-course questionnaires.	Significantly higher assessment outcome in the blended cohort (96.1% + 5.7%) compared with the control cohort (85.4% + 10.2%). High levels of satisfaction reported with both types of teaching. Significantly higher level of satisfaction was reported for blended learning for feedback, support and engagement.	Demonstrated that blended learning was a more effective approach than traditional approaches to teaching histopathology.
Azab et al. (2016)	146 second-year dental students (USA)	Analysis of online access relating to three basic science and three pre-clinical dental courses. Questionnaire used to evaluate attendance and use of online resources.	Generally no correlations found between attendance or use of online materials and individual course grades. Weak-to-moderate negative correlations were found between attendance and online usage for a epidemiology course ($p = .0002$) and overall for the pre-clinical dental courses ($p = .039$).	Student course grades were not affected by attendance or online usage. Generally, attendance was not affected by usage of online resources. Students found access to online resources useful.
Bains et al. (2011)	90 fourth-year dental students (UK)	Evaluation of effectiveness and attitudes towards online learning, F2F and blended learning for delivery of an orthodontic tutorial. Knowledge assessment using MCQ exam. Post-course questionnaire.	No statistical difference in MCQ assessment outcomes between blended learning and F2F. Sequencing of the F2F or online element of blended learning made no difference to outcomes. Blended learning was the most preferred option, online learning the least.	Both blended learning and F2F teaching were equally effective for knowledge recall. Overall, students preferred blended learning over the other teaching formats.

(Continues)

TABLE 18 (Continued)

Author, year	Study population and country	Study design	Main findings	Interpretation
Bak et al. (2023)	81 second-year dental students (USA)	Online questionnaire of denture course consisting of asynchronous lectures and pre-clinical lab sessions.	Reported on average time spent on studying per topic/week. Reported on difficulty ratings of the material and on degree of helpfulness of material provided.	Students found clinical portion of lectures to be the most difficult and didactic content least difficult. Demonstrations and videos were critical in understanding the clinical material. Note: no comparator group.
Bakr et al. (2016)	519 undergraduate dental students (Australia)	Retrospective study of two cohorts of traditional and two cohorts of blended learning (practical element only) for a dental anatomy course. Mid-term and end-of-course knowledge and practical assessments and questionnaires.	No significant difference in end-of-course knowledge exams. Significantly higher practical assessment outcomes for blended learning compared with traditional approach. High student satisfaction with online videos.	Blended learning more effective for practical elements of dental anatomy course compared to traditional approaches.
Bock et al. (2018)	150 senior undergraduate dental students (Germany)	Two cohorts: traditional teaching ($n = 74$) and blending learning ($n = 76$) in oral and maxillofacial surgery. Questionnaire to evaluate student perceptions.	Use of videos in blended learning aided understanding of surgical procedures. Online resources rated as very good. 67% engaged with online resources. Attendance at F2F lectures significantly reduced in blended learning group following introduction of the blended course ($p < .001$).	Positive impact of blended learning on student's perception of learning, but was associated with a significant reduction in attendance at F2F lectures.
Bock et al. (2020)	21 undergraduate dental students. Two-week clerkship in oral and maxillofacial surgery (Germany)	Implementation of an online module in oral and maxillofacial surgery. Flipped classroom using online asynchronous module; 20 multiple-choice assessment before and after clerkship. Post-course evaluation.	Significant improvement in post-course assessment. Mean score (SD) for pre-clerkship assessment was 12.7 (2.8) versus post-clerkship assessment of 15.8 (2.6) ($p < .0001$).76.2% engagement with online module. High overall satisfaction with hybrid learning.	No comparison with a control group, so difficult to draw conclusions on benefits over traditional teaching. High student satisfaction with blended learning module, especially use of surgical videos to aid understanding of procedures.
Bock, Elvers, et al. (2021)	36 third-year dental students (Germany)	Group A ($n = 12$) used the new PantoDict digital e-learning program for training. Group B ($n = 12$) used both PantoDict and conventional F2F classroom instruction. Group C ($n = 12$) used conventional instruction only.	Group B (blended learning) had highest examination results, significantly higher than Group C (conventional) and higher (not significantly) than Group A (digital seminars only). Evaluation: Group C (conventional) rated their improvement in knowledge of reporting panoramic radiographs the highest (not significant).	The e-learning program improved the learning outcome and can be used as a complementary tool (along with conventional F2F teaching) as a blended teaching and learning concept.
Bock, Kniha, et al. (2021)	37 third-year dental students (Germany)	Group I: blended learning ($n = 13$; unlimited) with access to e-learning package before lecture. Group II: e-learning ($n = 12$) with 1.5 h e-learning package. Group III: lecture group ($n = 12$) with 1.5 h lecture. MCQ to assess knowledge gain.	Blended group showed significantly better MCQ results than the two other groups. No difference between the MCQ results of the lecture group and the e-learning group. For clinical skills, there were no significant differences between the three groups. Student evaluation: both groups confirmed that e-learning is a useful supplement to the	The blended learning group showed significantly better results in the test assessing theoretical knowledge than the two other groups. For practical skills, blended learning is as effective as traditional teaching methods. Blended learning improves the learning outcome for

TABLE 18 (Continued)

Author, year	Study population and country	Study design	Main findings	Interpretation
			course but could not replace the practical seminars.	theoretical knowledge more than either F2F learning or e-learning alone. For acquiring practical skills, blended learning is as effective as other teaching methods and is highly appreciated by the students.
Botelho (2019)	Fourth-year dental students acquiring fixed prosthodontics clinical skills (China)	Evaluation of the use of 100 online videos/lectures in fixed prosthodontics by two consecutive cohorts. Evaluation questionnaire and analysis of student access data to video resources.	High levels of student satisfaction regarding benefits of online video resources in preparation for clinical skills sessions, revision and prior to carrying out procedures on patients. Vast majority of students reported preference for 5–10 min videos and watched videos at 150% playback speed to reduce time. High levels of access to videos took place at the start of clinical skills courses and prior to assessments.	Value of short online video resources, to most students, in supporting clinical skills training and transition to clinical practice in fixed prosthodontics. Not all students accessed the videos. Paper highlights student preferences for short videos and the common use of higher playback speeds.
Cho and Ganesh (2022)	131 third-year dental students (USA)	Part I = didactic courses presented virtually. Part II = simulated clinical activities on manikin/typodont for operative and radiology in the clinic + 3-week virtual treatment planning sessions via virtual classroom.	Part I – virtually delivered didactic materials increased students' knowledge in learning relevant key topics of clinic transition. Part II – virtual treatment planning sessions increased students' perceived confidence and knowledge in assessing or doing.	Hybrid model of delivery can be effective (no comparison group).
Eachempati et al. (2016)	145 undergraduate dental students (third year $n = 78$; fourth year $n = 67$) (India)	Cross-sectional study of blended learning course in oral medicine and pharmacology. Students completed weekly reflections for 9 weeks. Thematic analysis was used to assess the course.	Students reported several positive aspects to blended learning including greater flexibility, more time-efficient, better prepared for F2F sessions, improved feedback and self-awareness. 46% reported a preference for blended learning over traditional teaching.	Study highlighted positive aspects of blended learning; however, <50% of students preferred it to traditional teaching. No control group, so difficult to assess impact on student learning compared to traditional methods.
El Tantawi et al. (2013)	16 senior undergraduate dental students (Egypt)	Single cohort undertook a blended learning course on fluoride gel application followed by an F2F course on fissure sealing. Pre and post assessment assessed knowledge acquisition, and a checklist was used to test clinical skills. Post-course evaluation questionnaire.	Both blended and traditional teaching resulted in significant increases in knowledge acquisition, but no significant differences found between the teaching methods in terms of knowledge and skills. High levels of satisfaction in blended learning.	A small study, but suggests blended learning is as effective as traditional teaching methods.
Escobar et al. (2022)	53 second-year dental students (Colombia)	Students received conventional teaching (lecture, article, colour photo examples and group discussion). Students assessed 78 clinical photographs online and were given automated feedback. One week later, the students reassessed the (randomized) clinical photos.	Pre-test results showed students' lower accuracy in discriminating caries. Post test, pooled overall accuracy increased by 20%. Individual student overall accuracy increased for 52 out of 53 students.	Study showed that combining lectures and e-learning-assisted practice with feedback can be considered a suitable method for introducing dental students to caries detection. E-learning-assisted practice is a feasible alternative for inexperienced students for detecting and assessing dental caries.

(Continues)

TABLE 18 (Continued)

Author, year	Study population and country	Study design	Main findings	Interpretation
Farah-Franco et al. (2021)	277 dental students (USA)	Measured how an online pre-clinical hybrid curriculum impacts dental student clinic readiness, the outcomes of grades, critical thinking skills and student and faculty perceptions. Traditional curriculum (Group A, $n = 69$; Group B, $n = 70$). Hybrid curriculum (Group C, $n = 68$; Group D, $n = 70$).	Hybrid groups had improved mean course grades. Faculty survey: the hybrid curriculum improved self-assessment skills, initiative, proficiency and clinical practice readiness. Students' perception: the hybrid curriculum promoted their learning, independence, problem-solving skills, critical thinking, professionalism and clinical practice readiness.	Hybrid model of delivery enhanced mean course grades compared to traditional teaching. Among the hybrid curriculum, the Content Reinforcement sessions were unanimously most helpful for all categories of learning outcomes.
Faraone et al. (2013)	132 second-year dental students (USA)	Evaluation of a blended learning pre-clinical complete denture course. Questionnaire and comparison of assessment grades with the previous traditional course.	High levels of student satisfaction with blended learning. Significant increase in the numbers of A grade awarded in the blended learning course compared with previous traditional programme.	Blended approach allowed for effective and efficient teaching of a large student cohort while maintaining high levels of student satisfaction. Overall assessment grades were at least maintained, or possibly increased, following introduction of blended learning.
Farber et al. (2022)	138 dental students (Germany)	Analysis of student performance for first root canal treatment on patients. Control = F2F ($n = 49$). Test Group 1 = F2F and e-learning package ($n = 54$). Test Group 2 = Online and e-learning package ($n = 35$).	Treatment performance in test groups 1 and 2 was significantly higher than in the control group, and treatment errors were significantly lower. No difference in treatment performance or errors between test groups.	The multimedia e-learning application improved students' performance in the first root canal treatment on real patients. The e-learning application enabled students to achieve more effective practical exercises on artificial teeth, resulting in a better understanding of the treatment steps.
Gadbury-Amyot et al. (2017)	178 second-year dental students (USA)	Evaluation of how two consecutive cohorts (2014 $n = 84$; 2015 $n = 94$) utilized online resources following introduction of blended learning (flipped classroom) and preparation for F2F teaching events. Post-course questionnaire.	Watched >50% pre-recorded lectures: 62% 2014; 72.3% 2015. Note-taking/writing down questions during pre-recorded lectures: 58.3% 2014; 68.1% 2015. Paused/replayed recordings: 86% 2014; 100% 2015. Majority of both cohorts watched pre-recorded lectures between 7:00 PM and 11:00 PM. Few students in both cohorts read the assigned readings prior to the F2F session.	Student engagement with online resources was significantly less than 100% with many students not engaging with online material prior to F2F learning events, which may negatively impact deep learning.
Hong et al. (2023)	178 predoctoral dental students (Korea)	Dental student anxiety comparison between in-person CBE (2019, $n = 89$) and online OBE (2021, $n = 87$).	No mean difference in anxiety level between the in-person CBEs and the online OBEs. Final exam scores for 'Restorative Dentistry' in the final CBE were greater than in the mid-term CBE. The mean score of the in-person midterm CBEs was lower than the in online final OBEs. Analysis revealed reduced burden on the students in OBEs.	A blended assessment was as effective as traditional assessment in distinguishing good from poor students; furthermore, a low-achieving group was better predicted by blended assessment. No significant differences were found in dental students' anxiety level between traditional and blended assessments.

TABLE 18 (Continued)

Author, year	Study population and country	Study design	Main findings	Interpretation
Huynh et al. (2022)	69 third- and fourth-year dental students (USA)	Live lectures and access to an online module on periodontal classification (with case quizzes and interactive activities). Post-module survey to assess learning preferences, utilization of various learning methods and student perceived efficacy of blended learning.	Students' ranking of learning methods: 52.2% online module most effective; 72.5% reading module as the least effective learning method. >85% of participants agreed/strongly agreed that blended learning was more effective than a traditional lecture alone and that the online module improved their understanding.	Students had higher preference and self-perceived efficacy when using blended approach compared to traditional reading and lectures.
Iqbal et al. (2022)	45 second-year dental students (Saudi Arabia)	Control group ($n = 23$) was taught skill-based Class I cavity and restoration with the routine live lab demonstration. Experimental (blended) group ($n = 22$) was taught by procedure-specific educational video demonstration through an e-learning tool (Blackboard) plus the routine live lab demonstration.	Simulator position was the only aspect of the OSPE that was enhanced in the experimental (blended) group.	Blended strategy demonstrated enhanced learning and skill competency levels than participants who used only traditional teaching strategies (but only for simulator position and not infection control, tray organization, simulator position, cavity outline and extension, resistance form and retention form).
Jeganathan and Fleming (2020)	68 final-year dental students. Orthodontic-oral surgery seminar-based teaching course following orthodontic teaching in the previous year (UK)	Randomized allocation of students into seminar-based teaching (control group $n = 34$) or with additional e-learning resource (blended group $n = 34$). Pre- and post-course multiple-choice assessments.	No significant difference in post-course assessment scores between control (97.2%) and blended (98.3%) groups ($p = .36$). High levels of overall satisfaction with both approaches (control = 74%; blended 82%). Very high satisfaction with online learning resource (96.8%).	Effectiveness of blended learning was similar to that of traditional approach.
Kavadella et al. (2012)	47 final-year dental students (Greece)	Traditional teaching ($n = 23$) compared with blended learning ($n = 24$) in the teaching of radiological bone lesions. Pre- and post-course questionnaires and assessments.	Blended learning group had significantly higher post-course assessment scores (F > M) compared with the traditional teaching. Overall, students were very positive regarding blended learning but still highly valued F2F teaching to help clarify learning.	Blended learning effective in teaching a difficult subject area in undergraduate radiology. Students highly valued F2F teaching sessions.
Lee and Kim (2018)	106 third-year dental students (USA)	Comparison of traditional lecture group ($n = 35$) with blended learning group for a periodontal diagnosis and treatment planning course. Pre- and post-course quizzes and questionnaires.	Mean assessment outcome for blended learning (78%) was significantly higher than for traditional lectures (63%). High student satisfaction with blended learning, but 81% of students stated preference for traditional approach.	Blended learning more effective than traditional approach.
Lockhart et al. (2009)	76 final-year undergraduate dental students (UK)	Evaluation of a blended learning on local decontamination unit managers' course. Post-course questionnaire.	Online content of the course was reported to be a useful adjunct to the F2F lectures and practicals.	Blended learning effective approach to learning.

(Continues)

TABLE 18 (Continued)

Author, year	Study population and country	Study design	Main findings	Interpretation
Mac Giolla Phadraig et al. (2015)	100 third-year dental students (Ireland)	Evaluation of the effect of the introduction of a problem-based blended learning module on special care dentistry on student attitudes towards disability. Three consecutive cohorts. Pre- and post-course psychometric tests.	No significant change in students' attitudes towards disability following the blended learning course.	A blended learning module in special care dentistry did not affect student attitudes towards disability.
Maresca et al. (2014)	81 undergraduate dental students (USA)	Comparison of blended learning ($n = 41$) with traditional teaching ($n = 40$) on a pre-clinical endodontics clinical skills course. Pre- and post-course quizzes. Typodont teeth were collected after clinical skills session and were blind-graded. Post-course evaluation surveys.	No significant difference in the pre- and post-course quizzes between the blended learning and control groups. Significantly higher mean grades in clinical skills assessment in the blended learning group compared with the control group ($p = .0067$). High levels of satisfaction found in the blended cohort, and these students were more engaged with online lectures than the control group with F2F lectures.	Blended learning had a significant positive impact on endodontic clinical skills performance, but little effect on knowledge acquisition.
Mehta et al. (2016)	63 fourth-year dental students (UK)	Randomized study assessing the impact of an adjunctive online module in orthodontics ($n = 32$), compared with no additional teaching (control $n = 31$). Pre- and post-course online quizzes. Questionnaire and focus group used to evaluate student satisfaction.	No significant differences in assessment outcomes between blended learning and traditional approaches. Very high satisfaction regarding the online module, especially regarding content and immediate feedback. Students reported that the content and immediate feedback from questions aided learning.	An online module, in addition to previous orthodontic teaching, did not significantly improve assessment results. However, students perceived the online module to aid learning.
Mitov et al. (2010)	36 second-year dental students (Germany)	Evaluation of an online adjunct (3D models) to traditional teaching of tooth morphology. Post-course questionnaire.	Majority of students reported that 3D models helped with learning. Overall, students had a positive attitude towards online resources.	Online 3D models of teeth are useful adjuncts to traditional teaching of tooth morphology.
Nishigawa et al. (2017)	41 undergraduate dental students (Japan)	Analysis of fixed prosthodontic course assessment results following six sessions of flipped classroom teaching and eight team-based learning. End-of-course assessment.	No significant difference in mean assessments scores between team-based learning and flipped classroom.	Team-based learning and flipped classroom approaches are equally effective in teaching fixed prosthodontics.
Nkenke et al. (2012)	42 third-year dental students (Germany)	Randomized study, with students assigned to either blended learning or traditional teaching for a theoretical radiology course. Pre- and post-course questionnaires.	No significant difference in assessment scores between both groups, although the blended learning group was significantly less confident in passing. Attendance to F2F lectures was lower in the blended learning group.	No significant difference in assessment outcomes between blended learning and traditional approaches. Both cohorts were positive regarding the benefits of blended learning.

TABLE 18 (Continued)

Author, year	Study population and country	Study design	Main findings	Interpretation
Oliveira et al. (2019)	49 undergraduate dental students (26 third-year and 23 fourth-year students) (USA)	Pilot study evaluating the impact of students posting clinical cases for online discussion and discussion with staff in weekly F2F seminars (blended learning group). Control group of 10 students who did not engage with online discussions. Evaluation using a questionnaire.	No significant differences found in end-of-year questionnaire scores between the blended learning group and the control group, except for a significantly higher score in the blended learning group for specific learning opportunities. High levels of satisfaction were reported regarding the use of the online cases and F2F seminar.	Although students perceived that the blended learning approach had educational value, it did not significantly affect students' perception of their clinical learning.
Orozco et al. (2023)	463 dental students (all years). 452 completed hybrid learning questionnaire (El Salvador)	Online cross-sectional study during COVID-19 using questionnaire regarding hybrid learning.	Most students were neutral about the effectiveness of online learning, and the majority were concerned about lack of practical education.	Most students (62.1%) disagreed that online courses were more effective that F2F courses, and half of students were neutral about the effectiveness of online learning (50.2%).
Pacheco-Pereira et al. (2019)	16 final-year undergraduate dental therapy students (Canada)	Semi-structured interviews used to qualitatively assess student confidence in interpreting radiographs following introduction of a blended learning module in final year. Traditional teaching in radiography was delivered in the second year.	Some evidence that blended learning module improved confidence in interpreting radiographs, especially common findings.	Qualitatively demonstrated some improvement in perceived confidence in radiographic interpretation. No data on assessment outcomes.
Pahinis et al. (2007)	First-, third- and fourth-year dental students and dental hygiene/therapy undergraduate students and postgraduate students (UK)	Evaluation of a blended learning course in ICT using (i) questionnaires; (ii) student-led nominal group; and (iii) non-participant observers.	Overall, positive responses regarding the effectiveness of blended learning, although less positive responses in dental student cohorts. 65% stated that online component was a valuable learning resource.	Blended learning was generally well received as a means of delivery of a course in ICT.
Pahinis et al. (2008)	First-, third- and fourth-year dental students and dental hygiene/therapy undergraduate students and postgraduate students (UK)	Follow-up evaluation of a blended learning course in ICT using (i) questionnaires, (ii) student-led nominal group and (iii) non-participant observers.	61% reported that the course added to their skills, although there was significant variation between groups, especially between the dental student cohorts.	Changes made to a blended learning course may be perceived differently by different student groups.
Qutieshat et al. (2020)	617 fourth-year dental students taking a restorative dentistry course (Jordan)	Comparison of two consecutive cohorts. Control group ($n = 364$) taught by traditional methods and the other cohort ($n = 253$) taught using blended learning using a flipped classroom approach, including the use of a staff-supervised online discussion board. Identical assessments used in both cohorts.	Blended learning cohort achieved significantly higher assessment outcomes compared with the control group. Overall mean (SEM) assessment scores were traditional = 63.9 (0.7); blended = 71.1 (0.5) ($p < .0001$). Strong correlation between the number of interactions on discussion board and overall assessment performance. High satisfaction with blended learning.	Assessment outcomes of the blended learning cohort were significantly higher than of the previous conventional learning cohort; the blended approach was well received by the students. Difficult to ascertain the impact of the discussion boards on the increased assessment outcomes in the blended cohort. The authors acknowledge the significant resources required to implement blended learning.

(Continues)

TABLE 18 (Continued)

Author, year	Study population and country	Study design	Main findings	Interpretation
Quos et al. (2017)	121 third-year dental students (Germany)	Evaluation following introduction of blended learning (flipped classroom) course in restorative dentistry. F2F teaching involved problem-based and peer-assisted learning (PAL).	Positive student evaluation of implementation of blended learning course (6.97 + 1.93 on a 1–10 scale with 10 being excellent). PAL was rated 6.56 + 2.32.	Students positively rated the blended learning with PAL. Authors acknowledged that this approach required significant organization and resources.
Rafai et al. (2016)	52 second-year (pre-clinical) dental students (Germany)	Randomized evaluation of four learning approaches to teaching 'Palpation of head and neck muscles'. Groups: (i) lecture, (ii) lecture/online module, (iii) lecture/skills training and (iv) lecture/online module/skills training. OSCE used to evaluate learning.	Skills training (group iii) resulted in significantly higher OSCE scores compared with groups (i) and (ii). Inclusion of the online module with skills training (group iv) resulted in significantly higher OSCE scores compared with skills training alone.	Study demonstrates the positive value of blended learning on short-term recall of anatomy and clinical skills.
Reissmann et al. (2015)	Second-year dental students (Germany)	Evaluation of the inclusion of adjunctive online teaching resources on student satisfaction of a pre-clinical prosthodontic course ($n = 71$). Post-course questionnaires used to compare with previous two cohorts without blended learning ($n = 60$ and 56 students) and next 3 years with blended learning ($n = 51$, 48 and 69).	Significant increase in satisfaction following introduction of online learning resources regarding learning content ($p < .001$) and learning effect ($p < .05$). Satisfaction remained high during the following 3 years. Students' comments regarding online resources were generally very positive.	High levels of student satisfaction found following introduction of online material to a traditional pre-clinical prosthodontics course.
Ricci et al. (2022)	34 second-year medical and dental students (Switzerland)	Online questionnaires (×2) to participants completing an optional BLS course.	Lack of significant improvement in essential BLS knowledge.	Lack of improvement in BLS knowledge following an optional resuscitation course embedding a distance, asynchronous e-learning module. Low participation rate.
Rocha et al. (2021)	71 undergraduate dental students (Brazil)	Four student groups subdivided into the teaching methodologies used (traditional, hybrid, e-learning and problem-based learning).	Examination performance was similar across all four test groups. Student acceptance of traditional teaching was lower.	Learner achievement was same across all teaching modalities. Blended learning course was associated with improved student satisfaction.
Rohle et al. (2021)	1012 medical and dental students (Germany)	Human Medical Training ($n = 35$ training sessions). Dental Medicine Training ($n = 14$ training sessions). E-learning package followed by classroom sessions.	COVID adaptations of e-learning ahead of classroom teaching in small groups were successfully implemented based on staff and student evaluation.	Successful COVID adaptation using e-learning in flipped classroom but without any comparisons to traditional or other teaching styles.
Taramarcaz et al. (2022)	529 first-year medical and dental students (Switzerland)	Online questionnaires (×2) to participating subset ($n = 190$); e-learning subset ($n = 124$); certification subset ($n = 90$). Participants to assess BLS knowledge and determine confidence and intention to register as first responder.	Training pathway resulted in increased confidence of managing cardiac arrest.	No comparisons of training types made. Paper reporting on a training pathway, which included an asynchronous e-learning package and hands-on practice sessions.

TABLE 18 (Continued)

Author, year	Study population and country	Study design	Main findings	Interpretation
Turkyilmaz et al. (2019)	Second-, third- and fourth-year dental students (USA)	A 14-question survey evaluating student perception of online learning. 255 out of 1130 students responded (22.6%).	48.5% preference for blended learning compared with 18% for traditional. Students accessed a large range of online resources (e.g., YouTube), which they perceived to have enhanced their learning, especially if recommended by faculty. Organization and credibility of content were perceived as important factors on academic performance.	Although low response rate, students have a high perception of the value of online teaching material on learning and clinical performance in addition to traditional lectures.
Ullah et al. (2021)	98 first-year dental students (Pakistan)	A prospective non-randomized study comparing the outcomes and perception of blended learning (F2F teaching plus online learning; $n = 50$) versus (F2F alone; $n = 48$). Multiple choice questions used to assess the achievement of learning outcomes. DREEM to determine the educational environment during the course.	No significant difference in the pre-test scores of both groups. Mean post-test score for the blended learning group was significantly higher than for the F2F group. The DREEM scores were also significantly higher in the blended learning group than in the F2F group.	Blended learning course is associated with improved students' satisfaction and learner achievement compared to a conventionally administered dental anatomy course. In addition, blended learning enhanced students' accessibility, self-assessment and higher level of engagement compared to F2F delivery of the course.
Varthis and Anderson (2018)	20 second-year dental students (USA)	Questionnaires used to evaluate students' perceptions of blended learning (flipped classroom) in maxillofacial prosthetics. Data analysed using a network diagramming methodology to examine social/group cognition.	Very positive perception of blended learning regarding involvement in the learning process and promoting self-regulated learning. Inclusion of a problem-based patient scenario in the F2F session resulted in increased social cognition.	Positive perception of blended learning using the flipped classroom. Use of patient scenarios increased social cognition.
S. Wu et al. (2022)	60 fourth-year dental students (China)	Test group (online teaching video and discussion of clinical cases in groups; $n = 30$). Control group (traditional lecture-based group; $n = 30$). Closed-book test on subject area for both groups with results compared.	Academic testing revealed test group performed better than control group. Reported on satisfaction of students with online teaching video.	Academic outputs revealed online video group performed better than traditional teaching group. Satisfaction level was positive for online video teaching (no comparison with control/traditional teaching).

Abbreviations: BLS, Basic Life Support; CBE, closed-book examinations; DREEM, Dundee Ready Education Environment Measure; F2F, face-to-face; F-ALP, Formative Adaptive Learning Platform; ICT, information and communication technology; MCQ, Multiple choice questionnaire; OBE, open-book examination; OSCE, objective structured clinical examination; OSPE, objective structured practical examination; PAL, peer-assisted learning.

TABLE 19 Key findings from identified studies reporting on use of blended methods in postgraduate teaching and learning.

Author, year	Study population	Study design	Main findings	Interpretation
Costea et al. (2022)	97 postgraduate students (resident doctors) undertaking a 3-year full-time programme in periodontology. Two groups: PARO 1 ($n = 38$; first-year junior residents focused on systematic online teaching); PARO 2 ($n = 59$; senior residents focused on clinical activities) (Romania)	Cross-sectional multi-centre study, web-based survey/self-report questionnaire.	Self-isolation during the COVID-19 pandemic increased the efficiency of the overall learning process. Resident-centred outcomes differed between first-year and senior students. Residents were not satisfied with clinical practice during the pandemic, but positively rated the development of theoretical online courses, online pre-clinical and clinical internships.	The perception of how e-learning was recognized varied between less and more advanced students. Online learning sessions were, however, efficient for both groups. Reorganization with regard to a balanced ratio between online pre-clinical and F2F clinical courses may facilitate future teaching strategies with greater efficiency.
Naser-ud-Din (2015)	Nine postgraduate students undertaking orthodontics training (Australia)	Cohort study, paper-based anonymous survey.	Identified that blended learning was time-efficient and effective. Visualized content was highly valued among students. The lack of reduced interactivity with peers and tutor as well as instant feedback were rated as major limitations.	Blended learning is efficient when combined with F2F teaching.
Ratka-Kruger et al. (2018)	50 postgraduate students undertaking a 3-year Masters programme in periodontology in a blended learning setting (CPD programme). Qualitative interviews with subset ($n = 6$) (Germany)	Case study; qualitative interviews.	Identified levels of learning transfer (learning and knowledge acquisition, change of the participants' treatment behaviour and overall improvement of treatment and services) and its influencing factors in a postgraduate study programme.	Blended learning can be a successful approach for CPD in dentistry. The combination of close communication between participants and mentors, clear links to the working environment and practical supervision creates a structure for effective learning and skills development.
Varghese et al. (2019)	160 dental Masters students undertaking courses in biostatistics and research methodology. Group I ($n = 80$): video-based courses and in-class lectures; Group II: ($n = 80$): blended-based modules following the technique of Process-Oriented Guided Inquiry Learning (POGIL) including small group learning (India)	Parallel-arm prospective cohort study.	In final examination scores, no differences were found between the two groups.	Evaluation of final scores of Group I (video-based and class presentation) and Group II (POGIL teaching method) showed equal results. Video-based and blended-learning teaching approaches allow for individual repetition of the learning material and thus may improve the individual learning efficiency.

Abbreviation: CPD, continuing professional development; F2F, face-to-face.

motivation, critical thinking, problem solving and preparedness (Farah-Franco et al., 2021; Varthis & Anderson, 2018). Similar perceived benefits of blended learning were also reported by faculty (Farah-Franco et al., 2021). Students also reported a range of positive attributes associated with blended learning, including having a more flexible approach to learning and being more enjoyable and engaging than traditional lectures (Alsharif et al., 2020; Bock et al., 2020; El Tantawi et al., 2013; Huynh et al., 2022; Jeganathan & Fleming, 2020; Kavadella et al., 2013; Nkenke et al., 2012; Ullah et al., 2021). An important outcome of several studies was that students highlighted the importance of the F2F contact aspect of blended learning, especially regarding learning of more complex clinical material and the opportunity for teachers to check understanding of concepts (Bak et al., 2023; Kavadella et al., 2012).

In relation to undergraduate periodontology, just two studies reported on blended approaches in the teaching of periodontal diagnosis and treatment planning (Huynh et al., 2022; Lee & Kim, 2018). Lee and Kim (2018) compared blended learning (flipped classroom) with a traditional lecture format and evaluated the outcomes using pre- and post-course quizzes and surveys. The blended learning group attained significantly higher mean percentage post-quiz scores (78%) compared with the traditional group (63%) ($p < .01$). Although the student evaluation of blended learning was very positive, and 84% of students stated that it was effective and 89% agreed that they had a good understanding of periodontal diagnosis, 81% of students preferred the traditional lecture format. Huynh et al. (2022) carried out a similar study describing the implementation of blended learning for teaching third- and fourth-year undergraduate dental students the 2018 Classification of Periodontal and Peri-implant Diseases and Conditions (Caton et al., 2018). This comprised a 1-h live lecture, an online interactive module and a reading assignment. A post-course questionnaire was used to assess the students' perceptions of their learning. The online module was reported to be the most utilized learning format (95%) in comparison with the lecture (85%) and the reading assignment (18%). In terms of ranking their preferred learning format, the online module was ranked first by 52.2% of students and the lecture by 38.6% of students. Furthermore, 72.5% of students ranked the reading the least effective learning format. Blended learning was reported to be more effective than traditional lectures by 88% of students, and 87% stated that the online module increased their understanding of how to develop a periodontal diagnosis. This study strongly supported the use of blended learning and recommended the use of online quizzes to reinforce learning, and the use of different teaching formats to take into account different student learning preferences.

An essential measure of the effect of teaching methodology on student learning is the assessment of outcomes. Several studies have reported assessment outcomes of knowledge in relation to blended learning, mainly through the use of multiple-choice assessments, often in comparison with traditional learning. The majority of studies reported that blended learning was associated with significantly higher scores for assessment outcomes of knowledge compared with traditional approaches (Alsharif et al., 2020; Alwadei et al., 2020; Ariana et al., 2016; Bock, Kniha, et al., 2021; Farah-Franco et al., 2021; Kavadella et al., 2012; Qutieshat et al., 2020; Ullah et al., 2021; S. Wu et al., 2022), although several studies found no significant difference between the teaching formats (Bains et al., 2011; Bakr et al., 2016; El Tantawi et al., 2013; Jeganathan & Fleming, 2020; Mehta et al., 2016; Nkenke et al., 2012). Another approach employed in several studies was to study the effect of an additional e-learning module on knowledge following F2F teaching carried out in previous years (Jeganathan & Fleming, 2020; Mehta et al., 2016; Ricci et al., 2022). These studies reported that, although students appreciated access to additional online learning resources, it had no significant impact on assessment outcomes. Another complication in evaluating the literature was the diversity of approaches to blended learning. Only one study examined different types of blended learning and reported no significant difference in assessment outcomes between the flipped classroom and team-based learning (Nishigawa et al., 2017). Overall, the literature suggests that blended learning is likely to promote active student learning, resulting in higher assessment outcomes in knowledge-based assessments. Currently, there are no studies that have reported the effect of blended learning on long-term knowledge retention with regard to its impact in final examinations or performance post qualification.

A number of studies reported issues that may need to be taken into account when considering implementing blended learning. First, two studies reported significantly reduced attendance at F2F blended learning sessions (Bock et al., 2018; Nkenke et al., 2012), while another study reported a weak-to-moderate negative correlation between attendance and online usage for some pre-clinical courses (Azab et al., 2016). This suggests that students may prefer to use online material rather than attending F2F teaching sessions unless attendance is made compulsory. Evidence also suggests that not all students engage with online learning resources, including material required, before attending F2F teaching sessions. Gadbury-Amyot et al. (2017) studied student engagement with online resources in two consecutive student cohorts of a second-year paediatric dentistry course and found that in the most actively involved cohort, only 72% of students watched 50% or more of the asynchronous course videos and very few students read any of the pre-class reading resources. On a positive note, of the students who engaged with the videos, between 86% and 100% of students paused and replayed the videos, suggesting active engagement (Gadbury-Amyot et al., 2017). Bock et al. (2018) reported similar findings, with 67% of students engaging with an online module in oral surgery and maxillofacial surgery (Bock et al., 2018).

Blended teaching for knowledge: Assessment methods

Although several studies reported the effect of blended learning on assessment outcomes, these studies retained the same assessments previously used for the traditional learning approaches. We identified only one paper that reported on blended assessment (Hong et al., 2023). These authors compared test anxiety levels and assessment performance in two cohorts of students in restorative dentistry. One cohort sat directly invigilated closed-book examinations (CBEs),

while the other cohort took a directly invigilated CBE and an invigilated online open-book examination (OBE) (blended assessment). The rationale for the OBE was that it could be used to test higher order clinically related problems rather than testing simple knowledge recall. Both cohorts sat mid-term and end-of-course exams. As expected, both cohorts performed better in the end-of-course exams compared with the mid-term exams. No significant differences were found in student anxiety levels between the CBEs and OBEs. Both the CBE and OBE results could be used to predict the overall performance, and interestingly the blended assessment format had a much higher prediction for the low-achieving student group. Although the study suggested that blended assessment is as effective as traditional assessment formats in measuring attainment, students did report concerns of potential cheating with the online OBE even though it was invigilated using online videoconferencing. On a more positive note, students reported that the OBEs did not involve simple recall of knowledge but tested critical thinking in relation to clinical practice. More studies are required to fully ascertain the effectiveness of blended assessment in dental education.

Blended teaching for skills: Education methods

Currently, there are no papers that have directly examined the effect of blended learning on periodontal skills teaching, although there have been several papers related to other disciplines in undergraduate clinical dentistry, such as endodontics, cariology, operative dentistry and removable prosthodontics (Ab Ghani et al., 2022; Bak et al., 2023; Bock et al., 2020; Bock, Elvers, et al., 2021; Bock, Kniha, et al., 2021; Botelho, 2019; Cho & Ganesh, 2022; Escobar et al., 2022; Faraone et al., 2013; Farber et al., 2022; Iqbal et al., 2022; Maresca et al., 2014; Rafai et al., 2016; Reissmann et al., 2015; Rocha et al., 2021). Similar to the teaching of knowledge, student evaluation of blended learning for teaching clinical skills was generally very positive, especially regarding its effectiveness, promoting engagement, motivation, interaction and the positive impact of using online videos/e-learning resources (Alsharif et al., 2020; Bak et al., 2023; Bakr et al., 2016; Bock et al., 2020; Bock, Kniha, et al., 2021; Botelho, 2019; El Tantawi et al., 2013; Faraone et al., 2013; Farber et al., 2022; Maresca et al., 2014; Reissmann et al., 2015; Rocha et al., 2021; S. Wu et al., 2022). Several studies have indicated that the provision of online videos had a very positive impact on students' learning of skills, understanding of clinical procedures and preparation for carrying out these procedures on patients (Alsharif et al., 2020; Bakr et al., 2016; Bock et al., 2018; Bock et al., 2020; Botelho, 2019; Farber et al., 2022). Botelho (2019) reported that, in a fourth-year fixed prosthodontics course, students reported that the ideal duration of a video was between 5 and 10 min. Furthermore, 82% of students watched videos at increased playback speeds, typically at 150%. These findings may need to be taken into account when developing videos for teaching.

Similar to the assessment of knowledge, many studies have reported significantly higher skills assessment outcomes for blended learning compared with traditional teaching (Alsharif et al., 2020; Bakr et al., 2016; Bock, Elvers, et al., 2021; Faraone et al., 2013; Farber et al., 2022; Iqbal et al., 2022; Maresca et al., 2014; Rafai et al., 2016), while other studies have reported no difference (Ab Ghani et al., 2022; Bock, Kniha, et al., 2021; El Tantawi et al., 2013; Rocha et al., 2021). Interestingly, some studies have reported both the outcomes of knowledge and practical elements of courses, with different outcomes. For example, one study reported significantly better outcomes of a knowledge-based multiple-choice exam in a local anaesthetics course, compared with either traditional learning or e-learning, but found no significant difference between the teaching methodologies in the associated clinical assessment (delivery of an inferior dental block) (Bock, Kniha, et al., 2021). Other studies found no difference in knowledge assessments, but there were significantly higher clinical assessment outcomes in blended learning compared with traditional methods (Bakr et al., 2016; Maresca et al., 2014).

How the outcomes of these studies relate to periodontology is currently difficult to ascertain. Interestingly, two endodontic studies reported that the use of blended learning significantly improved treatment performance compared with traditional teaching. Maresca et al. reported that the use of pre-practical online material significantly improved the root canal preparations in the clinical skills laboratory (Maresca et al., 2014). Farber et al. (2022) found significantly better treatment performance and fewer treatment errors when students were undertaking root canal treatments for the first time in both blended and e-learning compared with traditional F2F teaching. There were no significant differences in treatment performance between the blended learning and the e-learning groups (Farber et al., 2022). Whether the outcomes of these studies translate to periodontology requires further research.

Blended teaching for skills: Assessment methods

We identified no studies to date, which have examined blended assessment in skills relating to dental education. The overall trend in the literature suggests that the use of blended approaches in undergraduate dental education for the transfer of knowledge and teaching of skills has a positive impact, which is likely to translate to periodontology, but further research is required. Currently, there is a deficiency in the literature regarding the use of blended approaches to assessment in dental education.

4.3.2 | Postgraduate education leading to specialization

Table 19 summarizes the identified literature regarding postgraduate education and its evaluation. Owing to the limited literature that addressed this topic, education delivery and assessment are considered together in this section.

The COVID-19-related rapid change of teaching and learning concepts was evaluated in a cross-sectional, multi-centre, survey-based study of PG students undertaking a 3-year programme in periodontology (Costea et al., 2022). In this study, 97 full-time PG students were included, and the results revealed discrepancies between first-year students and advanced students. In contrast to

advanced residents, first-year residents valued the online classes as efficient, had a higher attendance rate (100% vs. 89.8%, respectively), experienced online sessions as being more comfortable for asking questions (with more interaction with colleagues) and showed a higher interest in continuing online learning. Also, learning efficiency improved for all residents by repeating procedures on pre-clinical models, leading to a significant decrease in working times.

An evaluation of a blended module in biostatistics and research methodology was performed to compare a video-based learning with a blended small-group learning system undertaken by dental PG students (Varghese et al., 2019). The evaluation of final examination scores revealed no difference between the two teaching concepts. However, the in-course evaluation of projects and written exams showed higher scores for the blended small-group learning system compared to video-based classes in combination with slide presentations. Blended learning CPD undertaken by PG students in periodontology was analysed in the study by Ratka-Kruger et al. (2018), which is considered below under Continuing Professional Development, and also presented in Table 19. Blended learning was also evaluated for a PG programme in orthodontics, and the results showed that it was time-efficient and effective (Naser-ud-Din, 2015). In addition, it highlighted that there is a need for interactivity between students and teachers.

4.3.3 | Continuing professional development

Continuing (dental) professional development may be defined as 'the means by which members of the profession maintain, improve and broaden their knowledge, expertise and competence, and develop personal and professional qualities required throughout their careers' (FDI, 2017, 2019). Synonyms include CPE or CPD and it is a post-qualification professional and ethical obligation for (periodontal) specialists, dentists and oral healthcare professionals as part of their commitment to life-long learning. There are many providers with wide-ranging objectives for their involvement in the delivery of CPD. These include university dental schools, professional dental associations, scientific dental societies and postgraduate dental organizations. In addition, there are commercial companies, national regulatory bodies, private education organizations and state organizations across the European Union (Bullock et al., 2013).

Owing to the limited literature that addressed blended methods in CPD, education delivery and assessment are considered together in this section. Our search revealed only a single published article that focused on postgraduate CPD (Table 19). The study by Ratka-Kruger et al. (2018) evaluated a hybrid Master's programme consisting of blended-learning modules in combination with practical courses in anatomy, hands-on courses using porcine jaws and patient care (internships and supervision during periodontal surgery). The study took place over 7 years with dental practitioners enrolled onto the 'CPD Master's Online Periodontology and Implant Therapy' programme. Over that period, 50 students received the Master of Science degree through this web-supported blended delivery. Blended learning was achieved by providing the theoretical background in virtual classrooms with highly recognized teachers (mainly professors of periodontology and widely experienced practitioners) hosted by a tutor. This online content could then be repeatedly reviewed by the postgraduate students. The case study comprised structured interviews with course participants, online tutors and lecturers, revealing positive comments related to learning knowledge and acquisition, positive changes in participant behaviour towards treatment and improvements in participants' treatment and services. It was not the intention of the study to undertake any quantitative comparisons with traditional teaching methods; however, it confirmed that a blended CPD programme in periodontology was successfully implemented and feasible (Ratka-Kruger et al., 2018).

4.4 | Discussion

In this paper, we aimed to evaluate the use of blended teaching and learning methods in periodontology at three levels: UG, PG and CPD. Blended teaching has evolved considerably since the onset of the COVID-19 pandemic and will undoubtedly develop further in coming years. It is certainly the case that the pandemic resulted in a huge upsurge in delivery of teaching and learning in non-traditional formats, and as a result considerably advanced the utilization of such methods in dental education (Di Carvalho Melo et al., 2023). We adopted a systematic search strategy to identify relevant articles while also being aware that a conventional systematic review approach was not possible because of the heterogeneity of studies. We adopted broad inclusion criteria for the search while at the same time focusing on studies that purposefully investigated blended methods. Although our aim was to evaluate blended teaching in periodontology, the search criteria also enabled the identification of relevant articles from dentistry more broadly as well as some medical specialties.

Our literature search identified 55 relevant articles, and it was clear that there is great variability in the methods of application of blended methods within periodontal education and beyond. Significant diversity in undergraduate periodontology teaching more broadly has been noted previously in a survey of periodontal education and assessment across Europe (Gursoy et al., 2018). There is the potential, therefore, for blended approaches to facilitate closer harmonization of teaching methods in periodontology across Europe and beyond. It is also notable that the great majority of published studies on blended methods to date have focused on UG teaching and learning, with relatively few studies on PG teaching and hardly any on CPD. This may be because necessary infrastructure was already in place to support blended methods in universities and dental schools, which is where the great majority of dental UG teaching takes place, and dental school-based educators have been keen to explore and develop blended teaching and learning opportunities. Furthermore, undergraduate dental students, by virtue of their age demographics, may be highly adapted to engaging with blended methods utilizing online/electronic resources in addition to traditional teaching methods. Indeed, dental students have been shown to be very adaptable in

accepting e-learning or blended teaching environments (Qutieshat et al., 2020). The so-called 'Generation Z' (referring to those born between approximately 1993 and 2016, therefore comprising the majority of undergraduate dental students currently) is known to rely heavily on technology for communication, acquiring knowledge and for interaction with others (Walinski et al., 2023). This cohort may be particularly well adapted to modes of blended learning as well as flipped classroom and team-based approaches (Perera et al., 2020). There may also be components of the undergraduate programme that can more easily be applied to teaching using blended methods, compared to postgraduate or CPD education.

Furthermore, the development of digital dentistry workflows has also increased the opportunities for e-learning and blended learning. In a systematic review of digital education in undergraduate dentistry, a range of digital education approaches were identified, including online/web-based education, digital surface mapping, the use of simulation to develop skills and digital radiography (Zitzmann et al., 2020). Similar approaches were also identified in our literature review, particularly in UG education (Table 18). However, it is clear that there is certainly an opportunity to develop and investigate further blended methods across all areas of dental education.

4.4.1 | Undergraduate education

Our search results yielded just two studies that had evaluated blended teaching and learning in periodontology (Huynh et al., 2022; Lee & Kim, 2018), with other studies focusing on dental education more broadly and areas of related medical education. In a systematic review of technology-enhanced learning in periodontal education (including computer-assisted learning, internet-based video conferencing and virtual patients), it was found that the sole use of such techniques did not improve periodontal education compared to traditional methods; however, a combination of technology-enhanced learning and traditional methods can enhance periodontal education (Berry et al., 2020). Another systematic review of UG pre-clinical skills training (in specialties including operative dentistry, prosthodontics, endodontics and oral surgery) identified that whereas technology-enhanced learning and assessment has the potential to improve students' performance, further studies are needed to clearly identify any benefits (Khalaf et al., 2020).

It is important to note that blended methods such as flipped classroom approaches have been used successfully across a variety of medical disciplines. Indeed, a meta-analysis of eight studies showed a statistically significant effect in favour of flipped classrooms compared to traditional classroom teaching for health professional education across various medical specialty areas, with participants also indicating that they preferred the flipped classroom approach (Hew & Lo, 2018). This positive perception was considered to result from the students having unrestricted access to pre-recorded material, the opportunity to learn at their own pace and convenience and more in-class time for discussion with peers and teachers to enhance learning. This is supported by the findings of a systematic review of dental teaching, which concluded that flipped classrooms provide an effective means of delivering knowledge, with time flexibility being considered a beneficial aspect, allowing students to assimilate knowledge at their own pace (Gianoni-Capenakas et al., 2019).

Similar findings were also reported in the studies identified by our literature search, where most students reported positive evaluations of blended learning. Access to learning materials online at any time/any place fits with the current generation of students' expectations. The overall trend suggests that blended learning strategies, associated with active student learning, are likely to have a positive impact on student learning and assessment outcomes in periodontology; however, clearly more research is required in this area. Incorporation of quizzes, formative feedback and short videos (online and used in class/practicals) is likely to promote the effectiveness of blended learning.

However, potential disadvantages of incorporating blended teaching and learning must be acknowledged. These include the fact that blended learning is resource-heavy to implement and maintain (although this depends to a certain extent on the approach used). There may also be resistance from staff/students to change from traditional methods; and, of course, blended methods require digital literacy. There is also a need to ensure that students are not given excess material prior to F2F classes; otherwise they are unlikely to engage. The degree of preparation by students can be a concern, with evidence that less than half of students consistently viewed online material before attending F2F classes (Gadbury-Amyot et al., 2017). There is also the potential for students to overload themselves with online material, which may detract them from deep learning. Furthermore, increased levels of anxiety, stress, burnout and exhaustion have been reported with dental e-learning, as well as challenges relating to internet connectivity (Di Carvalho Melo et al., 2023).

A small number of studies evaluated student preferences for the different teaching methods assessed, again with mixed results. In preclinical prosthodontics training, there were no differences between groups in student preferences between conventional and blended teaching (Ab Ghani et al., 2022), whereas in blended learning, for the 2018 Classification of Periodontal and Peri-implant Diseases and Conditions, comprising an F2F lecture with an online module, the majority of students preferred the online module, with over 80% enjoying the blended approach and finding it more effective than traditional lecture alone (Huynh et al., 2022). These findings are broadly consistent with a previously conducted study, which found that dental and dental hygiene students found e-resources effective for learning and wanted them to supplement rather than replace traditional lectures (McCann et al., 2010). On the other hand, the study by Lee and Kim (2018) revealed that the great majority (81%) of students stated a preference for traditional approaches in learning periodontal diagnosis and treatment planning.

In addition to the lack of publications on blended learning directly related to periodontology, with only two studies identified that investigated blended methods in periodontal education (Huynh et al., 2022; Lee & Kim, 2018), there is a severe lack of publications relating to the impact of blended assessments in dental or periodontal

education. We identified only one paper that investigated this area, which showed that the blended assessment was as effective as traditional assessment in distinguishing good from poor students (Hong et al., 2023). This study also identified no significant differences in dental students' anxiety levels between traditional and blended assessment methods (Hong et al., 2023).

4.4.2 | Postgraduate education leading to specialization

In periodontal PG education, blended or e-learning concepts were introduced about 20 years ago. At that time, online-delivered aspects were mainly limited to the scientific community in periodontology, for example, when new technologies were introduced in molecular biology. More recently, the online content has evolved towards more clinically oriented aspects; however, the accessibility of high-speed internet as well as specific programmes for blended learning were partly limited.

In periodontal PG education, a hybrid concept consisting of blended teaching in combination with hands-on and patient-based clinical education may be the future concept, leading to specialization as well as for CPD (Ratka-Kruger et al., 2018). In general, blended concepts may help increase the number of dentists receiving postgraduate training in periodontology and lower the threshold to achieve specialization. In addition, online classes held in English would open the opportunity to build a postgraduate educational network facilitating more consistent periodontal postgraduate education across Europe.

In a blended format, educational methods for imparting knowledge should use different formats to deliver the educational content. In this context, online classrooms with a teacher and a moderator, animations to visualize, for example, the pathogenesis of periodontitis, videos showing practical instructions of periodontal treatment modalities as well as treatment sequences in patients, and live treatments/surgeries may be implemented in a blended format (Ratka-Kruger et al., 2018). Postgraduate periodontal education leading to specialization would also require interactive F2F formats that cover anatomy, clerkships in private practices/clinics and university clinics, internships for various treatment modalities and supervisions during periodontal surgeries.

Blended learning may be considered an efficient option in periodontal postgraduate education (Naser-ud-Din, 2015; Ratka-Kruger et al., 2018). Major advantages of online educational content are the better accessibility to postgraduate students irrespective of their current work situation (e.g., private practice vs. university) and the chance for multiple repetition with an increased probability to transfer knowledge to the clinical setting (Costea et al., 2022). Nonetheless, it is important to acknowledge the fact that blended learning concepts still show a need for a tutor/moderator guiding through online classes as well as time and space for students to interact with each other and teachers (Ratka-Kruger et al., 2018). In addition, blended learning cannot replace learning experiences from practical courses using models and porcine jaws for training surgical skills, internships and supervisions during periodontal surgeries. Further, it must be recognized that the available literature evaluating hybrid/blended teaching concepts in postgraduate programmes is sparse, which highlights the need for future studies.

4.4.3 | Continuing professional development

The DentCPD Erasmus Project (2010–2012) entitled 'Harmonization and Standardization of European Dental Schools Programs of Continuing Professional Development for Graduate Dentists' aimed to identify an agreed set of essential CPD requirements for an EU graduate dentist and provide guidelines for the management and delivery of high-quality CPD by European dental schools (DentCPD Erasmus Project, 2010). The project revealed that while there is a trend towards mandatory CPD in Europe and beyond, there is no harmonization of requirements and a wide range of providers, and there are variations in minimum hourly requirements for verifiable and non-verifiable CPD and recommended topics (Bullock et al., 2013). Given the range of providers and lack of harmonization, it is unsurprising that there is variation in the types of CPD available and their mode of delivery. Examples include courses and lectures, training days, peer review, clinical audit, reading journals, attending conferences and e-learning activity (General Dental Council, 2008). Over 15 years ago, the importance of information and communication technology was reviewed (Eaton & Reynolds, 2008), and the benefits for dental practitioners of e-learning identified with the anticipation of growing demand are now fully evident.

Recommendations for e-learning modules for delivering dental CPD in Europe have been published previously (Kavadella et al., 2013). More specific guidance for CPD in periodontology has also been produced, emphasizing the need for interactivity, flexibility, continuity and relevance to practice (Mattheos et al., 2010). It may also be relevant to consider that mature students undertaking CPD may face additional challenges due to financial, family and daily work commitments and that blended learning programmes likely offer additional flexibility to overcome some of these challenges.

In our search, the study that investigated blended methods in CPD teaching utilized a combination of F2F surgical skills combined with online learning materials facilitated by periodontal specialists and appears to have been well received, and was effective in knowledge and skills acquisition by participants (Ratka-Kruger et al., 2018). While no comparisons with traditional teaching methods alone was made, the study indicates that skills and knowledge can be acquired effectively using blended methods in the CPD context.

4.5 | Recommendations for future research

Based on the findings of this review, we make the following suggestions for future research:

- Studies should be conducted to consider the advantages/disadvantages and effectiveness of blended teaching and learning, across dental education in general and periodontology in particular.
- Studies are required to assess blended methods for (i) teaching and learning and (ii) assessment, for both knowledge and skills in periodontology and to compare these to traditional teaching methods.
- Such studies should encompass the full range of periodontal education, including UG, PG and CPD.
- There is a need to study the impact of blended methods on student behaviours as well as student performance and preferences.

4.6 | Conclusions

Based on the studies identified in this review, we conclude that there is great potential for further developing blended teaching and learning in periodontology at all levels of education (UG, PG and CPD). Blended teaching and learning is feasible in many areas of periodontal education, both in terms of knowledge and skills acquisition and assessment. The literature supports the impact of blended learning methods, which are likely to promote active student learning, resulting in higher assessment outcomes in knowledge-based assessments. Although pre-clinical subjects and UG dental education may be areas that can particularly benefit from blended approaches, especially given the demographic and life experiences of undergraduate students (with a high degree of comfort with technology, media and the Internet), postgraduate education and CPD will also benefit from the development of blended teaching methods. Furthermore, today's UG students will soon be tomorrow's PG and CPD students, and they may expect similar blended learning opportunities to those that they experienced as UG students. Further research is needed to evaluate the use of blended teaching and learning in periodontal education, both in knowledge and skills as well as in assessment.

AUTHOR CONTRIBUTIONS

All authors made substantial contributions to the conception and design of the work; the acquisition, analysis, and interpretation of data; the drafting of the work and revising it critically; and the final approval of the manuscript to be published. The original authors for Section 2 were Bruno G. Loos, Philip M. Preshaw and E. Etienne Verheijck. The original authors for Section 3 were Christoph A. Ramseier, Johanna B. Ettmayer, Aušra Balčiūnaitė, Tin Crnić, Graziano Zappalà and Clemens Walter. The original authors for Section 4 were Philip M. Preshaw, Anthony Roberts, Henrik Dommisch and Kevin Davey.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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