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DIGITAL TECHNOLOGIES IN TEACHING DENTAL PROSTHETICS: IMPROVING PRECLINICAL SKILLS IN DENTAL STUDENTS

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ABSTRACT

Digital workflows have altered prosthodontic practice and created a need to align preclinical education with three-dimensional scanning, computer-aided design and manufacturing (CAD/CAM), haptic simulation and objective evaluation of tooth preparation. This article aims to synthesize contemporary evidence on these technologies and propose a competency-based blended training framework for undergraduate dental students. A targeted narrative synthesis was conducted using 18 identifiable peer-reviewed sources, including systematic reviews, randomized studies and recent prosthodontic education reports published through November 2026. Evidence was organized by learning objective, modality, objective skill outcome and methodological limitation. Published findings indicate that digital feedback may improve selected preparation scores and support self-directed practice; however, results are heterogeneous, and several randomized comparisons show performance equivalent to conventional phantom training rather than clear superiority. In one 40-student longitudinal study, mean overall preparation scores increased from 6.52 at baseline to 7.35 at the sixth session but declined to 7.05 on an unaided seventh assessment. A separate scanner-supported educational study reported an increase in “perfect” crown preparations from 14% to 73%, without establishing causality through an independent control group. Four evidence-to-practice tables and an original six-stage instructional pathway link simulation, digital feedback and conventional phantom verification to transparent assessment. A blended, faculty-supervised approach is a defensible strategy for preclinical prosthodontics; prospective controlled validation is required before claiming that the proposed model improves clinical competence.

Keywords: prosthodontic education; preclinical training; dental students; CAD/CAM; virtual reality; haptic simulation; intraoral scanning; crown preparation; digital assessment; competency-based education.

INTRODUCTION

Contemporary prosthodontic care increasingly integrates intraoral scanning, virtual preparation planning, digital design of fixed restorations and computer-aided manufacturing. This transformation has shifted the competencies expected of dental

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graduates beyond conventional hand instrumentation. Students must understand how biologic reduction requirements, finish-line integrity, occlusal clearance, taper, restoration geometry and digital file quality interact in a clinical workflow. These competencies are acquired through repeated psychomotor practice, feedback and opportunities to correct error rather than through technology exposure alone [16,17].

Conventional phantom-head instruction remains indispensable because it provides authentic spatial constraints, operator positioning and physical instrument handling. Nevertheless, reliance on periodic instructor feedback can introduce delays, rater variation and limited opportunities to quantify deviations from a preparation target. Digital real-time evaluation systems, computer-assisted surface overlays, optical scanning and virtual-reality (VR) platforms are designed to address some of these limitations through repeatable scenarios and visual or haptic feedback [3–5,10,14]. Their educational validity must ultimately be judged by performance on independently assessed physical tasks and, where feasible, later patient care rather than by user enthusiasm alone.

Current literature does not justify a simple claim that digital instruction is superior. A 2024 systematic review of 14 randomized trials in prosthodontic education identified potential benefits but also substantial methodological concerns [1]. A 2026 randomized prosthodontic study found no statistically significant advantage from immersive haptic training on independently evaluated preparations [8]. These contrasting results suggest that educational sequence, feedback quality, task specificity and transfer of learning are more informative questions than the presence or absence of a device. Accordingly, the purpose of the present paper is to synthesize relevant evidence and develop a transparent, risk-aware framework for integrating digital technologies into preclinical prosthodontic instruction without replacing essential faculty supervision.

LITERATURE REVIEW

The digital technologies most relevant to preclinical prosthodontics fall into partially overlapping categories. Optical scanning permits documentation of a prepared tooth and comparison with a reference digital surface; real-time evaluation systems can visualize over-reduction, under-reduction, finish-line continuity and preparation geometry; CAD/CAM software adds restorative design constraints; and VR-haptic simulators provide repeatable rehearsal of hand movements with varying degrees of tactile fidelity. These functions are not interchangeable. A scanning platform may strengthen the learner's error detection but cannot reproduce tissue resistance, while haptic rehearsal may facilitate early motor control without proving that a student can safely execute a complex clinical restoration [4,5,15,16].

Focused prosthodontic studies reveal a mixed pattern of benefit. Pham and colleagues examined 40 third-year students across seven crown-preparation sessions, using digital feedback during intermediate practice and an unaided final session. Overall preparation scores improved during feedback-supported sessions, but gains were not uniform across tooth surfaces and the final unaided assessment was not significantly different from baseline [3]. Liu and colleagues described a self-directed intraoral-scanning learning model

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with improvements in preparation ratings and reported anxiety; because the intervention incorporated several educational components, its findings should not be interpreted as an isolated effect of the scanner [4]. Tang and colleagues found improved preparation performance after real-time evaluation and virtual simulation compared with no additional training, while Ge and colleagues observed similar expert and digital scores in integrated and conventional teaching arms in a randomized crown-preparation study [5,6].

Recent trials reinforce the need for cautious interpretation. Li and coauthors compared two VR systems and phantom-head training in 80 students performing veneer preparations and reported no significant difference among selected training configurations [7]. In a 2026 study of 85 students, Bandiaky and colleagues found similar prosthetic preparation scores across immersive haptic and conventional groups after correction for multiple comparisons [8]. Conversely, a 2026 investigation combining real-time evaluation and virtual simulation across three teaching cohorts reported better final preparation results in the digitally exposed cohorts, but the between-cohort design limits causal attribution [9]. Earlier studies of digital feedback, haptic sequencing and computer-assisted grading provide support for feedback precision and instructional flexibility but also show that implementation context matters [10–15].

Systematic reviews convey a similarly balanced message. The prosthodontic meta-analysis by Mai and colleagues reported a pooled performance estimate favoring VR interactive simulation, but its 95% confidence interval crossed the null and heterogeneity was substantial; it therefore did not establish a statistically significant overall advantage [2]. The broader review of haptic devices by Patil and colleagues and a 2026 umbrella review identified promising psychomotor outcomes while noting heterogeneous protocols and weaknesses in underlying evidence [12,18]. The most defensible educational inference is that digital tools can broaden the availability and consistency of formative feedback within a blended curriculum. Whether they produce durable independent skill transfer, reduced remediation time or safer subsequent clinical work remains an empirical question requiring prospectively defined outcomes.

MATERIALS AND METHODS

This paper was designed as a targeted narrative evidence synthesis and development of an original instructional framework, not as a randomized teaching intervention, prospective student cohort or systematic review. The manuscript was structured around contemporary pedagogical approaches to undergraduate fixed prosthodontic training, emphasizing objective digital assessment, practical skill transfer and blended curriculum design. Relevant records were identified in PubMed, journal websites and DOI-linked bibliographic records using terms such as “preclinical prosthodontics,” “tooth preparation,” “digital assessment,” “intraoral scanning,” “virtual reality,” “haptic simulation,” “CAD/CAM,” “phantom head” and “dental student performance.” A total of 18 traceable studies and reviews were selected for the focused synthesis on the basis of direct educational relevance, identifiable methods, measurable learning outcomes or conceptual importance [1–18]. This was a purposive selection, not an exhaustive database search; no PRISMA flow or formal risk-of-bias scores are claimed.

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The analytical unit was the published study or source document. Extracted characteristics comprised study type, educational population, modality, comparator, practical assessment method, principal numerical or directional result and interpretive limitations. Particular attention was given to the separation of faculty-assigned marks, software-based geometric measurements, student-reported confidence and authentic transfer assessments. When sources reported values for multiple sessions, only explicitly published measurements were reproduced. No new pooled effects, participant-level data, hypothesis tests or experimental measurements were generated. Figures 1 and 2 reproduce selected study-specific published values, while Figure 3 and Tables 1, 3 and 4 represent the proposed educational synthesis. Because no students were recruited and no private educational records were analyzed, this literature-based manuscript did not involve a human-subject research intervention. Any future prospective validation would require local educational and ethics review as applicable.

RESULTS

The synthesis identifies five complementary educational functions: procedural visualization, guided instrument control, objective geometric feedback, digital restoration planning and reflective competency assessment. These functions may be combined with phantom training, but technological presence should not be treated as a surrogate for student competence. Table 1 distinguishes educational affordances from the principal constraints that must be addressed before embedding each technology into a core teaching module.

Table 1. Digital technologies and their proposed role in preclinical prosthodontic education

Technology	Educational contribution	Practical verification / limitation
Intraoral / desktop 3D scanning	Surface capture and comparison with a reference preparation; self-review.	Requires calibrated scans and awareness of stitching/artifact errors [4].
Real-time digital evaluation	Visual feedback on reduction, finish line and preparation geometry.	Algorithmic scores must be checked against clinical judgment [3,5,10].
VR and haptic simulation	Repeatable hand-movement practice with guided feedback.	Haptic fidelity and transfer to real instrumentation vary [2,8,12,15].
CAD/CAM design exercises	Connects preparation geometry with restoration design and milling feasibility.	Digital design is no substitute for biological assessment and margin evaluation [16,17].
Digital portfolios / analytics	Tracks attempts, errors, progress and remediation needs.	Requires data governance, score calibration and equity of access [1,14,18].

Table 2 summarizes representative comparisons without converting unlike endpoints into a universal efficacy ranking. Important neutral findings are retained rather than excluded: equivalent performance may be educationally meaningful when digital systems expand

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access to supervised practice, but it does not establish superiority. Sample sizes and conclusions remain those reported in the individual articles.

Table 2. Selected published evidence on technology-enhanced prosthodontic skills training

Study	Design and sample	Selected result	Interpretive boundary
Pham et al., 2025 [3]	Repeated training; 40 students.	Overall score 6.52 (S1) to 7.35 (S6), then 7.05 unaided (S7).	Independent last-session gain versus S1 was not significant.
Liu et al., 2025 [4]	Scanner-supported self-directed model.	"Perfect" preparations 14% before versus 73% after training.	Within-study comparison; bundled education components.
Ge et al., 2025 [6]	Randomized integrated vs conventional; n=58.	Expert p=0.398; digital-assessment p=0.075.	No significant between-arm skill-score difference.
Li et al., 2025 [7]	Randomized veneer training; n=80.	Comparable results across selected virtual and phantom approaches.	Task- and simulator-specific findings.
Bandiaky et al., 2026 [8]	Randomized fixed prosthodontics; n=85.	Phase-one means 17.19 vs 16.55; p>0.05.	No demonstrated significant advantage.
Hu et al., 2026 [9]	Historical and intervention cohorts; n=32,28,32.	Digitally exposed cohorts improved on final tests.	Cohort and sequencing factors may confound effect.
Abu Arqub et al., 2024 [1]	Systematic review; 14 randomized trials.	Mixed findings; many practical skills comparable to control.	High/some risk-of-bias concerns across included RCTs.

A published longitudinal illustration is provided in Figure 1. The increase in mean overall tooth preparation score during digital-feedback sessions is clinically plausible as a learning effect, but the fall on the final unaided attempt emphasizes the distinction between supported task performance and stable transfer. These are observations from a single external study, not measurements of the proposed curriculum or the present author's students [3].

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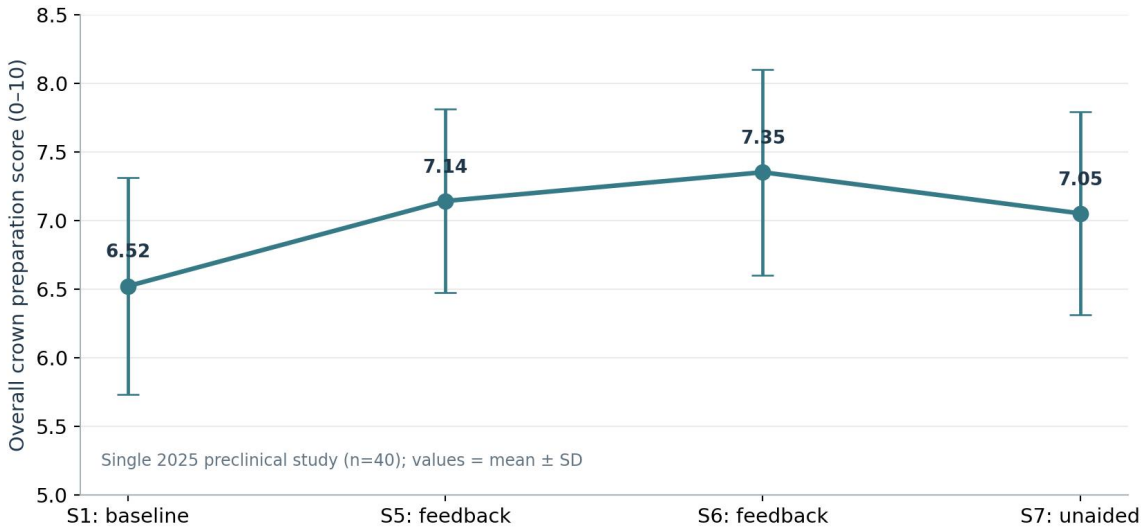


Figure 1. Published overall crown-preparation scores across selected sessions in Pham et al. (2025) [3]. Error bars represent reported standard deviations; sessions S2–S4 are omitted for visual clarity, and this is not a new experiment.

Figure 2 illustrates a second published educational report in which preparation quality was classified before and after a scanner-supported self-directed training approach. Its increase reflects the original study and should not be converted into an estimated treatment effect because the curriculum included practice, feedback and reflection together [4]. Together, Figures 1 and 2 motivate an approach that provides multiple opportunities for practice while retaining final unaided performance as a distinct outcome.

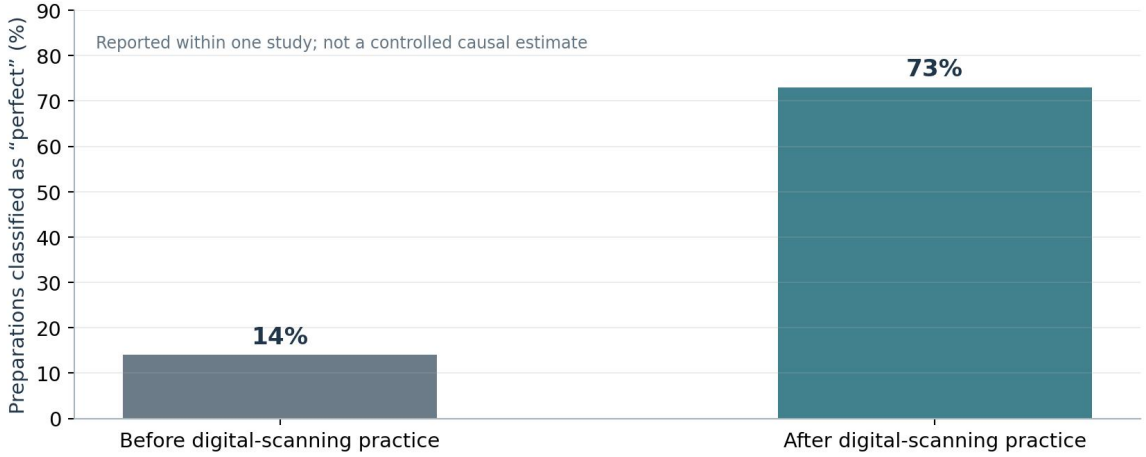


Figure 2. Percentage of "perfect" crown preparations reported before and after a digital-scanning teaching model in Liu et al. (2025) [4]. Values are original reported observations, not a controlled estimate of the isolated effect of intraoral scanning.

On this basis, a six-stage blended instructional pathway was developed as a proposed, not validated, pedagogical model. It begins with a faculty-calibrated baseline phantom preparation, introduces VR and digital workflow rehearsal, uses scans and feedback to

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identify specific errors, returns the student to a physical phantom, and concludes with guided reflection followed by an unaided transfer assessment. The pathway allows flexible iteration rather than obliging all learners to complete an identical number of digital exercises (Figure 3).

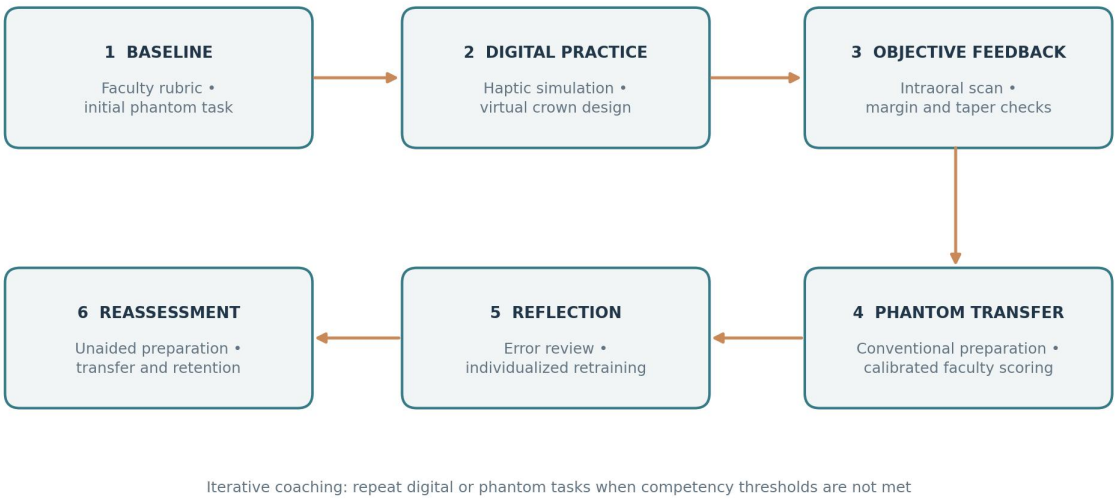


Figure 3. Original conceptual six-stage blended learning pathway for preclinical prosthodontic skills. Arrows represent proposed instructional sequence; the model has not undergone prospective validation.

The proposed curriculum is operationalized in Table 3 as a six-week teaching module, where each stage produces a verifiable artifact rather than an unmeasured claim of competence. The sequence can be compressed or expanded depending on local teaching resources, patient safety requirements and student prerequisites. Where VR-haptic hardware is unavailable, a comparable feedback cycle may be constructed from digital photographs, standard intraoral scans and calibrated instructor evaluation, without claiming full equivalence to immersive simulation.

Table 3. Proposed six-week blended preclinical module for fixed dental prosthetics

Week	Learning activity	Documented output / checkpoint
1	Orientation; anatomy and finish-line principles; unaided diagnostic phantom preparation.	Baseline faculty rubric; identified individual errors.
2	Guided virtual or video-based rehearsal of reduction, taper and insertion axis.	Digital practice log and self-explanation of errors.
3	CAD/CAM case review and optical scanning of prepared resin teeth.	STL/scan quality review; targeted reduction and margin feedback.
4	Physical phantom preparation with calibrated coaching and digital overlay.	Evidence of correction of the three most frequent errors.
5	Independent restorative design task and peer/faculty debrief.	CAD design rationale, material-space and margin checklist.

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Week	Learning activity	Documented output / checkpoint
6	Unaided final tooth preparation and follow-up reflection.	Blinded faculty score, digital quality check and remediation decision.

Table 4 sets out a proposed transparent assessment rubric. The percentage weights are pedagogical design choices, not validated psychometric coefficients or measured student outcomes. A meaningful validation study should establish agreement between instructors and digital systems, select appropriate failure thresholds and determine whether final scores predict subsequent clinical performance. Score reporting should separate technical accuracy, safety behaviors and reflective learning rather than collapse these constructs without evidence.

Table 4. Proposed competency assessment rubric (100 points; not yet validated)

Domain	Points	Evidence source / decision rule to validate
Preparation geometry, occlusal reduction and taper	25	Physical preparation plus calibrated scan overlay.
Finish-line continuity and marginal integrity	20	Magnified inspection and digital visualization.
Conservation of sound tooth structure	15	Standardized reduction and surface integrity criteria.
Scanning accuracy, file integrity and data interpretation	15	Complete digital file plus artifact/error identification.
CAD/CAM design reasoning and restorative fit concepts	10	Structured design discussion against case constraints.
Ergonomics, safety and instrument handling	10	Observed performance on phantom setup.
Reflection, feedback use and individualized correction	5	Error log and corrective plan documented.
TOTAL	100	Requires inter-rater and predictive validation before adoption as a high-stakes score.

DISCUSSION

A competency-based interpretation of the evidence discourages technology-centered teaching plans that count simulator hours without specifying what the student has learned. Virtual environments may provide rapid repetitions, low-stakes exposure to errors and visual explanations of geometric criteria, while conventional phantom tasks preserve handpiece ergonomics, access restrictions and authentic physical feedback. The practical question is therefore how each modality contributes to a deliberate learning cycle and how the resulting performance is verified. The present model treats digital feedback as formative and preserves independent faculty assessment as a safeguard [1,3,6,16].

The apparent discrepancy between favorable longitudinal findings and neutral randomized comparisons has several explanations that warrant investigation rather than premature reconciliation. Outcome scores may reflect different dental surfaces and tasks; simulator

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fidelity may differ; learners can have dissimilar prior experience; and a trial may assess performance immediately after exposure without measuring later retention. In the 2025 randomized veneer study, final results were similar across the tested educational strategies [7], and the 2026 haptic trial likewise observed no significant performance advantage [8]. These observations coexist with within-learner improvements during repeated practice in the digital-feedback study [3] and cohort-level improvements in a combined digital curriculum [9]. Neither category of findings should be used to justify a universal recommendation without attention to study design.

The educational value of digital scanning and CAD/CAM may also extend beyond score change. Students learn to distinguish a visually attractive preparation from a technically acceptable one, recognize data artifacts in three-dimensional surfaces and relate axial taper or occlusal reduction to prosthesis manufacture. These activities can make clinically important concepts more tangible; however, accurate computer outputs may still conceal misconceptions if learners do not explain the rationale behind a virtual design. Thus, software feedback should prompt clinical reasoning, not merely reward compliance with a target shape [4,5,14,17].

A resource-conscious implementation strategy is particularly relevant to universities where access to simulation hardware or CAD/CAM licenses is limited. Shared scanning sessions, standardized photographic stations and annotated digital portfolios can support some feedback functions at lower infrastructure cost, although the comparative effectiveness of such alternatives remains to be determined. Before expansion, local instructors should test calibration, technical maintenance requirements, equitable access and the effect of digital teaching on faculty workload. The model also requires attention to digital consent, safe handling of student work and restrictions on uploading clinical or educational data into third-party systems without authorization.

The present article has important limitations. The literature was purposively selected and not searched with a registered protocol; evidence extraction was not performed by independent reviewers and no formal quality-rating procedure was undertaken. Several source studies focus on restorative tooth preparation rather than the complete prosthodontic workflow; their implications for crown-and-bridge design or removable prosthetics are indirect. The selected numerical examples come from separate studies with different tasks, endpoints and feedback conditions; they are not pooled or directly compared as effect sizes. Most importantly, the proposed six-stage pathway and 100-point rubric have not been tested in a student cohort. Neither effectiveness, reliability nor generalizability to other institutions can be asserted from the present synthesis.

A future pragmatic study could prospectively assign similar cohorts to conventional teaching or a prespecified blended curriculum, ensure comparable baseline phantom experience and use independent blinded assessors to score final unaided crown preparations. The primary outcome should be a clinically meaningful standardized preparation score measured at a planned post-training time point. Secondary outcomes could include time to reach a competency threshold, repeated-attempt error patterns, scan-quality accuracy, learner workload, delayed retention, faculty scoring agreement and educational costs. Sample-size determination, ethics review, pre-registration and a

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predefined analysis plan would distinguish an original intervention study from the present conceptual article. The most consequential test is whether measurable laboratory gains persist when students undertake new prosthodontic tasks under faculty supervision.

CONCLUSION

Digital technologies can enrich preclinical education in dental prosthetics through repeatable practice, three-dimensional visualization and timely assessment of selected preparation errors. The current literature supports their use as carefully structured adjuncts to conventional phantom instruction, but it does not establish consistent superiority across all prosthodontic tasks or guarantee transfer to clinical practice. An original six-stage blended pathway integrating baseline evaluation, virtual rehearsal, objective scanning feedback, physical verification, reflection and unaided reassessment is proposed as a transparent educational framework. Its value remains a hypothesis for prospective testing. Faculty calibration, attention to patient-safety principles and clinically meaningful competency outcomes should determine adoption more strongly than technological novelty.

DECLARATIONS

Study design: Targeted narrative evidence synthesis and original conceptual educational framework; no new student or patient observations. Ethical approval and consent: Not applicable to this literature-only article; a future training trial would require applicable approvals. Funding: To be confirmed by the author. Conflicts of interest: To be confirmed by the author. Institutional affiliation and final author-contribution statement: To be confirmed by the author. Data availability: No primary dataset was generated; numerical figures reproduce results from references [3] and [4].

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