

Original Article

Effect of CAD/CAM Hands-On Training on Dental Students' Perceived Competence and Attitudes Toward Digital Dentistry: A Controlled Survey Study

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ABSTRACT

This study aimed to evaluate dental students' perceptions of digital technologies after engaging in a CAD/CAM exercise involving scanning, designing, and producing computer-assisted provisional fixed dental restorations. A survey was administered to second-year (pre-D2 and post-D2), first-year (D1, negative control), third-year, and fourth-year students (D3 and D4, positive controls). Only participants from the OSU College of Dentistry who completed both the exercise and the survey were included. Seven items were rated to assess changes in knowledge, skill, interest, perceived importance of technology in dental offices, patients' view of such technologies, significance of having access to them, and the anticipated frequency of their clinical use. Statistical testing was conducted at a 0.05 significance level. In total, 74 pre-D2 and 77 post-D2 surveys were returned, along with 63 from D1, 43 from D3, and 39 from D4 students. Significant differences were observed in "knowledge" and "skill" between pre-D2 and post-D2, and between pre-D2 and control groups ($p < 0.001$). Post-D2 participants showed higher "interest" ($p = 0.0127$) and greater preference for in-office technology ($p < 0.05$) compared to all controls. Moreover, there were notable differences regarding the perceived importance of technology in offices ($p < 0.001$) and expected frequency of its use ($p = 0.01$). No significant changes were found in "patients' value of technology" and "importance of owning the technology." Overall, exposure to digital systems in both clinical and educational settings significantly enhanced students' interest, confidence, and self-perceived competence.

Keywords: Digital dentistry, CAD/CAM, Dental education, Technology integration, Student perception

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Introduction

The rise of digital dentistry and CAD/CAM systems—built on oral and dental scans—has encouraged dental institutions to adapt their curricula and embed these technologies into student training [1, 2]. CAD/CAM composite restorative materials, designed for subtractive manufacturing using milling machines and standardized blocks, now show improved qualities compared to direct composites, featuring resin polymer matrices with ceramic-based fillers [3]. Variations in formulation, ratio, and filler distribution among

CAD/CAM materials yield different physical and mechanical behaviors [3–8].

Digital impression techniques and CAD/CAM manufacturing, including machine milling and 3D printing, have revolutionized restorative and prosthetic workflows. Today, it is feasible to produce monolithic zirconia crowns [9], orthodontic devices [10], and surgical guides [11] via digital fabrication. Such innovations are now widely accepted in private practice, reshaping clinical approaches and perceptions [4, 12–14]. However, research on composite-based CAD/CAM materials remains limited, with most

studies being in vitro and emphasizing mechanical aspects like fatigue and fracture resistance, particularly in veneers [15–20].

Resin composites used for 3D printing are typically acrylic-based photopolymers [21]. The inclusion of ceramic nanoparticles has led to nanohybrid resin composites capable of supporting permanent restorations [22, 23]. Other formulations, such as self-curing acrylic or bis-acryl resins, are also in use [24]. Inorganic fillers enhance flexural strength, stiffness, and hardness [25]. Additionally, manufacturers generally recommend a 50 µm layer thickness to minimize surface roughness [26], while increasing to 100 µm reduces printing time by roughly 40% [27], though it can affect material performance [28].

Integrating digital technology into dental training is essential to match ongoing technological and material advancements. Yet, few studies have explored how students perceive these changes or how it shapes their career plans. Surveys provide a useful method to evaluate such perceptions. A prior study [29] reviewed 99 survey-based dental publications and found that while introductions and ethics reporting were well-presented, elements like participant incentives, data analysis, and nonresponse details were often incomplete. Magnuson *et al.* [30] later outlined key reporting standards, including: (1) respondent sampling; (2) survey design; (3) pilot testing; (4) participant recruitment; (5) distribution and follow-up details; (6) response rates; (7) total usable responses; (8) data management methods and software; and (9) inclusion of tables and figures.

Following these principles, the present study aimed to measure dental students' perceptions of digital technologies after a simulated CAD/CAM-based exercise involving scanning, designing, and manufacturing provisional restorations. It was hypothesized that comprehensive digital training would positively influence students' future adoption of dental technologies. The null hypothesis stated that no perceptual differences would occur after the learning experience.

Materials and Methods

This research was reviewed and approved by the University's Institutional Ethics Committee (approval #20220799).

Sample selection and grouping

In the College of Dentistry curriculum, second-year students receive pre-clinical instruction in Fixed Prosthodontics and Operative Dentistry. Previously, these students were introduced to intraoral digital

scanning and basic computer-aided design (CAD) but not computer-aided manufacturing (CAM). As part of a curriculum redesign, a full CAD/CAM exercise was introduced in the fourth operative dentistry course during the fall semester of the second year. A perception survey was then conducted among these students to evaluate shifts in their understanding and attitudes toward digital dentistry.

Eligibility criteria

Table 1 outlines the inclusion requirements, which involved second-year dental students both before and after the CAD/CAM exercise. The same questionnaire was also distributed to first-year students (without prior exposure to digital dentistry) and to third- and fourth-year students (who had limited prior experience with intraoral scanning and CAD training) serving as control groups. All students across the four years were invited, but only those who completed every required survey were included in the final analysis.

Table 1. The results of quantum-chemical calculations

Inclusion Criteria	Exclusion Criteria
Students enrolled at the OSU College of Dentistry	Students from other medical disciplines or unrelated fields
Completed the CAD/CAM activity	Researchers or postdoctoral students at the OSU College of Dentistry
Completed both pre- and post-surveys	Declined to complete the survey
Classified as: • 1st-year students (negative control) • 2nd-year students (test group) • 3rd- and 4th-year students (positive control)	Did not complete the CAD/CAM activity

Table 1 summarizes the criteria: only OSU College of Dentistry (OH, USA) students who agreed to participate, completed the CAD/CAM activity, and filled both the pre- and post-exercise surveys were included. First-year students, unfamiliar with digital dentistry, acted as negative controls, while third- and fourth-year students served as positive controls. Students who missed the exercise or failed to complete their surveys were excluded.

Sample size calculation

To validate the instrument, five professional dentists (the study's authors) completed the same questionnaire twice, one week apart. Test–retest reliability was measured using intra-class correlation coefficients

(ICCs), assuming a minimum acceptable reliability (ρ_0) of 0.7 and a target reliability (ρ_1) of 0.9. Based on these values, the minimum required sample size was 65 participants. Accounting for an anticipated 10% dropout rate, a total of 72 participants was determined as the target number.

Activity description

The pre-clinical simulation took place in the laboratory, where each student prepared an ivory molar (#46, Nissin Dental Products—Kilgore, Kyoto, Japan) for a CAD/CAM onlay restoration. The activity started with a digital impression using the 3Shape TRIOS® intraoral scanner (3Shape, Copenhagen, Denmark). Students then designed their restorations using 3Shape TRIOS® Design Studio software (v.2022.1, 3Shape, Copenhagen, Denmark), assisted by tutorial videos and in-lab faculty supervision. After the CAD design, the onlay was exported as an STL file and imported into AnyCubic Workshop (v.2.1.29, Anycubic, Shenzhen, China) for 3D printing.

In this software, students could rotate models, add support structures, and include personalized name tags before slicing the file for printing.

The CAM phase was executed using Photon M2 3D printers (AnyCubic, Shenzhen, China), allowing students to print customized restorations for their prepared teeth. The session concluded with fitting and cementing the printed provisional onlays using TempBond NE (non-eugenol) cement (KaVo Kerr, Brea, CA, USA) (**Figure 1**).

The practical activity was supported by several lectures covering CAD/CAM theory, a joint 3D-printing session co-taught with the College of Engineering for a multidisciplinary perspective, and a practice management lecture focusing on the clinical application of digital systems. Later, students participated in a group-based active learning session, analyzing fictional practice settings and deciding whether to invest in CAD/CAM technology based on various office profiles.



Figure 1. A 3D-printed block immediately after the exercise.

Survey (Questionnaire)

The survey was structured around five main dimensions: (1) knowledge, (2) skill, (3) interest, (4) value of technology, and (5) practice aspirations. The first category assessed prior and post-exercise familiarity with digital dentistry; the second measured perceived competence; the third evaluated motivation and interest; the fourth addressed the perceived relationship between technology and patient care; and the fifth examined career-related perspectives and motivations.

Given the educational emphasis on early exposure to CAD/CAM, the survey aimed to understand how this exercise affected students' appreciation of digital tools and their professional outlook. Responses were anonymous and recorded in Microsoft Excel (v.16.70, Redmond, WA, USA) for analysis.

Seven items were rated on a 10-point scale (1 = lowest/I strongly disagree; 10 = highest/I strongly agree), covering: (i) change in knowledge, (ii) skill,

(iii) interest, (iv) perceived importance of technology in dental offices, (v) perceived value of technology for patients, (vi) importance of having access to the technology, and (vii) expected prevalence of clinics using such systems (**Table 2**).

Table 2. Student questionnaire (1 = lowest/I strongly disagree; 10 = highest/I strongly agree).

#	Rephrased Survey Question
1	How would you assess your current understanding of digital dentistry?
2	How would you evaluate your proficiency in using digital dentistry tools?
3	How would you describe your level of enthusiasm for digital dentistry?
4	The presence of digital technology in a practice would strongly influence my choice to work there.
5	Patients place high value on the integration of advanced dental technology.
6	Digital technology is essential for the operation of any modern dental practice.

7 The majority of dental clinics, if not all, currently employ intraoral scanners.

were conducted using R software (v3.6.1; R Core Team, 2021) with a significance threshold of 0.05.

Statistical analysis

Normality of the data was assessed using the Kolmogorov–Smirnov test. Subsequently, the Kruskal–Wallis test was applied to determine similarities among the control groups (D1, D3, D4) and the post-D2 group. Since D2 students' "knowledge" and "skill" levels could differ substantially from controls, these variables were not included in that test. The pre-D2 data, being dependent on post-D2, were analyzed separately. Additional Kruskal–Wallis tests compared post-D2 with all control groups. To compare pre-D2 students with the combined control groups (D1 as negative control and D3–D4 as positive controls), Wilcoxon's test with Bonferroni correction for multiple comparisons was employed. All analyses

Results and Discussion

Sample

A cohort of 118 students in their second year of dental school fabricated 118 separate printed restorations tailored to their prepared typodont models. Among these individuals, 74 (62.71%) completed the baseline questionnaire (pre-D2), and 77 (65.25%) responded after the instructional phase (post-D2). The negative control consisted of 120 first-year students (D1), of whom 63 (52.5%) submitted responses. A total of 240 students from advanced years (120 third-year and 120 fourth-year) acted as positive controls, with replies received from 43 D3 (35.83%) and 39 D4 (32.5%) participants. Class distribution is detailed in **Table 3**.

Table 3. Group breakdown of participants.

Graduating Class	Cohort Size	Age Range / Mean	Gender Distribution			Underrepresented Minority
			Male	Female	Other	
2023	120	21–34 / 24	65	55	1	8
2024	120	19–50 / 23	54	66	0	13
2025	118	20–38 / 22	55	63	0	14
2026	120	19–41 / 22	55	65	0	5

Knowledge and skill

Assessment of "knowledge" and "skill" parameters (**Figure 2**) showed marked statistical differences between pre-D2 students and all control cohorts ($p < 0.001$ in both measures). Consequently, pre-D2

findings were not directly comparable to any control group except within these specific variables. For that reason, comparing post-D2 to the controls on these items was not meaningful, as the difference could not be solely attributed to the training component.

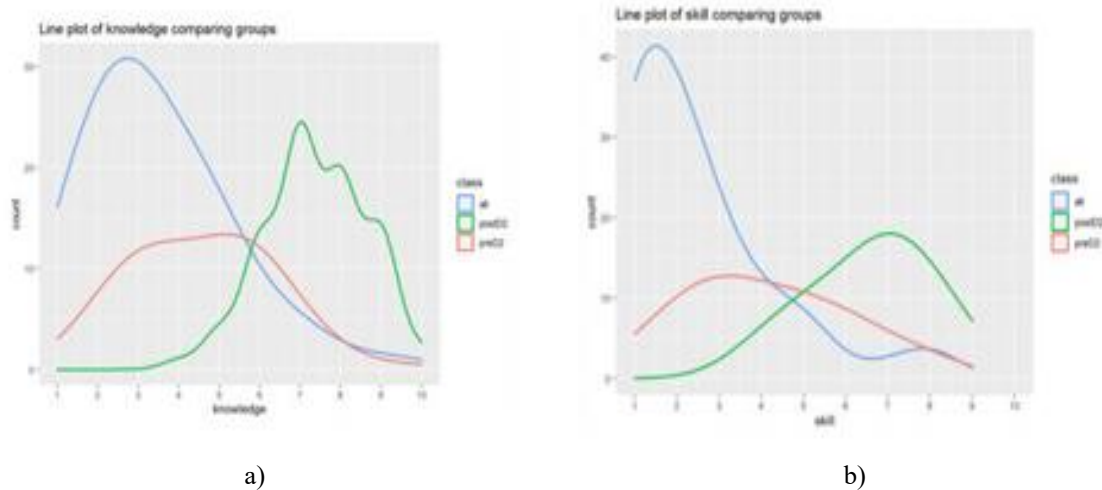


Figure 2. Density plots for self-perceived knowledge (left) and skill (right) for all study participants.

When the same group was evaluated before and after intervention, significant gains were identified in

"knowledge" ($p < 0.001$) and "skill" ($p < 0.001$) (**Figure 3**). Post-D2 scores also significantly exceeded

those of all control groups (D1, D3, and D4) for both categories ($p < 0.001$). When D3 and D4 were pooled, the comparison remained significant—"knowledge" ($p < 0.001$) and "skill" ($p < 0.0001$).

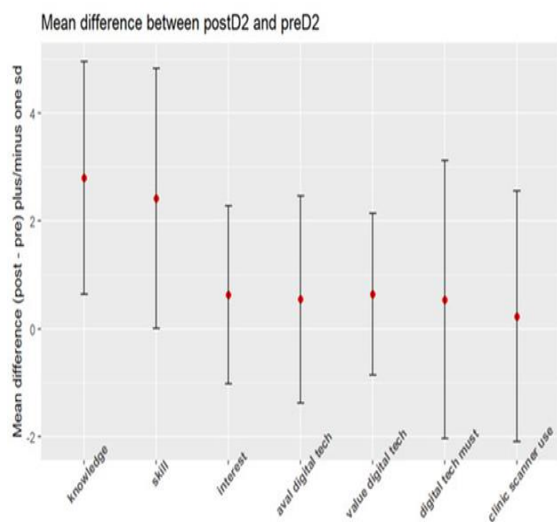


Figure 3. Mean change observed in each domain between pre-D2 and post-D2 assessments.

Interest

The measure of "interest" reached statistical significance ($p < 0.05$), showing that pre-D2 students did not differ from controls regarding enthusiasm for digital dentistry. Post-D2, however, diverged significantly from all control groups ($p = 0.02$), with a specific difference between post-D2 and D1 ($p = 0.0362$). Within the same group, the pre- and post-assessments demonstrated a significant increase in interest ($p = 0.0102$) (**Figure 3**).

Post-D2 also differed from all controls combined ($p = 0.0127$), and the difference persisted when D3 and D4 were analyzed together ($p = 0.0065$). In contrast, no

statistical variation was observed between D1 and the merged D3–D4 controls (**Figure 4**).

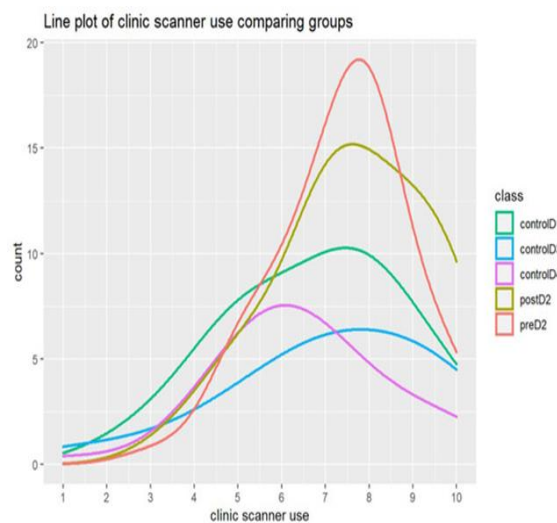


Figure 4. Distribution of responses regarding the "importance of having technology" across pre-D2, post-D2, and all control categories.

Practice aspiration

Responses to the "practice aspiration" question showed significant trends ($p < 0.05$), suggesting that pre-D2 participants aligned with controls regarding the role of dental technology in professional settings. Post-D2 students, however, differed notably from D1, D3, and D4 groups in "importance of technology availability in a clinic" ($p < 0.001$) and in "perceived prevalence of clinics equipped with the technology" ($p = 0.01$). Pairwise comparisons revealed significant gaps between post-D2/D1 ($p = 0.00284$) and post-D2/D4 ($p = 0.0399$) for the first variable, while the second showed significance between post-D2 and D4 ($p = 0.01213$) (**Table 4**).

Table 4. Statistical summary of responses.

Variable	Post-D2 n=77 Mean (SD)	Pre-D2 n=74 Mean (SD)	D1 Control n=63 Mean (SD)	D3 Control n=43 Mean (SD)	D4 Control n=39 Mean (SD)	Combined D3/D4 n=82 Mean (SD)	All Controls n=145 Mean (SD)
Knowledge	7.38 (1.26)	4.58 (1.75)	3.68 (2.18)	3.51 (1.53)	3.15 (1.44)	3.34 (1.49)	3.49 (1.82)
Skill	6.57 (1.46)	4.15 (1.91)	2.60 (2.11)	2.70 (1.49)	2.13 (1.47)	2.43 (1.50)	2.50 (1.78)
Interest	9.45 (0.90)	8.82 (1.39)	8.79 (1.56)	8.84 (1.40)	9.13 (0.95)	8.98 (1.21)	8.90 (1.37)
Availability of Digital Tech in Practice	8.90 (1.30)	8.35 (1.41)	7.78 (2.02)	8.19 (1.79)	7.79 (2.14)	8.00 (1.96)	7.90 (1.98)
Value of Digital Tech to Patients	9.49 (0.87)	8.85 (1.22)	9.05 (1.30)	9.33 (1.02)	9.10 (1.19)	9.22 (1.10)	9.14 (1.19)
Digital Tech is Essential in Clinics	8.30 (1.86)	7.76 (1.78)	7.78 (2.18)	8.02 (2.06)	7.82 (2.02)	7.93 (2.04)	7.86 (2.09)

Expected							
Scanner Use in Clinics	7.60 (1.76)	7.36 (1.51)	6.79 (2.01)	7.12 (2.38)	6.49 (1.92)	6.82 (2.18)	6.81 (2.10)

Within-subject analysis of pre-D2 versus post-D2 demonstrated an improvement in perceived “importance of technology availability” ($p = 0.0024$) (**Figure 3**). Comparisons of post-D2 against all controls also revealed significance for the same factor ($p < 0.002$). When D3 and D4 were grouped, post-D2 results remained higher for “importance of technology availability” ($p = 0.0043$) and “relative frequency of clinics having the technology” ($p = 0.0203$). No differences were detected between D1 and the aggregated D3–D4 control set (**Figure 4**).

Value of technology

All “value”-related indicators achieved statistical significance ($p < 0.05$), showing that pre-D2 students were on par with all control groups in recognizing the relevance of digital systems. Across all cohorts, there was no significant contrast for “value of technology to patients” or “importance of possessing technology” ($p < 0.05$). The pre-/post-D2 comparison likewise showed no change for these measures (**Figure 3**).

Additionally, post-D2 data did not differ significantly from D1, D3, or D4 controls. Grouped analysis (post-D2 vs. combined D3–D4, and D1 vs. combined D3–D4) also yielded non-significant results (**Figure 4**).

This study aimed to evaluate dental students' perceptions regarding digital dental technologies. The main objective was to determine whether pre-clinical exposure to simulated exercises involving digital scanning, design, and computer-assisted fabrication of provisional fixed restorations would influence students' motivation to integrate such technologies into their future professional practice (positive hypothesis). The outcomes demonstrated notable improvements in students' self-assessed knowledge, technical ability, interest level, and perceptions of technology (including perceived importance of availability in clinics, patient value, overall importance, and the frequency of clinics equipped with such systems).

It is important to acknowledge that the educational landscape was considerably altered by the COVID-19 pandemic [31]. The sudden shift to online education caused a decline in interpersonal interaction, patient contact, and group collaboration [32, 33]. Consequently, dental curricula have been restructured to better prepare beginners through the use of digital systems and evidence-based technological instruction. Among these advancements, CAD/CAM represents one of the most influential innovations in modern dentistry, although its academic implementation has

been gradual—particularly when integrated into undergraduate coursework [34]. Since the early 2010s, several studies have examined how such introductions influence academic engagement. For example, Dehghan *et al.* (2012) [35] documented the introduction of the CEREC (ceramic reconstruction) CAD/CAM system at the University of Tennessee College of Dentistry, the first U.S. dental school to adopt it in the senior-year curriculum. Their findings revealed that this technology provided both cost-efficiency and improved clinical outcomes for students and patients alike.

Browning *et al.* [36] studied undergraduate students over a one-year period as they produced 125 all-ceramic crowns for patients using CAD/CAM processes (designing, milling, sintering, and staining). Their results indicated a substantial reduction in laboratory costs, and faculty members noted superior marginal fit and esthetics. The same research group later reported [37] on integrating CAD/CAM systems into the predoctoral program at the Indiana University School of Dentistry. Of 105 first-year students, 88 participated (84% response rate), with 80% rating the experience as good or excellent and 43% feeling competent to independently fabricate a crown.

In comparison, the present study extended the survey across all academic levels, emphasizing second-year students as the intervention group. A total of 118 second-year students scanned, designed, and 3D-printed 118 restorations. Of these, 74 (62.71%) completed the pre-intervention (pre-D2) questionnaire, and 77 (65.25%) responded post-intervention (post-D2). Significant differences were identified between pre- and post-D2 and among all control groups (D1, D3, and D4) for both “knowledge” ($p < 0.001$) and “skill” ($p < 0.001$). Similarly, meaningful differences appeared between post-D2 and the controls for “availability of technology in practice” ($p < 0.001$) and “frequency of technology-equipped clinics” ($p = 0.01$). Another investigation [2] conducted in 2017 detailed the inclusion of CAD/CAM technology in the University of Illinois at Chicago College of Dentistry's implant program. The results showed an increase in digitally fabricated implant restorations relative to conventional techniques. Subsequently, Schweyen *et al.* [38] examined similar integration within a prosthodontic curriculum at a German dental school in 2018. Participation reached 94% of all students, reflecting a stronger level of interest than the current findings, and restorations exhibited favorable clinical

outcomes. The researchers concluded that students trained with CAD/CAM systems were more likely to prepare additional digital restorations compared with peers unfamiliar with the technology.

In the present investigation, clear differences emerged between the second-year (intervention) group and both the first-year (negative control) and the third- and fourth-year (positive control) students. Consistent with previous reports [1], the introduction of digital workflows produced favorable perceptions and attitudes toward future clinical application. Earlier findings [1] indicated that more than 90% of participants were comfortable using intraoral scanners and intended to implement them in their professional work. The current project likewise enhanced the second-year group's digital proficiency and theoretical understanding compared with the control cohorts. The weaker performance observed in first-year students can be attributed to their lack of exposure to digital content, while the modest results among senior students likely stem from limited digital training introduced one or two years prior. Timely incorporation of digital systems in predoctoral education is therefore crucial for maximizing student learning experiences [2].

Interestingly, both the first- and second-year cohorts expressed greater appreciation for the importance of digital technologies in clinical practice than the senior classes. This may relate to the limited access to such tools in the clinical curriculum at the time of data collection, potentially influencing students' practical viewpoints.

Following the digital fabrication activity, second-year students also reported stronger aspirations to work in clinics equipped with digital technologies, suggesting that the hands-on exercise positively shaped their career goals. Similar trends were present among first-year students and, to a lesser degree, among third- and fourth-years. Reduced enthusiasm among senior participants may again reflect the minimal exposure to digital systems within their clinical training. Across all levels, student interest in digital dentistry remained high, with the intervention group showing the greatest increase—supporting previous evidence of dental students' generally positive and enthusiastic attitudes toward emerging digital technologies [39].

Towers *et al.* [40] also examined how students perceived the integration of virtual reality (VR) and 3D printing in operative instruction. Their findings reinforced the outcomes of this study, emphasizing the importance of technology for students and innovative teaching methods that can be directly applied to clinical contexts. The study further underlined the significance of instructor support, which this survey did not

evaluate. The impact of such training on both clinical practice and patient outcomes was noteworthy, particularly in boosting students' confidence and readiness.

A separate investigation published in 2023 [41] assessed predoctoral dental students' education, understanding, attitudes, and professional conduct related to CAD/CAM technology, as well as correlations between academic year and other variables. A total of 358 participants from 17 of 68 U.S. dental schools (25%) completed an anonymous online questionnaire. Paralleling this research, reported percentages for instructional methods were simulated tasks (86.9%), video-based demonstrations (81.8%), lecture demonstrations (76.4%), small-group sessions (69.2%), hands-on activities (65.6%), and individual instruction (50.4%). There was a statistically significant rise in both knowledge and attitude toward CAD/CAM application ($p < 0.001$ and $p < 0.05$, respectively), whereas student satisfaction did not differ notably. The study concluded that most U.S. dental students viewed CAD/CAM as the future of dentistry, enhancing their clinical competence.

Study limitation

Certain limitations should be acknowledged. The feedback collected represented a restricted student sample, and opinions do not necessarily equate to demonstrated ability. Furthermore, students' perceptions of "skills" and "knowledge" may lead to inflated self-assessments. The data were obtained from a single institution, despite similar digital transition efforts elsewhere. The analysis could be broadened to include all academic years rather than just the second year, allowing evaluation of knowledge retention through later stages (third and fourth years). To preserve anonymity, no identifying details were recorded from respondents. Consequently, it was not possible to match pre- and post-intervention answers for the same individuals, leading to the assumption of independent samples.

Recommendations for future studies

Further longitudinal cohort research is advised, ideally with a multicenter approach, to monitor larger student populations over time. Expanding upon this study's focus on students' perceptions of digital tools and the design and fabrication of computer-aided provisional restorations, upcoming work could explore emerging materials and techniques, such as zirconia crown fabrication or new resin formulations, assessing aspects like mechanical strength, artificial aging, tensile modulus, surface finish after polishing, thermocycling effects, and fractal dimension analysis,

thereby providing updated insights for both practitioners and academics [42].

Conclusion

Within the boundaries of this investigation, the following conclusions were reached:

- (i) Approximately 60% of the second-year (experimental) students completed the questionnaire, showing statistically significant outcomes in interest;
- (ii) Marked improvements were seen in knowledge and skills when comparing pre-D2 with post-D2 and all control groups (D1, D3, and D4);
- (iii) A notable influence was observed regarding students' perception of technology use in both clinical and academic environments.

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