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ORIGINAL ARTICLE

Pre-doctoral dental students' computer-aided design/computer-aided manufacturing-related education, knowledge, attitudes and behavior: A national survey

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Abstract

Objectives: Computer-aided design/computer-aided manufacturing (CAD/CAM) technology transformed the world of restorative dentistry. The objectives were to assess pre-doctoral dental students' CAD/CAM-related education, knowledge, attitudes, and professional behavior, and to explore the relationships between the year in dental school and these constructs.

Methods: A total of 358 pre-doctoral dental students from 17 of the 68 US dental schools responded to a web-based anonymous survey.

Results: CAD/CAM-related classroom-based education was likely to happen in lectures (87.2%) and simulated exercises as part of a class (86.9%). Faculty were most likely to provide CAD/CAM instruction (87.9%), with staff (44.8%) and dental technicians (20.2%) being engaged as well. Preclinical education included video demonstrations (81.8%), demonstrations during a lecture (76.4%) or for smaller groups of students (69.2%), hands-on workshops (65.6%), and individual instruction (50.4%). Considering the digital workflow in clinics, 45.2% reported using intraoral scans. The more advanced the students were in their program, the more CAD/CAM knowledge ($r = 0.27$; $p < 0.001$) and knowledge about what can be fabricated with CAD/CAM technology they had ($r = 0.25$; $p < 0.001$). However, the student's satisfaction with the education about CAD/CAM did not increase over the years ($r = -0.04$; n.s.) and remained neutral, while their attitudes became more positive the longer they were in dental school ($r = 0.13$; $p < 0.05$). Their attitudes were quite positive, with most students considering that CAD/CAM is the future of dentistry (5 = most positive: Mean = 4.34), agreeing that they enjoyed working with CAD/CAM (Mean = 4.11) and that CAD/CAM has the potential of making them a better dentist (Mean = 4.07).

Conclusions: The majority of students in the US dental schools appreciate CAD/CAM technology, consider it to be the future of dentistry, and believe it makes them better dentists. The fact that the majority is not satisfied with their

classroom-based, preclinical and clinical CAD/CAM-related education should therefore be a call to action to rethink dental school curricula in this content area.

KEYWORDS
CAD/CAM, curriculum, dental, dental curriculum, dental computer-aided design, education, educational technology, schools, students, technology

1 | INTRODUCTION

Computer-aided design and computer-aided manufacturing (CAD/CAM) technology is becoming widely accepted in dental offices all over the world. Already in 2011, Davidowitz and Kotick reported that more than 30,000 dentists worldwide owned scanning and milling machines and that a third of these dentists were located in the United States and Canada. They also reported that more than 15 million CEREC restorations were completed worldwide at this time.[1] More recently in 2019, a survey found a substantial increase in dentists recommending digital restorations to their patients from 35% in 2010 to 70% in 2019.[2] These authors also showed that the number of dentists using intraoral scanners had increased from 17% in 2012 to 61% in 2019, with an additional 17% expecting to purchase an intraoral scanner in the coming year.

Utilizing CAD/CAM technology has numerous advantages over traditional techniques. These advantages include higher speed and ease of use, high quality of restorations, reduced labor, saving time, and being faster than traditional impressions since it eliminates the pouring, waxing up, casting, and firing steps to fabricate a prosthesis.[1,3–5]

An additional advantage would be the elimination of traditional impressions, which results in no more bubbles, voids, debris of the casts or on the impressions, and ill-defined margins.[6,7] Most importantly, CAD/CAM technology allows clinicians to provide their patients with same-day, one-visit indirect chair-side restorations that are accurate and esthetically satisfactory. On the other hand, some authors reported drawbacks related to this technology such as the high cost of equipment and special training for clinicians and staff members.[3]

Digital technology is also a valuable learning tool because it can be used to improve motor skills training, analyze students' preclinical preparations, enable students' self-assessment, and enhance the quality of dental education.[8] Dental schools have therefore started to incorporate CAD/CAM technology into preclinical and clinical pre-doctoral dental curricula.[9,10]

Several studies compared different learning techniques used in students' CAD/CAM-related dental school education. They studied its use in preclinical and clinical settings,[11] and for traditional self-assessment vs. digital assessment.[12–15] They also explored the benefits of digital vs. conventional treatment approaches in clinical settings.[16] While most of the previous studies were limited to the preclinical setting, this study explored the current state of CAD/CAM education in all types of educational settings.

In addition to assessing CAD/CAM-related education in dental schools in the United States, it is also important to assess future dentists' CAD/CAM-related knowledge. Two previous studies by Sheba et al. (2021) in the United States and Palanisamy et al. (2019) in India explored this question in a general way.[17,18] The objective of our study was to investigate more specifically what dental students know about which procedures can be done with CAD/CAM and which materials can be used.

Several authors assessed pre-doctoral dental students' attitudes toward the use of CAD/CAM vs. traditional approaches.[15,18–21] The current survey analyzed dental students' attitudes toward this new technology in general and asked them what they liked about it and which challenges they encountered when using it. In addition, it inquired about the dental students' actual clinical CAD/CAM behavior and their intentions to use this technology in the future.

In summary, the objectives were (a) to assess pre-doctoral dental students' CAD/CAM-related education as well as their satisfaction with this education and their interest in additional instruction, (b) to evaluate students' knowledge about different CAD/CAM systems, restorations, and materials, (c) to gain a better understanding about their attitudes toward this technology, and (d) to explore their current professional behavior and behavioral intentions to adopt this technology in the future. In addition, this study investigated the relationships between the year in dental school and CAD/CAM-related education, knowledge, attitudes, and behavior.

2 | METHODS

This research was determined to be exempt from Institutional Review Board (IRB) oversight by the Health Sciences and Behavioral Sciences IRB at the University of Michigan

(#HUM00207058). It is based on survey research and has a cross-sectional study design.

2.1 | Respondents

An a priori power analysis with the G3.1.3. Power Analysis Program (http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/) was conducted to determine the sample size needed to have the power to test hypotheses about relationships between constructs of interest. We assumed one-sided hypotheses, a medium to a small effect size of $|\rho| = 0.20$, an alpha error probability of 0.05, and a power of 0.95. The results showed that 262 respondents would be required to have the power to test such hypotheses.

Recruitment emails were sent to the academic deans of the 68 dental schools in the United States. Overall, 358 pre-doctoral dental students from 17 dental schools in the United States responded to the survey (Response rate for dental schools: 25%).

2.2 | Procedure

In late October 2021, a recruitment email was sent to the academic deans of all 68 dental schools in the United States. This email explained the purpose of the research and asked these deans to forward an attached recruitment email to their dental students. It is unknown how many of these academic deans actually forwarded the recruitment email to their students.

In November 2021, a follow-up recruitment email was sent to the academic deans, asking them again to forward a follow-up recruitment email to their students. At the home school of the authors, first and second-year dental students received an extra credit point for responding to this web-based survey. A comparison of the average responses of these first-year students with the responses of first-year students without extra credit did not show significant differences and the responses of second-year students with vs. without extra credit did also not differ significantly. The data were therefore combined.

2.3 | Materials

The survey was developed by the authors with several questions being adapted based on items used in a study by Prager and Liss (2020).[22] Five dental students participated in a pilot test. They suggested minor changes concerning the sequencing of the questions and the clarity of some answer categories. Their feedback allowed finalizing of the survey.

The questionnaire consisted of four parts. Part 1 inquired about the students' background and educational characteristics; Part 2 assessed their CAD/CAM-related educational experiences and considerations such as their satisfaction with this education and their interest in more related training. Part 3 consisted of questions concerning their knowledge about and attitudes toward CAD/CAM technology. Part 4 evaluated the students' current CAD/CAM-related professional behavior and behavioral intentions for the future.

2.4 | Statistical analysis

The web-based data were downloaded from the Qualtrics website as an SPSS (IBM SPSS Statistics for Windows, Version 26; IBM Corp., Armonk, NY, USA) data file. The responses to the paper surveys were then entered into the same SPSS file. Descriptive statistics such as frequency distributions, percentages, and means were computed to provide an overview of the responses to the closed-ended questions.

Two-factor analyses (extraction method: principal component analysis; rotation method: Varimax with Kaiser normalization) were conducted with (a) education-related items and (b) attitudinal items to determine if indices could be constructed. Items with factor loadings over 0.40 on a specific factor were considered for creating indices. However, indices based on these items were only computed if Cronbach alpha coefficients were over 0.70.[23,24] Doing so ensured that the indices had good inter-item consistency. The actual indices were computed by averaging the responses to the items that loaded on one factor, respectively. In addition, sum score indices were created for the knowledge and professional behavior items by adding one point for each correct answer.

Pearson correlation coefficients were used to explore the relationships between the students' years in dental school and these indices of interest. Inferential statistics were used to test the significance of relationships between these constructs of interest. The significance level was set at $p < 0.001$.

3 | RESULTS

An overview of the background and educational characteristics of the respondents showed that 201 female (56.3%), 152 male (42.6%), and four non-binary (1.1%) students responded to the survey. Respondents from 17 of the 68 US dental schools (25%) participated in this survey. About a third of the students were first-year students ($N = 113$; 31.6%) and second year students ($N = 125$; 34.9%), respectively, with the rest being split between third-year

($N = 56$; 15.6%) and fourth year students ($N = 64$; 17.9%). More than half of the participants were planning to work as a dentist after graduation ($N = 191$; 53.4%); others wanted to join a General Practice Residency Program ($N = 35$; 9.8%), an Advanced Education in General Dentistry Program ($N = 29$; 8.1%), or a graduate program ($N = 84$; 23.5%).

Table 1 shows that CAD/CAM education took place in all four dental school years, with more than three out of four students learning about it in their second year ($N = 280$; 78.2%) and 41.1% in their third year of dental school. Nearly nine out of ten students learned about CAD/CAM in lectures that were part of a class (87.2%) and simulated exercises as part of a class (86.9%), followed by learning in a required class (54.2%) and elective courses (30.7%). Faculty (87.9%) and staff members (44.8%) were most likely to provide CAD/CAM instruction.

Concerning preclinical education about CAD/CAM, the students reported receiving on average 7.5 hours of this type of training. Most of this instruction was didactic and consisted of watching a video demonstration (81.8%), a demonstration as part of lecture (76.4%) or demonstrations to small groups of students (69.2%). However, 65.6% reported having hands-on-workshops and 50.4% individual instruction.

Students used CAD/CAM in the preclinical setting mostly for self-assessment of their preparations (67.4%), and for designing (64.6%) and fabricating restorations (62.0%). CEREC was the dominant digital system used in preclinical education (CEREC Omnicam: 48.6%; CEREC PrimeScan: 23.6%).

CAD/CAM technology used in clinical settings included using digital scanners (45.2%) and performing digital scanning mostly for crown and bridge fabrication (24.6%). While 45.2% of the students performed intraoral scanning only, 18.4% scanned and designed and then sent it to the lab for restoration fabrication (18.4%). Only 14.7% performed same-day treatments. Again, most students used CEREC systems in the clinical setting (CEREC Primescan: 21.3%; CEREC Omnicam: 20.4%).

Table 2 provides an overview of the students' evaluations of their CAD/CAM education, their satisfaction with this instruction, and their interest in receiving more education. Only 45.2% agreed/strongly agreed that they were well educated in classroom-based setting, 53.2% in preclinical settings and 33.5% in clinical settings. The students' average neutral satisfaction scores with their classroom-based (on 5-point scale with 5 = most positive: Mean = 3.12), preclinical (Mean = 3.14) and clinical education (Mean = 2.94) were consistent with their mean neutral ratings of the quality of their CAD/CAM education. However, nearly 80% of

TABLE 1 Respondents' computer-aided design/computer-aided manufacturing (CAD/CAM)-related educational experiences

CAD/CAM-related education	Frequencies YES	Percentages YES
Dental school education about CAD/CAM is in:		
- D1 year	132	36.9%[1]
- D2 year	280	78.2%
- D3 year	147	41.1%
- D4 year	104	29.1%
CAD/CAM classroom-based education as:		
- required class	194	54.2%[1]
- lectures as a part of a class	312	87.2%
- simulated exercises as part of a class	311	86.9%
- elective course	110	30.7%
- other	27	7.5%
CAD/CAM training is provided by:		
- faculty	304	87.9%[1]
- staff	155	44.8%
- graduate students	94	27.2%
- corporate trainers (from companies)	40	11.6%
- trained dental technician	70	20.2%
- older dental students	5	1.4%
Preclinical education about CAD/CAM	**Frequencies YES**	**Percentages YES**
Hours of preclinical CAD/CAM education	Mean = 7.58	$SD^2 = 11.077$ Range: 0–88
Types of preclinical education about CAD/CAM:		
- watch a video demonstration	284	81.8%
- demonstration as part of a lecture	265	76.4%
- demonstrations for small groups of students	240	69.2%
- hands-on workshop	228	65.6%
- individual instruction	175	50.4%[1]
- other	15	4.3%
CAD/CAM systems used in preclinic:		
- CEREC Omnicam	174	48.6%[1]
- CEREC PrimeScan	82	23.6%
- Planmeca Emerald	49	14.1%
- 3Shape Trios	37	10.3%
- CEREC Bluecam	25	7.2%
- Other	25	7.2%

(Continues)

TABLE 1 (Continued)

Preclinical education about CAD/CAM	Frequencies YES	Percentages YES
Use of CAD/CAM technology for:		
- self-assessment of preparations	234	67.4%[1]
- self-assessment of restorations	170	49.0%
- designing restorations	224	64.6%
- fabricating restorations	215	62.0%
- faculty evaluation/grading	163	47.0%
- other	11	3.2%
CAD/CAM experiences in a clinical settings	**Mean *N* = 358**	**SD[2]/Range**
# times of use of digital scanners instead of traditional impressions	2.00	4.857 0–40
CAD/CAM experiences in a clinical setting	**Frequencies YES**	**Percentages YES**
Procedures with the use of a scanner in the clinic:		
- Crown, bridge	88	24.6%
- Intraoral impressions/ scans	30	8.4%
- Bite splint	29	8.1%
- Inlays, onlays	19	5.3%
- Orthodontics	4	1.1%
Aspects of digital workflow done in the clinic:		
- Intraoral scan	157	45.2%
- Intraoral scan and design (export PDF file to the lab for restoration fabrication)	64	18.4%
- Intraoral scan, design, and mill (one appointment)	51	14.7%
- Intraoral scan, design, and mill (two appointments)	51	14.7%
- Student scanning of the cast and sending it to the lab	41	11.8%
- Others	56	16.1%
Use the following CAD/CAM systems in the clinic when treating patients:		
- CEREC PrimeScan	74	21.3%
- CEREC Omnicam	73	20.4%
- Planmeca Emerald	37	10.3%
- 3Shape Trios	24	6.9%
- Other	21	5.9%
- CEREC Bluecam	9	2.6%

[1]Percentages do not add up to 100%, because the students could check more than one answer.

[2]The term "standard deviation" is abbreviated as "SD".

the students were interested in more CAD/CAM related instruction in the future and 78.1% agreed/strongly agreed that they were interested to utilize digital technology in their professional future.

Concerning respondents' knowledge about this topic, nine questions asked which restorations can be fabricated with CAD/CAM (Table 3). Results showed that more than half of the respondents knew that CAD/CAM can be used to fabricate inlays/onlays (58.5%), and anterior (65.5%) and posterior crowns (65.6%). However, overall, the average number of correct answers to these nine questions was only 3.56, which indicates that the students did not have a solid foundation in this context. Consistent with this low objective knowledge score were the students' self- evaluations of their knowledge concerning how much they knew about different CAD/CAM systems (Mean = 2.29 on 5-point scale with 5 = most positive), designing different CAD/CAM restorations (Mean = 2.28) and different CAD/CAM ceramic materials (Mean = 2.41).

Table 4 provides an overview of the results concerning the respondents' CAD/CAM related attitudes. The absolute majority agreed/strongly agreed with the positive statements such as that "CAD/CAM is the future of dentistry" (87%), that they enjoy working with CAD/CAM (67.7%), that it allows completing treatments quicker (76.1%), and that it saves labor (75.5%). However, 80.3% agreed/strongly agreed that purchasing CAD/CAM equipment is very expensive and that a lack of faculty calibration is a problem (58%). Three out of four respondents (75.9%) agreed/strongly agreed that this technology can make them better dentists.

Table 5 shows responses concerning students' current CAD/CAM-related behavior, specifically related to the use of CAD/CAM for different dental treatments and the use of different materials. While half of the total sample had used this technology for digital impressions (50.0%), and 41.9% for fabricated posterior crowns, lower percentages of students had used CAD/CAM for other procedures. On average, they had used it for only 1.95 out of ten possible procedures. When asked about whether they had used different materials with the CAD/CAM system, lithium disilicate (28.5%) and zirconia (28.5%) were the most commonly used materials. On average, they had used 0.86 of the six presented material choices.

In addition to analyzing the CAD/CAM-related education, knowledge, attitudes, and behavior overall, it is crucial to consider how students in different stages of their education respond to these questions. The final objective of this study, therefore, was to analyze the relationships between the students' years in dental school and the indices and sum scores constructed to assess their

TABLE 2 Computer-aided design/computer-aided manufacturing (CAD/CAM)-related educational considerations

My dental school educates me well about CAD/CAM	**1**[1]	**2**	**3**	**4**	**5**	**Mean**
a. In classroom-based settings.	5%	14.6%	35.2%	34.2%	11%	3.32
b. In preclinical settings.	5%	11.6%	30.2%	37.9%	15.3%	3.47
c. In clinical settings.	7.9%	11.3%	47.3%	23.6%	9.9%	3.16
"Dental school education" Index[2] *(Cronbach alpha = 0.845)*	Mean = 3.33		SD[3] = 0.886		Range:1–5	
I am satisfied with my education in CAD/CAM	**1**[1]	**2**	**3**	**4**	**5**	**Mean**
d. In classroom-based settings.	10.7%	16.3%	33.3%	30%	9.7%	3.12
e. In preclinical settings.	11.2%	15.6%	30.3%	33.7%	9.2%	3.14
f. In clinical settings.	11.8%	18.1%	42.9%	18.1%	9.1%	2.94
"Average satisfaction with education" Index[4] *(Cronbach alpha = 0.906)*	Mean = 3.08		SD[3] = 1.021		Range: 1–5	
How interested are you in:	**1**[5]	**2**	**3**	**4**	**5**	**Mean**
g. learning more about different CAD/CAM systems?	2%	5%	16.2%	37.7%	39.1%	4.07
h. learning more about different CAD/CAM restoration designing?	2%	3.7%	15.9%	38.2%	40.2%	4.11
i. learning more about different CAD/CAM ceramic materials?	2.6%	5%	15.6%	39.7%	37.1%	4.04
j. utilizing digital technology?	1%	1.6%	9.2%	28.6%	59.5%	4.44
k. utilizing CAD/CAM in your professional future?	1.3%	2.6%	10.3%	24.8%	60.9%	4.41
l. taking Continuing Education courses about CAD/CAM in the future?	2%	2.3%	9.5%	31.6%	54.6%	4.35
"Interest in education about CAD/CAM" Index[6] *(Cronbach alpha = 0.970)*	Mean = 4.24		SD[3] = 0.803		Range: 1–5	

[1]Answers ranged from 1 = disagree strongly, 2 = disagree, 3 = neither disagree nor agree, 4 = agree to 5 = agree strongly.
[2]The "Dental school education" Index was constructed by averaging the responses to items a to c.
[3]The term "standard deviation" is abbreviated as "SD".
[4]The "Average satisfaction with education" Index was constructed by averaging the responses to items d to f.
[5]Answers ranged from 1 = not at all to 5 = very much.
[6]The "Interest in education about CAD/CAM" Index was constructed by averaging the responses to items g to l.

education, knowledge, attitudes, and behavior. Table 6 shows that while the year in the dental school program correlated significantly with the numbers of preclinical education received ($r = 0.39$; $p < 0.001$), it did not correlate with their evaluation of the average quality of their CAD/CAM education, nor with their satisfaction with this education or with their interest in future education. However, the more years they spent in dental school, the more they knew about what can be fabricated with this technology ($r = 0.25$; $p < 0.001$), and the more subjective knowledge they reported to have about CAD/CAM ($r = 0.27$; $p < 0.001$). Concerning how their CAD/CAM related attitudes might differ as a function of the year in dental school, the data showed that neither their average satisfaction with the CAD/CAM technology nor their average attitude related to potential problems correlated with the year in school. However, the year in dental school did correlate with the Positive Attitude Index ($r = 0.13$; $p < 0.05$). In addition, it also correlated with the students' CAD/CAM related behavior. Specifically, the year in dental school correlated with the number of times the students had used a digital scanner instead of a traditional approach ($r = 0.33$; $p < 0.001$), the sum of treatments for which CAD/CAM were used ($r = 0.24$; $p < 0.001$) and the sum of different materials they had used ($r = 0.48$; $p < 0.001$).

4 | DISCUSSION

Digital dental technology makes numerous positive contributions to dentistry. It is therefore not surprising that digital dentistry education has grown in favor among dental educators.[18] Assessing dental students' experiences with CAD/CAM education can provide insight into the current state of this education and can help to develop recommendations for changes. Therefore, this study focused on pre-doctoral dental students' responses related to their CAD/CAM education, knowledge, attitudes, and behavior.

The most positive educational findings were the students' desire to learn more about different CAD/CAM systems, and different materials and about designing different restorations. This result is consistent with findings by Reifeis et al. in 2014 and by Schwindling et al. in 2015. Both groups of authors found that students showed enthusiasm to learn in both preclinical and clinical setting about CAD/CAM.[9,11] However, this very positive interest in more education in our study and these two studies stands in contrast to the less positive evaluation of their current education and the finding that less than 50% agreed/strongly agreed that they were satisfied with their education, independent of the year in dental school.

TABLE 3 Computer-aided design/computer-aided manufacturing (CAD/CAM)-related knowledge and satisfaction with the technology

Knowledge about CAD/CAM technology: What can be fabricated with CAD/CAM?						**No. of correct answers**	**% correct answers**
Inlays/onlays						204	58.5%
Veneers						121	36.0%
Posterior crowns						227	65.6%
Anterior crowns						226	65.5%
Implant retained crowns						147	41.1%
Provisional restorations						129	37.1%
Fixed partial dentures						124	34.6%
Complete dentures						96	27.7%
RPD frameworks						62	18.3%
"Sum of correct answers" Index[1] (out of nine possible answers)			Mean = 3.56			SD[2] = 3.150	Range: 0–9
How much do you know about:	**1[3]**	**2**	**3**	**4**	**5**		**Mean**
a. different CAD/CAM systems?	23.8%	38.9%	24.8%	9.9%	2.6%		2.29
b. different CAD/CAM restoration designing?	26.7%	33.3%	28.1%	8.6%	3.3%		2.28
c. different CAD/CAM ceramic materials?	25.1%	30.7%	27.1%	12.5%	4.6%		2.41
"Dental education knowledge" Index[4] (Cronbach alpha = 0.919)		Mean = 2.33		SD[2] = 0.992		Range: 1–5	
Satisfaction with the use of CAD/CAM technology for[5]:	**1[4]**	**2**	**3**	**4**	**5**		**Mean**
Intraoral digital impressions	2.6%	5.8%	39.1%	32.8%	19.7%		3.61
Inlays/onlays	2.7%	7.7%	63.1%	19.6%	6.9%		3.20
Veneers	3.9%	8.2%	72.2%	12.2%	3.5%		3.03
Posterior crowns	2.7%	6.1%	52.7%	25%	13.6%		3.41
Anterior crowns	3.4%	7.2%	53.6%	20.2%	15.5%		3.37
Implant retained crowns	3.1%	7.9%	68.1%	13.8%	7.1%		3.14
Provisional restorations	3.9%	7.4%	67.7%	13.2%	7.8%		3.14
Fixed partial dentures	3.9%	8.7%	73.6%	10.2%	3.5%		3.01
Complete dentures	4%	10%	75.1%	7.6%	3.2%		2.96
RPD framework	4%	9.6%	87.9%	6%	1.6%		2.92
"Overall satisfaction" Index (Cronbach alpha = 0.939)		Mean = 3.15		SD[2] = 0.624		Range: 1–5	

[1]The "Sum of correct answers" Index was computed by adding one point for each correct answer to the nine questions above.
[2]The term "standard deviation" is abbreviated as "SD".
[3]Answers ranged from 1 = Nothing, 2 = A little, 3 = Something, 4 = Much to 5 = Very much.
[4]The "Dental education knowledge" Index was computed by averaging the responses to items a to c.
[5]Answers ranged from 1 = very dissatisfied, 2 = dissatisfied, 3 = neither dissatisfied nor satisfied, 4 = satisfied to 5 = very satisfied.
[6]The "Overall satisfaction" Index was computed by averaging the responses to the 10 single items above.

One potential reason might be the finding that high percentages of students reported that their preclinical education consisted of watching video demonstrations, demonstrations as part of a lecture, or demonstrations for small groups of students, with only two-thirds of the students reporting that they have hands-on workshops. When Schwindling et al. compared hands-on learning with education based on video demonstrations, they did not only find that the hands-on approach resulted in higher knowledge but also in higher satisfaction with this learning approach.[11] In addition, the systematic review by Burgess et al. also concluded that intensive small-group education enhances students' performance on examinations.[25] Therefore, rethinking current educational approaches and increasing hands-on education is likely to be of benefit for students.

A second education-related consideration focuses on the use of CAD/CAM technology as a teaching tool. The data showed that students responded that they used CAD/CAM in preclinical courses for self-assessment of their preparations as well as for designing and fabrication of restorations. This raises the question of how to utilize CAD/CAM technology optimally for self-assessment. Studies by Park et al. and Chiang et al. showed that students agreed that the use of CAD/CAM in preclinical dentistry was useful and supported the self-assessment skills of students in preclinical dentistry.[14,26] In addition, Wolgin et al. reported that digitally based self-assessment for preclinical

TABLE 4 Positive and negative computer-aided design/computer-aided manufacturing (CAD/CAM) related attitudes

Positive CAD/CAM attitudes	**1**[1]	**2**	**3**	**4**	**5**	**Mean**
CAD/CAM is the future of dentistry.	0.3%	1%	11.9%	38%	48.8%	4.34
I enjoy working with CAD/CAM technology.	0.3%	2.7%	29.3%	33.7%	34%	4.11
Using CAD/CAM allows for completing treatments quicker.	0.3%	3.3%	20.3%	37.2%	38.9%	4.09
Using CAD/CAM saves labor.	0.3%	2.3%	21.9%	39.1%	36.4%	4.09
Using CAD/CAM allows the usage of a wide shade range of materials.	0.3%	3.7%	32.6%	35.2%	28.2%	3.87
Using CAD/CAM saves costs.	0.7%	5%	40.5%	31.3%	22.7%	3.70
"Positive CAD/CAM attitudes" Index (Cronbach alpha = 0.877)	Mean = 4.01		SD[2] = 0.670		Range: 2–5	
Negative CAD/CAM attitudes	**1**[1]	**2**	**3**	**4**	**5**	**Mean**
Buying CAD/CAM equipment is very expensive.	0%	1.7%	18%	40.3%	40%	4.19
Lack of faculty calibration with CAD/CAM workflow is a problem.	0.7%	4.7%	36.7%	35.4%	22.6%	3.74
Losing data can be a problem.	0.3%	5.7%	29.8%	46.8%	17.1%	3.74
Computer glitches can happen.	0.3%	1.7%	19.3%	48%	30.7%	4.07
CAD/CAM has the potential of making me a better dentist.	0.7%	1.7%	21.7%	41.5%	34.4%	4.07
"CAD/CAM problem-related attitudes Index (Cronbach alpha = 0.652)	Mean = 3.93		SD[2] = 0.606		Range: 1.75–5	
Single item	**1**[1]	**2**	**3**	**4**	**5**	**Mean**
CAD/CAM produces an inferior quality of restorations.	8.7%	38.8%	37.8%	9.4%	5.4%	2.64

[1]Answers ranged from 1 = disagree strongly, 2 = disagree, 3 = neither disagree nor agree, 4 = agree to 5 = agree strongly. .
[2]The term "standard deviation" is abbreviated as "SD".

undergraduates was qualitatively equivalent to the conventional form of supervision.[13] Yamakami et al. found that nearly all students agreed that digital technology helped them to learn operative dentistry. However, most students agreed at the same time that conventional assessment should be the main evaluation system.[15] Based on these research findings, one suggestion could be to combine the excellent self-assessment benefits of CAD/CAM technology with personal faculty support to optimize students' learning.

Concerning the educational interventions in clinical settings, the data showed that the highest percentage of students had experiences with CAD/CAM manufactured crowns and bridges (24%) and the lowest percentage had experiences with bite splints and orthodontics fabrication. Additionally, when asked about the digital workflow in the clinical setting, 45% reported that intraoral examination was the major workflow. Only 14% had scanned, designed, and delivered restorations in one or two appointments. These findings are similar to results reported by Prager and Liss in 2019. These authors also reported that intraoral digital impressions were performed in 55% of North America's dental schools most of the time, and had been used mainly for crown fabrication.[22]

Concerning the respondents' CAD/CAM-related knowledge, it is alarming that very low percentages of students responded that they knew much/very much about CAD/CAM systems, restoration designing, and ceramic materials. These results are consistent with the findings by Palanisamy et al. who found in 2019 that most students were ignorant about materials used to fabricate CAD/CAM prostheses.[17]

In contrast to the relatively low level of knowledge, the attitudes toward CAD/CAM technology were quite positive. The majority of students agreed/strongly agreed that CAD/CAM is the future of dentistry and more than 70% agreed that they would utilize digital technology in their professional future. These results are consistent with the findings by Ahmed et al. in 2019. The students in their study stated that the use of intraoral scanners was time-saving compared to conventional impressions and that they were more likely to adopt this technology after graduation.[21] In addition, Zitzmann et al. (2017) also found that their students favored digital impressions. It seems clear that current dental students are very interested in learning more about CAD/CAM and have quite positive attitudes toward this new technology.[20]

This study has three limitations. First, although the number of respondents exceeded the number of respondents determined to be needed in the a priori power analysis, it is not ideal that only students from 17 of the 68 dental schools responded. Second, these data were collected in 2021. During this year, dental schools might have changed their educational interventions because of the coronavirus disease 2019. It is unclear if the extensive use of video demonstration was related to this fact. Third, as in every survey, it cannot be ruled out that students with more interest in this technology were more likely to answer. Therefore, the results should be interpreted with this potential consideration in mind.

TABLE 5 Frequencies/percentages of behaviors related to the use of computer-aided design/computer-aided manufacturing (CAD/CAM) or digital scanner

Using CAD/CAM or digital scanners for:	**Used *N***	**Used %**
Digital impression	179	50.0%
Posterior crowns	150	41.9%
Anterior crowns	76	21.2%
Inlays/ Onlays	72	20.1%
Implant retained crowns	54	15.1%
Provisional restorations	48	13.4%
Fixed partial dentures	36	10.1%
Veneers	32	8.9%
Complete dentures	31	8.7%
RPD framework	19	5.3%
"Average sum of activities for which CAD/ CAM or digital scanners were used" Index[1]	Mean = 1.95	SD[2] = 2.424 Range: 0–10
Use of materials with the CAD/CAM system:	**Used *N***	**Used %**
Lithium disilicate (Emax)	102	28.5%
Zirconia	102	28.5%
Luecite reinforced ceramic	28	7.8%
PMMAs	28	7.8%
Hybrid / Resilient materials	25	7.0%
Feldspethic ceramic	23	6.4%
"Average sum of materials used with CAD/CAM system" Index[3]	Mean = 0.86	SD = 1.344 Range: 0–6

[1]The "Average sum of activities for which CAD/ CAM or digital scanners were used" Index was computed by adding one point for each use (Range of possible values: 0–10).
[2]The term "standard deviation" is abbreviated as "SD".
[3]The "Average sum of materials used with CAD/CAM system" Index was computed by adding one point for each use of one of the six possible materials (Range of possible values: 0–6).

TABLE 6 Pearson correlation coefficients for relationships between years in dental school and computer-aided design/computer-aided manufacturing (CAD/CAM)-related education, knowledge, satisfaction, and attitudes

CAD/CAM related education	**Year in program**
# of hours of preclinical education about CAD/CAM	0.39***
"Average quality of CAD/CAM-related education" Index[1]	0.10
"Average satisfaction with CAD/CAM-related education" Index[1]	−0.04
"Average interest in more CAD/CAM-related education" Index[1]	0.05
CAD/CAM related knowledge	
"Sum of knowledge about what can be fabricated with CAD/CAM"[2]	0.25***
"Average knowledge about CAD/CAD" Index[2]	0.27***
"Average satisfaction with CAD/CAM technology" Index[2]	−0.01
CAD/CAM related attitudes	
"Average positive attitudes about the benefits of CAD/CAM" Index[3]	0.13*
"Average attitudes about problems with CAD/CAM" Index[3]	0.11
CAD/CAM related behaviors	
# of times a digital scanner was used instead of a traditional approach	0.33***
"Average sum of activities for which CAD/ CAM or digital scanners were used" Index[4]	0.24***
"Sum of different materials used by students" Index[4]	0.48***
Interest in using CAD/CAM in the future.[5]	0.04

Note:* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.
[1]Table 2 provides information about how these indices were constructed.
[2]Table 3 provides information about how these indices were constructed.
[3]Table 4 provides information about how these indices were constructed.
[4]Table 5 provides information about how these indices were constructed.
[5]Answers ranged from 1 = disagree strongly, 2 = disagree, 3 = neither disagree nor agree, 4 = agree to 5 = agree strongly.

5 | CONCLUSIONS

Based on these findings, several conclusions can be drawn. Concerning CAD/CAM-related education, it is obvious that all dental students, independent of the year in dental school, are very interested in more education about this technology. However, their average evaluations of their current education are not as positive, nor are their satisfaction ratings. Responding to this situation based on existing research would suggest (a) increasing hands-on activities in preclinical and clinical settings and (b) combining the use of CAD/CAM for self-evaluations with individualized faculty support. Students' objective knowledge related to what can be fabricated with CAD/CAM and their evaluations of their knowledge increased over the years. However, increasing students' exposure and hands-on experiences might support an increase in knowledge.

The students' CAD/CAM-related attitudes are exceptionally positive. This finding in connection with the high interest in learning more about CAD/CAM provides an excellent basis for increasing future educational interventions. It should also serve as a call to action for all dental educators.

Concerning their professional behavior, students currently are mainly using CAD/CAM for intraoral scanning and fabricating crowns. They have very limited experience with almost all other dental procedures.

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