Use of Technology in Dental Education

Effect of Computer-Assisted Learning on Students’ Dental Anatomy Waxing Performance

So Ran Kwon, DDS, MS, PhD, MS; Marcela Hernández, DDS, MS; Derek R. Blanchette, MS; Matthew T. Lam; David G. Gratton, BSc, DDS, MS; Steven A. Aquilino, DDS, MS

Abstract: The aim of this study was to evaluate the impact of computer-assisted learning on first-year dental students’ waxing abilities and self-evaluation skills. Additionally, this study sought to determine how well digital evaluation software performed compared to faculty grading with respect to students’ technical scores on a practical competency examination. First-year students at one U.S. dental school were assigned to one of three groups: control (n=40), E4D Compare (n=20), and Sirona prepCheck (n=19). Students in the control group were taught by traditional teaching methodologies, and the technology-assisted groups received both traditional training and supplementary feedback from the corresponding digital system. Five outcomes were measured: visual assessment score, self-evaluation score, and digital assessment scores at 0.25 mm, 0.30 mm, and 0.35 mm tolerance. The scores from visual assessment and self-evaluation were examined for differences among groups using the Kruskal-Wallis test. Correlation between the visual assessment and digital scores was measured using Pearson and Spearman rank correlation coefficients. At completion of the course, students were asked to complete a survey on the use of these digital technologies. All 79 students in the first-year class participated in the study, for a 100% response rate. The results showed that the visual assessment and self-evaluation scores did not differ among groups (p>0.05). Overall correlations between visual and digital assessment scores were modest though statistically significant (5% level of significance). Analysis of survey responses completed by students in the technology groups showed that profiles for the two groups were similar and not favorable towards digital technology. The study concluded that technology-assisted training did not affect these students’ waxing performance or self-evaluation skills and that visual scores given by faculty and digital assessment scores correlated moderately.

Dr. Kwon is Associate Professor, Department of Operative Dentistry, University of Iowa College of Dentistry & Dental Clinics; Dr. Hernández is Clinical Associate Professor, Department of Family Dentistry, University of Iowa College of Dentistry & Dental Clinics; Mr. Blanchette is Biostatistician, Division of Biostatistics and Research Design, University of Iowa College of Dentistry & Dental Clinics; Mr. Lam is a fourth-year dental student, University of Iowa College of Dentistry & Dental Clinics; Dr. Gratton is Associate Professor and Director, Division of Maxillofacial Prosthodontics, Hospital Dentistry Institute, University of Iowa Hospitals & Clinics; and Dr. Aquilino is Professor Emeritus, Department of Prosthodontics, University of Iowa College of Dentistry & Dental Clinics. Direct correspondence to Dr. So Ran Kwon, University of Iowa College of Dentistry & Dental Clinics, 801 Newton Road, DSB S235, Iowa City, IA 52242; 319-335-8871; soran-kwon@uiowa.edu.

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The introduction of computer-aided design/computer-aided manufacturing (CAD/CAM) technology in the 1980s has laid a foundation for advancement in digital dentistry. Despite intense initial debate, the adoption of restorations fabricated using this approach has profoundly benefited both clinical dentistry and dental laboratories.1 Furthermore, long-term survival rates for CAD/CAM-fabricated single-tooth restorations have demonstrated that outcomes are not significantly different from those for conventionally manufactured restorations.2,3 These key points have driven widespread adoption of CAD/CAM technology and illustrate one of the earliest successes of digital dentistry.4 Given the success of CAD/CAM approaches in the clinical setting, computer-assisted learning/computer-assisted simulation systems (CAL/CAS) are being introduced into dental education. These systems are promoted for their ability to facilitate individual learning by providing objective and consistent feedback.5,6 In the CAL/CAS framework, digital evaluation and feedback are generated based on comparison of scanned student work to a scanned gold standard. This approach allows for detailed
examination and evaluation of deviations from the gold standard and provides a permanent record on which improvement efforts can be focused.

The CAL/CAS technology incorporates well into the curriculum and serves as an added layer of learning for dental students. The requirements for technical performance and self-evaluation are taught through traditional instruction using PowerPoint presentations, checklist-based self-evaluation, and visual feedback by instructors in the preclinic. CAL/CAS then provides an extra digital dimension that seeks to enhance these processes. The expectation is that the additional digital feedback will enable students to establish a clearer and more accurate understanding of the many components that produce a desirable outcome. Such an understanding is also expected to enhance the efficiency with which required psychomotor skills are learned and thereby might contribute to greater student success overall.

However, it must be noted that digital dental imaging devices and associated evaluation software are only now emerging. As such, only a limited number of studies have evaluated the efficacy of this technology with respect to students’ attaining clinical and self-evaluation skills and its utility in objectively assessing performance. Demonstrated effectiveness in these areas will be key to justifying the continued adoption of CAL/CAS for dental education, as the required equipment necessitates a major financial investment.

The study reported here attempted to address these concerns. Its aim was to evaluate the impact that computer-assisted learning and evaluation technology have on the development of first-year dental students’ technical abilities and self-evaluation skills. Additionally, this study examined how feedback by digital evaluation software compared to traditional faculty feedback prepares students for their practical competency examination. The specific goals of the study were to determine whether students using digital technology performed differently from control students; whether either of two technologies (E4D Compare, D4D Technologies, Richardson, TX, USA; and prepCheck, Sirona Dental, Bensheim, Germany) outperformed the other; and whether technical scores provided by faculty correlated with digital evaluation scores. The following three null hypotheses were tested: the digital technology had no influence on the students’ performance; between the two systems there were no different impacts on the students’ performance; and there was no correlation between the technical scores and digital evaluation scores.

### Materials and Methods

The study was approved by the University of Iowa Institutional Review Board prior to enrollment (IRB ID# 201308742). In the semester this study was carried out, 79 first-year dental students (age 21-36 years, M 55%, F 45%) were enrolled in the dental anatomy course (81:120) at the University of Iowa College of Dentistry & Dental Clinics. Students were assigned to one of three groups: control (n=40), E4D Compare (n=20), and prepCheck (n=19). Assignments were based on seating to facilitate placement of the digital units and to maintain an ideal ratio of ten students per digital scanner. Students assigned to the control group were instructed using only traditional teaching methodologies, whereas students in the experimental groups received traditional instruction supplemented with feedback by the corresponding digital evaluation system. At the conclusion of the course, students in the experimental groups completed a survey on their learning from and satisfaction with the relevant system.

Each experimental group had access to two digital scanning stations at the instructor pod. Once a project was scanned, the corresponding files were transferred to the student’s own computer workstation to be analyzed by the evaluation software. The procedures for scanning and for using the evaluation software were taught during out-of-class sessions at the beginning of the course. On completion of the digital training, students could use the scanner and evaluation software during classes as well as after class hours.

All students received a random number from the Office of the Registrar to ensure that grading by faculty members was carried out in blinded fashion. The competency exam consisted of a full contour wax-up of the maxillary left first molar tooth (#14) custom-prepared for a full-coverage restoration, using a digitally scanned dental model (Lava Model, 3M ESPE Digital Oral Care, Oakdale, MN, USA); this is a replica of the KaVo basic study model (KaVo Dental GmbH, Biberach, Germany). Students were allowed a total of three hours to complete their projects and then handed them in at the grading room, along with a completed self-evaluation form that contains a checklist of 28 criteria also used during the instructor’s visual grading (Figure 1). For the purpose of this study, we selected tooth #14 to evaluate; it is the third tooth that students wax-up during the 12-week dental anatomy course.
students: 1) contact, line angle, and embrasure; 2) facial and lingual contours, cusps, and grooves; or 3) occlusal anatomy and surface finish. A graduate student counted the correct/error scores and matched them to the self-evaluation scores. A bonus point was given to a student when the match between the self-evaluation and faculty criteria was above 60%.

This point in their first year allowed students to be more familiar with the waxing as well as the digital scanning process.

Three faculty members involved in teaching the dental anatomy course participated in the grading, and each independently evaluated the same particular section of the evaluation sheet for the 79 students: 1) contact, line angle, and embrasure; 2) facial and lingual contours, cusps, and grooves; or 3) occlusal anatomy and surface finish. A graduate student counted the correct/error scores and matched them to the self-evaluation scores. A bonus point was given to a student when the match between the self-evaluation and faculty criteria was above 60%.

Figure 1. Evaluation checklist for tooth #14
The 28-point score scale was then converted to a percentage for final score assignment.

For digital grading, the students’ projects were compared to a master wax-up that had been generated by a faculty member and was displayed during the regular class sessions. The master wax-up was agreed upon by the course faculty members and based on the visual inspection of the waxing aspects as outlined in Figure 1. For each group, one operator used a laser scanner (Nevo scanner, D4D Technologies, Richardson, TX, USA) to image the master model and all other samples. A second operator then used the E4D Compare software to align, superimpose, and score wax-ups, using three tolerance levels: 0.25 mm, 0.30 mm, and 0.35 mm.

The final scores from faculty evaluation and self-evaluation were examined for differences among the groups; the Kruskal-Wallis test was used for this assessment due to distributional concerns. Descriptive statistics were compiled for all outcomes. Correlation between the visual assessment scores and the three digital scores was assessed using Pearson and Spearman rank correlations.

At the completion of the course, students in the technology groups were asked to complete a brief survey on a 1-to-10-point rating scale, providing information on their experiences with hardware and software manipulation as well as their general satisfaction. Descriptive statistics were compiled for each question by group. All analyses were performed at the 5% level of significance, using Statistical Analysis Software v. 9.3 (SAS Inc., Cary, NC, USA).

### Results

All 79 students in the class participated in the study, for a 100% response rate. Five outcomes were measured for each student: visual assessment score, self-evaluation score, digital assessment score at 0.25 mm tolerance, digital assessment score at 0.30 mm tolerance, and digital assessment score at 0.35 mm tolerance. The descriptive statistics for student scores, both by group and overall, are summarized in Table 1. Neither the visual assessment score nor the self-evaluation score revealed statistically significant differences among groups (p=0.2321 and p=0.5684, respectively).

Correlational analyses (Table 2) were performed to examine whether technical scores determined by the faculty correlated with digital evaluation scores for each of the three tolerance levels. These analyses excluded the results for two students from the control group: their work was not properly captured and the data were unavailable. Within the control group, correlations were moderate and statis-
A 2009 survey on dental school curricula identified the development of new techniques for assessing students’ competence as a high priority. The University of Iowa College of Dentistry & Dental Clinics has made active incorporation of new technology and assessment techniques into the curricula an educational objective. It thus evaluated the benefits of expanding use of CAD/CAM technology from the clinical setting (during the third and fourth years) to the preclinical setting (courses taken during the first and second years).

A requirement for passing the dental anatomy course is the acquisition of proficiency in the psychomotor skills needed to reproduce tooth contours in wax, which all students will need to apply in their future clinical practice. An additional goal of this course is to develop students’ ability to make detailed observations and critically evaluate their own work in order to foster lifelong learning. Although dental students value feedback from the preclinic instructors, subjectivity and variability are widespread sources of concern, as is often pointed out in course evaluations. A lack of consistency, both among raters and even in scoring by individual raters, has been widely reported. Our study evaluated the initial outcome of introducing computer-assisted learning and assessment tools into a dental anatomy course, with the aim of establishing the potential of such a

discursively significant for all three tolerances. The Pearson correlation ranged from 0.5847 to 0.6237, and the Spearman correlation from 0.5046 to 0.5979. However, none of the correlations was significantly different from zero for either of the experimental groups or any of the tolerances. When considered overall (in the absence of group stratification), correlations between visual and digital grading were modest but statistically significant for all three tolerances. The Pearson correlation ranged from 0.3282 to 0.3558, and the Spearman correlation from 0.2646 to 0.2897.

Therefore only the third study hypothesis could be rejected, for the results showed a significant although modest correlation between the visual and digital scores. The first and second hypotheses were supported. The digital technology had no influence on the students’ performance and there were no different impacts on the students’ performance between the two systems.

Analysis of the survey responses (Table 3 and Table 4) showed that the profiles for the two experimental groups were similar. When the abundance of favorable responses were considered, students were found to be nearly split on their sentiments regarding the difficulties in learning and completing an evaluation. The least favorable responses were to the question of whether the technologies should be incorporated into the curriculum. This was especially true in the case of prepCheck; none of the students using this system felt that it should be purchased and implemented.
preparation. Our school acquired two of these: E4D Compare and prepCheck. The decision to test these systems in particular was based mainly on the fact that similar CAD/CAM systems were already used in the clinic. Both provide color-coded feedback on specific preparation criteria and are set to the institution’s tolerance level. For this study, the numerical value for the percent surface area that was within the set ranges of 0.25 mm, 0.30 mm, and 0.35 mm from the

<table>
<thead>
<tr>
<th>Question</th>
<th>Very Easy</th>
<th>Very Hard</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How easy/hard was it to learn the scanning protocol?</td>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
<td>6 1 1</td>
<td>6.13 (1.61)</td>
</tr>
<tr>
<td>2. How easy/hard was it to complete a scan?</td>
<td>0 2 1 1 2 3 16 9 3 2</td>
<td>6.92 (1.81)</td>
<td></td>
</tr>
<tr>
<td>3. How easy/hard was it to learn the evaluation protocol?</td>
<td>0 3 4 9 3 6 11 3 0 0</td>
<td>5.28 (1.82)</td>
<td></td>
</tr>
<tr>
<td>4. How easy/hard was it to complete an evaluation?</td>
<td>1 4 3 8 2 6 7 6 2 0</td>
<td>5.41 (2.21)</td>
<td></td>
</tr>
<tr>
<td>5. How helpful was the evaluation protocol in improving your performance?</td>
<td>0 1 4 3 4 3 1 7 9 7 7</td>
<td>7.13 (2.52)</td>
<td></td>
</tr>
<tr>
<td>6. How strongly do you agree with the following statement: the college should invest in this technology and implement it throughout the preclinical curriculum.</td>
<td>7 9 7 6 7 1 2 0 0 0</td>
<td>3.21 (1.7)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Descriptive statistics for survey responses by experimental group

<table>
<thead>
<tr>
<th>Group</th>
<th>Question</th>
<th>N</th>
<th>Mean</th>
<th>Std</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Score of 1</th>
<th>Score of 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>prepCheck</td>
<td>1</td>
<td>19</td>
<td>5.84</td>
<td>1.80</td>
<td>6</td>
<td>2</td>
<td>9</td>
<td>Very easy</td>
<td>Very hard</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>19</td>
<td>7.11</td>
<td>1.66</td>
<td>7</td>
<td>2</td>
<td>10</td>
<td>Very easy</td>
<td>Very hard</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>19</td>
<td>4.89</td>
<td>1.97</td>
<td>5</td>
<td>2</td>
<td>8</td>
<td>Very easy</td>
<td>Very hard</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>19</td>
<td>5.00</td>
<td>2.38</td>
<td>5</td>
<td>1</td>
<td>9</td>
<td>Very easy</td>
<td>Very hard</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>19</td>
<td>7.42</td>
<td>2.59</td>
<td>8</td>
<td>2</td>
<td>10</td>
<td>Very helpful</td>
<td>Not helpful</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>19</td>
<td>3.00</td>
<td>1.49</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>Strongly disagree</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>E4D</td>
<td>1</td>
<td>20</td>
<td>6.40</td>
<td>1.39</td>
<td>6</td>
<td>4</td>
<td>10</td>
<td>Very easy</td>
<td>Very hard</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>6.75</td>
<td>1.97</td>
<td>7</td>
<td>2</td>
<td>10</td>
<td>Very easy</td>
<td>Very hard</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20</td>
<td>5.65</td>
<td>1.63</td>
<td>6</td>
<td>3</td>
<td>8</td>
<td>Very easy</td>
<td>Very hard</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>20</td>
<td>5.80</td>
<td>2.02</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>Very easy</td>
<td>Very hard</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>20</td>
<td>6.85</td>
<td>2.48</td>
<td>8</td>
<td>3</td>
<td>10</td>
<td>Very helpful</td>
<td>Not helpful</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>20</td>
<td>3.40</td>
<td>1.90</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>Strongly disagree</td>
<td>Strongly agree</td>
</tr>
</tbody>
</table>
ideal was recorded based on a study that found that a tolerance level of 0.30 mm most closely correlated to faculty grades for tooth preparations.\textsuperscript{14} Unlike comparisons for tooth preparations that utilize a variety of criteria, the software for the dental anatomy course generates only a general agreement score, based on software formulation. Henceforth, this overall evaluation of tooth contours does not enable feedback on specific criteria that the faculty members’ visual evaluation can provide to the students.

We had expected that digital feedback would improve both performance and self-evaluation, but our study did not provide evidence in support of this; the scores for the control and digital technology groups did not differ. Notably, a systematic review of the effectiveness of computer-aided, self-instructional programs in dental education by Rosenberg et al. revealed disparate outcomes, with some studies finding no difference between CAL and other learning strategies and others indicating that CAL provided a significant advantage in terms of knowledge gain.\textsuperscript{15} It should be noted, however, that the outcome measured in our study was improvement in technical performance and self-evaluation, which is different from knowledge gain. Thus, it was interesting to see that the introduction of this technology into the curriculum did not as of yet justify the financial investment, effort, and time spent.

The goal of testing for differences between digital systems was to assist the college as it engages in a decision to determine which system should be acquired for future use in the preclinical setting. Although our study did not find evidence of differences in either performance or self-evaluation skills between the E4D Compare and prepCheck groups, we observed that E4D Compare provided more useful information, generating a score based on which an objective score could be given, whereas prepCheck provided only color-coded feedback on overcontouring or undercontouring.

Correlation of the visual and digital scores is an important aspect of our evaluation and must be considered prior to implementing a new system into the grading system; this need was addressed by the third hypothesis. Our results indicated that this correlation was significant but nevertheless modest. This is consistent with findings from a study that evaluated the correlation of visual grading performed by two faculty members with digital grading of dental wax-ups and found only a modest correlation.\textsuperscript{16} Another study also showed that correlation for visual and digital rating was criterion-dependent with satisfactory correlations for convergence angle, shoulder width, and occlusal reduction.\textsuperscript{19} However, the ratings were more divergent when other criteria, such as grooving/notching, surface texture, and undercuts, were considered. The failure to assess these important parameters highlights the need to further develop criteria in the evaluation software if it is to be used in dental anatomy.

The most surprising result of our study came from the survey that students in the digital technology groups turned in on completing the course. It was expected that students would be excited about the introduction of this new technology, which provides immediate and objective feedback on their performance. However, both the E4D Compare and prepCheck groups found it difficult to learn the scanning process and the evaluation protocol and also found it not helpful in improving their performance. This negative response is inconsistent with those in other studies, in which the majority of students were reported to prefer the digital grading system over traditional visual-grading methods because of the ability to provide instant, objective feedback that allowed students to easily see where their deficiencies were and provided guidance in working towards an ideal final product.\textsuperscript{14,17}

The reason for the negative responses of our students was discussed in meetings among instructors from the various preclinical courses involved in this study. It was commonly agreed that when new technology was incorporated into the curriculum, too little time was allocated for acquiring proficiency in the scanning skills and use of the evaluation software, given that all projects of the core curriculum still remained to be completed with the addition of the digital dentistry component. Specifically, all digital training was compressed into out-of-class evening sessions rather than being incorporated into the regular class sessions. Another important issue was a lack of time to train all instructors involved in the course in the new technology; most of the digital training for faculty members occurred prior to the course by manufacturer representatives that only a few were able to attend. Additionally, both E4D Compare and prepCheck were designed to provide feedback on tooth preparations rather than wax-ups, and as such, the feedback on certain criteria was not ideally suited to dental anatomy. Lastly, the official grading on the projects was the visual grading; the students were not rewarded for a good digital system evaluation, and that may have discouraged the active use of both digital systems.
A limitation of our study is that it took place in only one dental school, so its results may not be applicable to students in other dental schools. Also, since the study participants were all from one class, we could not assess the possible influence of other factors that may have affected this particular class’s responses. Within these limitations, however, the study demonstrated the challenges inherent in incorporating a new technology into a dental curriculum. It prompted instructors involved in the course to review both new systems in greater detail and to find ways of improving their integration into the curriculum to make them more effective and user-friendly. Our findings support the need for multicenter research and development projects monitored by appropriate institutions to promote the future implementation of these systems into predoctoral and advanced dental education, as proposed by Welk et al.18

Conclusion

The results of this study suggested that the implementation of digital technology in the context of an existing dental anatomy course did not enhance students’ technical performance and self-evaluation skills. A modest correlation between the visual and digital scores gave some support to the potential usefulness of digital technology in grading dental anatomy projects. The majority of students did not appreciate implementation of the digital systems, but this was partly attributed to non-strategic integration into the curriculum.

REFERENCES