An Evaluation of Two Dental Simulation Systems: Virtual Reality versus Contemporary Non-Computer-Assisted

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Abstract: Contemporary dental simulation systems were developed to improve dental students' transition from the preclinical laboratory to the clinic. The purpose of this study was to compare the efficacy of a virtual reality computer-assisted simulation system (VR) with a contemporary non-computer-assisted simulation system (CS). The objectives were to determine whether there were differences between the two systems in the quality of dental students' preparations and the amount of faculty instruction time. Students who completed their first year of dental school and had no previous experience preparing teeth were group matched according to their performance in the first-year Dental Anatomy laboratory course and assigned to VR (n=15) or CS (n=13). In the summer, they spent two weeks (~3 hrs/day) executing amalgam and crown preparations on typodont teeth. Short presentations describing the preparations were given to both groups; however, preparation criteria were available on the computer for the VR group, while the CS group received handouts. Both groups could request feedback from faculty, although VR also obtained input from the computer. A log was kept of all student-faculty (S-F) interactions. Analysis of the data indicated significant differences between groups for the following variables: mean number of S-F interactions was sixteen for the VR group versus forty-two for the CS group; and mean time of S-F interactions was 1.9±2 minutes versus 4.0±3 minutes ($p<0.001$) for VR and CS, respectively. Faculty spent 44.3 hours "interacting" with twenty-eight students, averaging 0.5 hours per VR student and 2.8 hours per CS student. Thus, CS students received five times more instructional time from faculty than did VR students. There were no statistical differences in the quality of the preparations. While further study is needed to assess virtual reality technology, this decreased faculty time in instruction could impact the dental curriculum.

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This study was supported by the Walter Nord Grant from Case Western Reserve University, University Center for Innovation in Teaching and Education.

Key words: virtual reality, preclinical teaching, simulation, virtual reality, computer-assisted teaching, psychomotor skills, fixed prosthodontics, operative dentistry, restorative dentistry

Submitted for publication 6/25/04; accepted 9/7/04

Training using virtual reality, simulation, and robotic technologies has reduced the risks to students and personnel in military defense, aeronautical, and aviation fields.[1-3] In the health care arena, medicine is investigating the implementation of virtual reality simulation systems, such as a flexible sigmoidoscope simulator,[4] a laparoscopy trainer,[5-7] a bronchoscopy simulator,[8,9] an orthopedic surgery simulator,[10] and an interactive stereoscopic virtual reality system to create three-dimensional neurosurgical experiences.[11] Dental educators, because they must provide the requisite psychomotor training to students during their predoctoral education, are also assessing various simulation systems,[12-14] computer and web-assisted programs,[15-17] and surgical planning protocols,[18] as well as haptic[19] and virtual reality simulations.[20-28]

Historically, preclinical dental instruction was accomplished in a bench-type laboratory environment where students learned psychomotor skills using hand-held dentiforms or mannequin heads mounted on metal rods. Even the mannequin heads mounted on metal rods concept was an advancement over bench top exercises. To get away from the traditional laboratory bench technique laboratories, more contemporary dental simulation systems were developed in the late 1980s. The goal was to create a clinic-like setting in which the students prepared and restored teeth on dentiforms (models of maxillary or mandibular plastic jaws with removable plastic teeth). In addition, institutions often incorporated multimedia instructional capabilities in the design of their preclinical laboratories to enhance the delivery of information to the students.[29] Currently, the four basic types of preclinical teaching environments are 1) the traditional laboratory with mannequin heads mounted on metal rods, 2) the contemporary simulation clinics, 3) clinical simulation in actual treatment clinics, and 4) the virtual reality or computer-assisted simulation clinics. The majority of the contemporary systems use sophisticated mannequins that can be positioned like patients because the dentiforms can be adjusted to an average intraoral opening and the mandibles can be manipulated to make eccentric excursions. The virtual reality system most often used, the DentSim (DenX Ltd., Australia), has the added capability of evaluating students' preparations through the use of computer tracking.

It has been suggested that simply exposing the students to a more clinic-like environment should improve their transition from preclinical laboratory to the clinic.[29] Hence, many U.S. and Canadian dental schools have adopted a more realistic preclinical environment by replacing their ergonomically incorrect benches with contemporary non-computer-assisted dental simulation systems. While faculty and students who currently use the non-computerized simulation clinics endorse the use of these simulators, these concepts may actually require more faculty supervision. The daily evaluations of students' progress generally require instructors to be physically present at the "simulation unit." Faculty no longer sit at the front desk and grade the dentiform preparations in their hands; they must move from student simulator to student simulator to evaluate the preparations and restorations as though they were evaluating procedures on a clinical patient. It has been suggested that even more faculty are needed to staff the simulation clinics if the number of procedures is to remain the same.[29-31]

The DentSim is a computer-directed simulation system.[32] It utilizes a simulator coupled to a computerized learning module that can direct the teaching of dental tooth preparation in real time and has the ability to evaluate the product by giving students instantaneous feedback as they work. Also, it does not require direct faculty contact. The DentSim system is a complete training unit that includes hardware and software, as well as a mannequin head with a KaVo dentiform attached to a torso. The simulator/patient's position can be pneumatically controlled. There is a complete dental delivery unit (handpieces, air, water, light, and suction). The computer hardware consists of an optic motion sensor system, Pentium computer, 17" monitor, professional three-dimensional graphic accelerator, CD ROM, floppy disk drive, mouse, and keyboard.[33]

Studies assessing DentSim technology found that students learn at a faster rate, developing their skills in significantly less time.[20,21,29,34] However, the results of studies comparing training that students receive from only the VR system to conventional instruction and/or a combination of VR and conventional indicate that VR should not be used without supplemental faculty instruction.[24] Studies in other fields have also suggested a combination approach for teaching.[35] Indeed, the incorporation of virtual simulation technology as an adjunct for improving students' skills appears to be successful.[26,28] It has also been suggested that this technology could be used to predict which students may need additional tutoring in preclinical operative courses.[23] Most studies have compared VR to the traditional bench type environment. Very few have compared virtual reality systems with the contemporary non-computer-aided simulation systems. Nor have the studies included faculty time as a variable. The purpose of our study, therefore, was to compare the efficacy of the virtual reality simulation technology (VR) with the contemporary simulation systems (CS) in training novice-level dental students. The specific aims of the study were to determine whether there were differences between the VR and the CS group for the following variables: 1) length of time per student-faculty (S-F) interaction, 2) type of information requested from the faculty, 3) number of preparations executed, 4) length of time used to prepare teeth, and 5) quality of the preparations.

Methods

In the spring of 2001, students who had successfully completed their first year of dental school were invited to participate in this study. The study was an ungraded, voluntary activity. Although the participants did receive a small monetary stipend, the students did not know they would be compensated at the initiation of the study, as funding was not approved until midsummer. Thirty-five students volunteered, representing just over 50 percent of the class (35/69). There were conflicts with the schedules of seven students, so the study ultimately included twenty-eight volunteer students who were then matched according to their performance in the first-year Dental Anatomy Laboratory Course and assigned to either the VR or CS group. The group matching was accomplished by categorizing students as having excellent, good, and average psychomotor skills according to their Dental Anatomy Laboratory course grade. Students from each psychomotor skills category were randomly assigned to either the VR or CS group. The VR and CS groups were comprised of three to four students from each of the three categories. Gender distribution for the project was similar to class demographics (20 percent of the class female); three were assigned to the VR and two to the CS. None of the students had previously prepared teeth. Human subject approval was obtained from the Case Western Reserve University (CWRU) Institutional Review Board. The participating students were asked to sign a consent form describing the purpose of the investigation, risks, benefits, etc. All information was kept confidential.

The students in the VR group used one of the four virtual reality simulation units—the Classic DentSim (DenX, Israel, presently DenX Ltd., Australia); the CS students used one of three non-computer assisted units—the KaVo Simulator (KaVo America Corporation). Since the DentSim Simulators use KaVo dentiforms, the KaVo Simulator with KaVo dentiforms (EWL Study Models and teeth) was chosen as the contemporary, non-computer-assisted simulation system.

During the summer of 2001, three two-week laboratory sessions were scheduled. Students were assigned to the different sessions based on their work schedules and their preferences for morning, afternoon, or evening sessions. The students spent 2.5-3 hours per day for two weeks preparing teeth. All training and instruction were done in one designated area. Every effort was made to control the environment and limit the variables; hence, each group was instructed by the same faculty, listened to the same presentations on cavity design, and used the same teeth and dentiforms (KaVo EWL Study Models), preparation criteria, burs (Brasseler), and handpieces (KaVo). Four twenty- to thirty-minute presentations describing introductory, Class I, Class II, and crown preparations were presented by either author A. Urbankova (AU) or T.R. Jasinevicius (TRJ). To ensure consistency, TRJ was present for all presentations. Both groups prepared the following: introductory rectangle-type of preparations on tooth #19, Class I preparations on tooth #19, Class II preparations on tooth #18, and full gold crown (FGC) preparations on tooth #19.

As the participating students had never prepared teeth nor worked with any type of simulation system, the first day of each two-week session was primarily an orientation day in which all the students were introduced to both the DentSim and KaVo simulators. Students and faculty were instructed not to record any S-F interactions on the first day; hence, none of the figures or tables includes S-F interactions from Day 1. Nor are interactions recorded for Day 10 when the students prepared a Class I, II, and FGC preparation as an assignment/test.

The same faculty members were present for instruction and advice for both the VR and CS groups. The supervising faculty included the authors (TRJ, MAL, AU), as well as six members of the Restorative Department. Every effort was made to assign the same faculty on specific days during the three sessions; nevertheless, due to conflicts in schedules, occasionally the restorative faculty members were unable to assist during an assigned session. However, inconsistency was minimized because one or both of the authors (TRJ or MAL) was present for every non-assignment day.

Consistent with the terminology used by the DentSim software, all tests are referred to as Assignments. The DentSim has an Assignment Option that restricts students' access to immediate feedback while they are preparing the tooth. This option is used for testing or to evaluate preparations made without feedback. During the Assignment sessions, neither group of students received feedback from faculty or from the DentSim computer.

The students in the CS or non-computer-assisted group received feedback and evaluations of their daily work, as well as final evaluations for their preparations from the faculty. The evaluation criteria based on the DentSim preparation specifications were the same for CS and VR. The VR students were also able to ask the faculty questions regarding their preparations, in addition to the feedback from the DentSim computer.

Students and faculty kept a daily log of all student-faculty (S-F) interactions. Each S-F interaction was documented by the faculty in the Daily Faculty Log. For each S-F interaction the faculty recorded the following: student identification number, group assignment (VR or CS), the length of time (minutes), and a brief description of the type of interaction. The student questions were categorized as technical, preparation-related, ergonomic, final evaluation of the preparation, and other. Any interaction of less than one minute was recorded as 0.5 minutes. Students also kept a daily log and recorded their perceptions of the learning process.

Each student in both groups received a binder that included the schedule, list of appropriate burs, daily log sheets, and ten 8x10 inch envelopes (one for each day). Photocopies of all the DentSim preparation criteria and illustrations were also enclosed in the CS binders. At the end of each day, students submitted all their preparations by placing each preparation into a coin envelope (one prepared tooth per envelope) labeled with their identification number, type of preparation, and date. These were then placed into the appropriate 8x10 inch envelope labeled by student identification number and date. Three two-week sessions were conducted. Each daily lab session was 2.5 to 3 hours in duration. Session I (6/4 through 6/14) occurred three times each day: morning, afternoon, and evening; Session II (6/18 through 6/29) occurred in the morning and afternoon; Session III (7/9 through 7/20) was scheduled only during the evening.

After completion of the labs, a representative sample of the prepared teeth (one per coin envelope) was collected from the binders to assess the quality of the preparations. For each student, three coin envelopes were randomly selected from Day 4 (second day of preparing Class I), Day 6 (second day of preparing Class II), and Day 9 (second day of preparing FGC). A total of 238 of the expected 252 envelopes were collected, as some students submitted only two coin envelopes on Days 4, 6, or 9. Of the 238 envelopes collected, 215 contained preparations that were recoded for subsequent quality assessment (twenty-three envelopes were empty, contained an unprepared tooth, or the type of preparation did not match the information on the envelope, for example, a Class II preparation labeled as a Class I). Two authors who were blind to the identity of the grouping visually evaluated the preparations and assigned ratings using this scale: 4=excellent, 3=clinically acceptable, 2=clinically acceptable with minor modifications, 1=not clinically acceptable. Fifteen percent of the preparations were later reevaluated to determine intra-rater reliability. The evaluations also were analyzed for inter-rater reliability. To determine whether the adage "good students perform well, while poor students perform poorly" holds true, a one-way analysis of variance was applied to the preparation ratings received by VR and CS students who were assigned to the excellent, good, and average categories based on their Dental Anatomy performance.

Analysis included descriptive analysis (totals, means, and standard deviations). A one-way analysis of variance was applied to the data to determine whether there were differences among the S-F interactions from the three two-week sessions. Independent t-tests, chi squares, and non-parametric tests were applied to the data to determine if there were significant differences in variables between and among groups. All quantitative analysis was done using SPSS for Windows (Version 10, 2000); significance was set at $p \leq 0.05$.

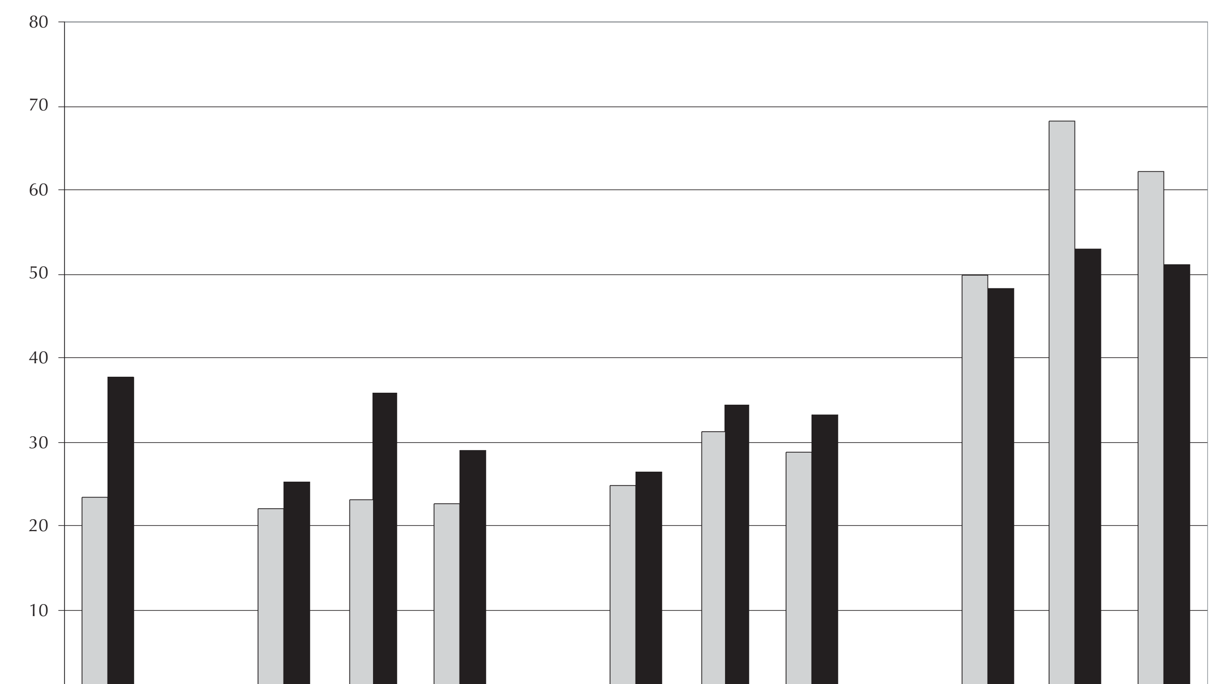
Results

A one-way analysis of variance applied to the data from the three two-week sessions indicated no differences in the evaluations of the students' preparations at the 0.05 level among students participating in session 1, 2, and 3. Hence, all data for the project were combined.

Over 700 teeth were prepared by the two groups: approximately 430 for VR and 310 for CS. There were differences in the number of preparations and the amount of time it took to execute the preparations by the two groups. The VR group prepared an average of five rectangular preparations per student while the CS students prepared an average of three. The VR group prepared an average of ten Class I preparations per student while the CS students prepared an average of 7.5. The numbers of Class II and crown preparations were virtually identical for both groups. The VR and CS groups each prepared seven Class II preparations per student. The VR and CS students completed 6.6 and 6.5 crown preparations respectively. Figure 1 graphically describes the average length of time per preparation by VR and CS students.

In the Faculty Daily Log Sheet for each S-F interaction, the faculty recorded student identification number, group assignment (VR or CS), the length of time (minutes), and a brief description of the type of interaction. The student questions were categorized as technical, preparation-related, ergonomic, final evaluation of the preparation, and other. Technical questions from both groups included but were not limited to inquiries related to water spray regulation, water disposal, and changing burs. The VR groups' technical questions also included those regarding handpiece placement in relation to the infrared sensors and software calibration issues. Preparation questions included typical student inquiries such as: is the preparation too deep or too shallow? too wide or too narrow? too facial or too lingual? etc. Ergonomic queries generally related to appropriate positioning of the simulator, student, or both. Table 1 summarizes the number and mean length of time per S-F interaction type. There were significant differences between the VR and CS groups in number of questions and amount of time the faculty used to answer questions and evaluate preparations. The CS had significantly more interactions in three of the five categories. The VR faculty-student interactions (mean 1.91±2.0 minutes) were shorter than CS's (mean 4.0±3.4 minutes), $p<0.001$. There were significant differences in the amount of time spent for some categories between groups.

Figures 2 and 3 illustrate the disparity in number of interactions per day and mean length of each interaction for the two groups. During the first week, the length of S-F interactions for the VR and CS groups did not differ as dramatically as they did during the second week. In fact, there were significant differences in length of S-F interactions between groups on six out of eight days (t-test, $p\leq0.001$). Sig-



	Rect D2		Class I D3	Class I D4	Class I avg		Class II D5/6	Class II D6/7	Class II avg		FGC D8	FGC D9	FGC avg
VR	23.6		22	22.8	22.3		24.6	30.9	28.6		49.6	67.9	62
CS	37.8		25.3	35.9	29.1		26.5	34.6	33.3		48.3	53	51.3

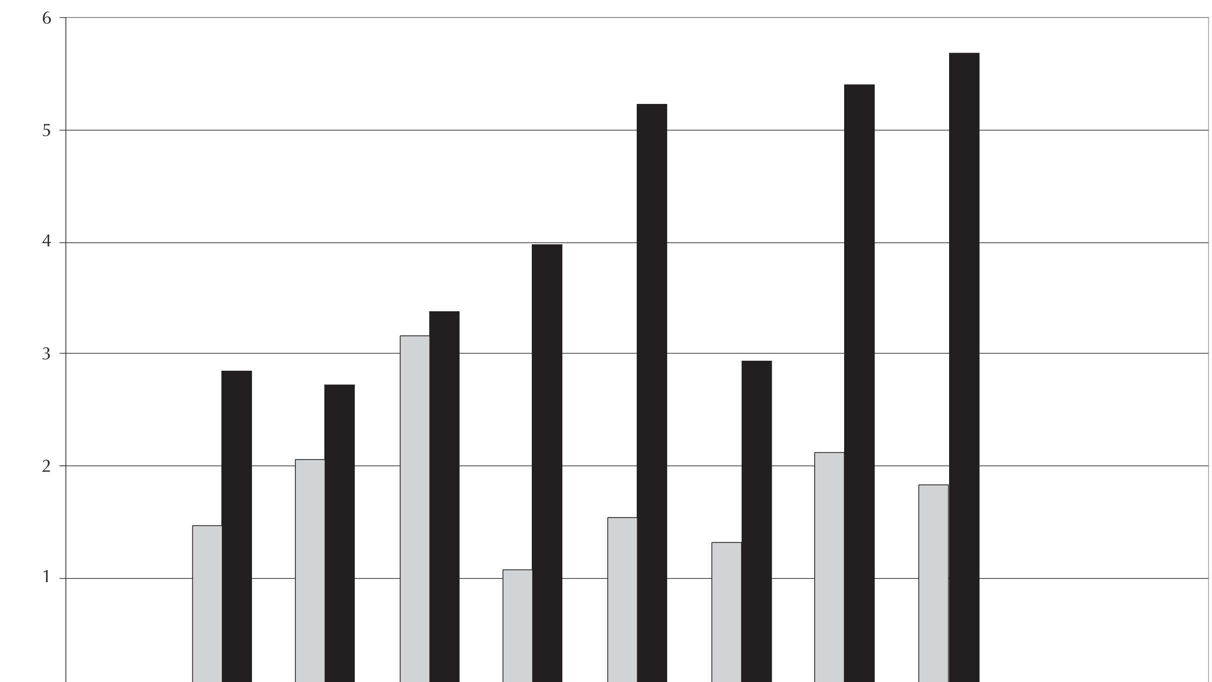
Rect = introductory rectangular prep, D = day, FGC = full gold crown preparation

Figure 1. Amount of time (in minutes) spent by virtual reality (VR) and contemporary non-computer-assisted simulation (CS) groups executing the four preparations

Table 1. Number and length (in minutes) of each type of student-faculty interactions by virtual reality (VR) and contemporary non-computer-assisted simulation (CS) group

	Technical	Ongoing Prep Feedback	Ergonomics	Final Prep Evaluation	Other	Total
	n	n	n	n	n	n
VR interactions #	72	79	33	54	5	246*
CS interactions #	21	155	42	320	5	546*
p = chi square test	<0.0001	<0.0001	0.299	<0.0001	1.000	<0.0001
	mean±sd	**mean±sd**	**mean±sd**	**mean±sd**	**mean±sd**	**mean±sd**
VR mean length of time (minutes)	2.42±2.9	1.35±1.0	2.21±1.8	1.86±1.7	2.50±2.3	1.9±2.0
CS mean length of time (minutes)	1.74±1.4	2.84±2.4	1.92±1.5	5.02±3.7	1.10±1.1	4.0±3.4
p = independent t-test	0.0321	<0.0001	0.793	<0.0001	0.789	<0.0001

*Six faculty entries (three VR and three CS) did not include description of interaction; hence, totals are greater than sum.



	D1-Intro	D2-Rect	D3-Cl I	D4-Cl I	D5-Cl II	D6-Cl II	D7- II/FGC	D8-FGC	D9-FGC	D10-ex	
☐ VR		1.5	2.09	3.2	1.1	1.56	1.34	2.16	1.88		
■ CS		2.86	2.73	3.38	3.99	5.23	2.94	5.41	5.69		
		*			*	*	*	*	*		

D = day, Rect = introductory rectangular prep, Cl I = Class I preparation, Cl II = Class II preparation, FGC = full gold crown preparation, ex = assignment/exam

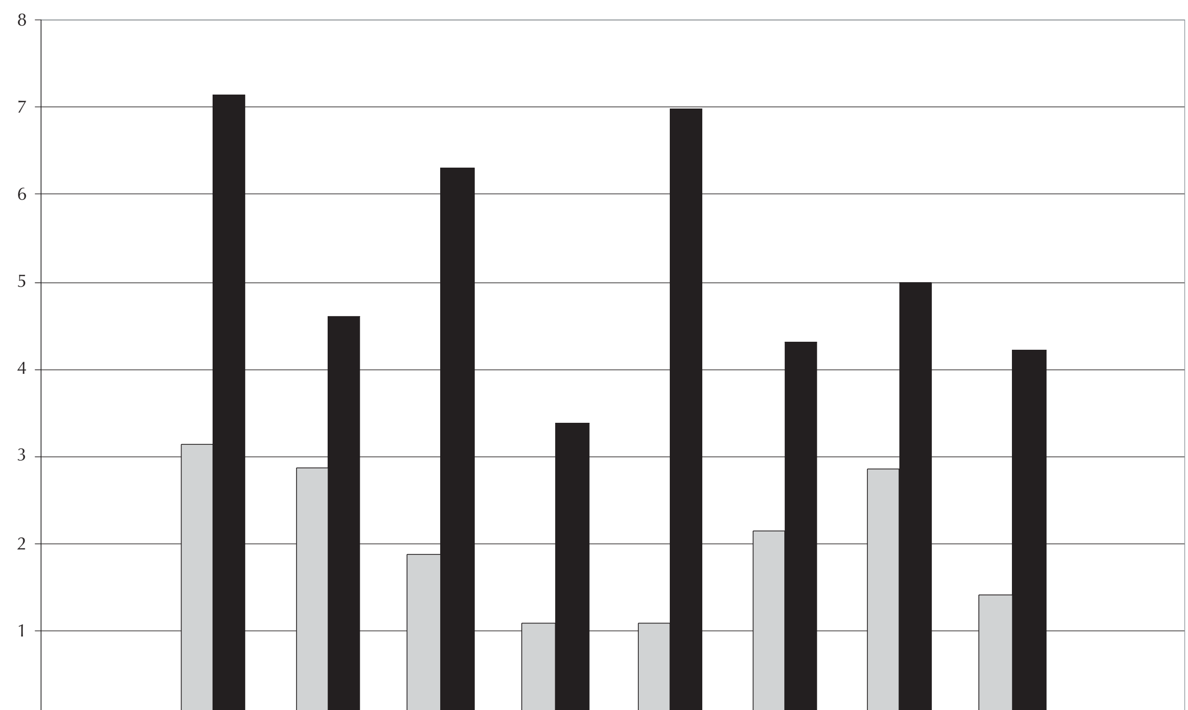
*independent t-test, p≤0.001

Figure 2. Mean length of time (in minutes) for student-faculty (S-F) interaction for virtual reality (VR) and contemporary non-computer-assisted simulation (CS) students

nificantly more questions and more S-F interaction time were needed by the CS group for the Class II and crown preparations. There was also a difference in the number of interactions. The average number of interactions was sixteen for VR (246 for fifteen students) and forty-two for CS (546 for thirteen students).

Faculty spent 44.3 hours "interacting" with the students: 7.8 hours with fifteen VR students (0.5 hrs/student) and 36.5 hours with thirteen CS students (2.8 hrs/student). Instruction time per student for the CS was longer than for the VR group. Figure 4 presents the breakdown of the total amount of time faculty spent each day with the two groups.

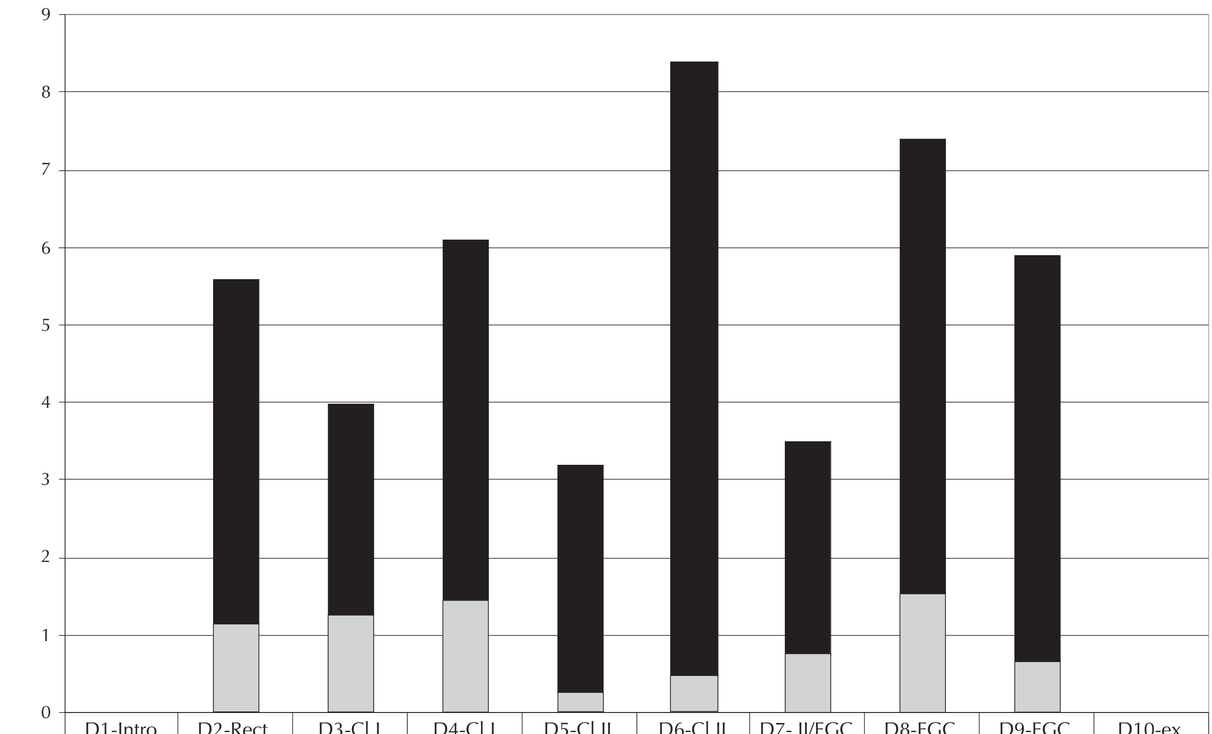
Two months after the study, two of the authors visually evaluated the preparations and rated them: 4=excellent, 3=clinically acceptable, 2=clinically acceptable with minor modifications, 1=not clinically acceptable. One author (TRJ) rated all 215 preparations, while the other (AU) rated 180 preps. To test the intra-rater reliability, each evaluator re-evaluated at least 15 percent of the preps; the first author reevaluated forty-five preparations (25 percent), while the second reevaluated thirty-five preparations (16.3 percent). Pearson correlation coefficients were used to determine the intra-rater reliability and the inter-rater reliability. The intra-rater correlation values were computed for ratings of each type of preparation (Class I, II, and crown), as well as for the total mean rating. The r values calculated for preparation types ranged from 0.807 to 0.992 (p values from 0.002 to <0.001), and the average correlation coefficient for all preparation types was r=0.933 and r=0.838, for the two evaluators. The inter-rater reliability was also acceptable, ranging from r=0.460 to



	D1-Intro	D2-Rect	D3-Cl I	D4-Cl I	D5-Cl II	D6-Cl II	D7- II/FGC	D8-FGC	D9-FGC	D10-ex
VR		3.13	2.86	1.86	1.06	1.06	2.13	2.86	1.4	
CS		7.15	4.61	6.31	3.38	7	4.31	5	4.23	

D = day, Rect = rectangular prep, CL I = Class I preparation, Cl II = Class II preparation, FGC = full gold crown preparation, ex = assignment/exam

Figure 3. Mean number of student-faculty (S-F) interactions by day for virtual reality (VR) and contemporary non-computer-assisted simulation (CS) students



	D1-Intro	D2-Rect	D3-Cl I	D4-Cl I	D5-Cl II	D6-Cl II	D7- II/FGC	D8-FGC	D9-FGC	D10-ex
■ CS		4.44	2.73	4.63	2.93	7.93	2.75	5.86	5.22	
□ VR		1.16	1.27	1.47	0.27	0.47	0.75	1.54	0.68	

D = day, Rect =introductory rectangular prep, Cl I = Class I preparation, Cl II = Class II preparation,
FGC = full gold crown preparation, ex = assignment/exam

Figure 4. Total number of hours of faculty time spent interacting with virtual reality (VR) and contemporary non-computer-assisted simulation (CS) students by day

0.772 for different types of preps ($p \leq 0.001$), with the average for all the preps of $r = 0.661$ ($p < 0.001$).

The scores of the evaluators were then averaged. Table 2 reports the mean ratings for Class I, Class II, and crown preparations for the VR and CS groups. Non-parametric analyses (Mann-Whitney U) were undertaken with respect to the ratings of the two groups. No statistical differences were found. An ANOVA (Sheffe post hoc test) was used to compare the preparation scores of students who were categorized as excellent, good, and average based on their Dental Anatomy Laboratory course performance. The results for the total and individual groups are reported in Table 3. The preparation scores decreased by Dental Anatomy groupings in the expected direction for the CS group, with significant differences between the average and the excellent scores for both groups.

Table 2. Comparison of mean preparation scores* by virtual reality (VR) and contemporary non-computer-assisted simulation (CS) students

	Class I		Class II		Crown Prep		Combined scores: Class I, II, Crown	
	n	mean±sd	n	mean±sd	n	mean±sd	N	mean±sd
VR	44	2.11±1.0	39	1.94±0.8	27	2.07±0.7	110	2.04±0.9
CS	36	2.32±0.8	40	2.21±0.8	29	1.90±0.6	105	2.18±0.8
p**		0.290		0.181		0.237		0.262

*Scores based on 4-1 point scale/scores of two evaluators were averaged.
**Mann-Whitney U test

Discussion

As anticipated, faculty spent significantly more time interacting with CS students using the non-computer-assisted simulators than with the VR students using the computer-assisted DentSim simulators. This occurred because the CS group asked more questions and the faculty members' responses and evaluations took longer than for the VR group. What was not expected was the magnitude of the difference in time the faculty spent with the CS students over the VR students. Students using the DentSim asked for significantly less help or feedback than the students using the contemporary simulation system. In fact, faculty spent more than five times longer assisting the CS group. In a typical preclinical laboratory environment, where the student-faculty ratio ranges from 10:1 to 20:1, it would be almost impossible for an instructor to spend that amount of time per student.

The goal of this study was to assess the efficacy of the virtual realty/computer simulator under ideal conditions; hence, the learning environment was unusual in that the faculty-student ratio was never less than 1:4. Faculty were available to respond to students' inquiries or give feedback on the students' preparations at any time (except during assignments) throughout the entire study. At no time did students have to wait for more than one to two minutes before a faculty member was able to respond. This was definitely not a typical preclinical laboratory situation. In fact, every effort was to model an "ideal," albeit unrealistic, preclinical laboratory environment where students had immediate access to feedback whether through the DentSim computer (for the VR students) or through faculty interactions (for both CS and VR students). The goal was to assess how much the novice-level students could accomplish in an ideal environment and determine how much faculty time was necessary to accomplish this goal. Hence, it is not possible to compare the results of this study with those of the University of Pennsylvania (UP). In the UP studies,[20-22,34] the preclinical laboratory environment for the non-computer-assisted students was real, and the faculty-student ratio was closer to the norm. Therefore, one would expect that the UP students had to wait "in line" before receiving feedback from their instructors. It is not surprising that the UP students using the DentSim prepared significantly more teeth than the students in their more traditional laboratory.[22,34] This was not the case in our study. In the CWRU idealized environment, neither the number of preparations nor the length of time it took to prepare the teeth was dramatically different between the two groups (although the VR group did prepare a few more teeth and did spend a little less time executing the preparations, except for the FGC, where the VR spent slightly more time).

Remarkably, both the VR and CS students used their time efficiently. For example, the VR students spent on average of one hour (sixty-two minutes) per crown preparation—executing 6.6 FGC preparations during the 2.5 days allotted (90.7 percent utilization; they worked 6.8 hours of the 7.5 hours available); the CS students spent fifty-one minutes per crown preparation—executing 6.5 FGC preparations in the same amount of time (73.3 percent utilization; 5.5 hours/7.5 hours available). This efficiency was most likely the result of in-time feedback from both the faculty and the DentSim.

There was a trend for the CS group to have higher scores on the intracoronal preparations and the Class I and II preparations and for the VR group to have slightly higher scores on the crown prep, although there were no statistically significant differences between the groups. One might have expected the CS groups to have significantly higher scores based on the amount of feedback they received from the faculty. Conversations with students and the re-

Table 3. Comparison of mean scores* by Dental Anatomy Laboratory course groupings of excellent, good, and average for virtual reality (VR) and contemporary non-computer-assisted simulation (CS) students

	VR		CS		Both VR +CS	
	n	mean±sd	n	mean±sd	n	mean±sd
Excellent	49	2.08±0.9	35	2.54±0.8	84	2.27±0.9
Good	35	2.34±0.8	33	2.11±0.8	68	2.23±0.8
Average	25	1.58±0.6	37	1.85±0.8	63	1.76±0.6
Total	109	2.05±0.8	105	2.16±0.8	215	2.11±0.8
**	Av:Ex	p=0.048	Av:Ex	p=0.001	Av:Ex	p=0.001
	Av:Gd	p=0.002	Av:Gd	p=0.338	Av:Gd	p=0.004
	Gd:Ex	p=0.333	Gd:Ex	p=0.062	Gd:Ex	p=0.955

*Scores based on 4-1 point scale/scores of two evaluators were averaged.

**ANOVA (Sheffe post hoc test), Ex=excellent, Gd=good, Av=average sults of several previous studies suggest that students prefer the feedback of a real person or a combination of VR and human instruction.[20-24,27,36] The extensively detailed and frequent computer feedback from VR systems can be discouraging to students and, therefore, may be of limited value, especially for the inexperienced student with little understanding of the underlying concepts.[24,26,28] Interpersonal training has been the traditional approach in dental education. The faculty instruct in lecture format. Then the students proceed to the preclinical laboratory, where they receive formative and summative feedback regarding their progress from the faculty (and sometimes their peers). This has been a fairly reliable system for the last half century; hence, based on the aforementioned arguments, the quality of the CS preparations should have been as good as if not better than the VR computer group who received minimal faculty feedback. However, there were no statically significant differences in the quality of the preparations in this study. While students may prefer human interaction and faculty may be more comfortable with traditional methods, the results of this study indicate that students can acquire psychomotor skills using computer-generated feedback and limited interpersonal instruction.

One variable not included in this study was learning style. It is possible that certain types of learners do better in a more conventional environment, while others prefer independent, self-directed learning.[20] With only twenty-eight participants it was not possible to group match by learning style in addition to Dental Anatomy Laboratory course performance. Even though a majority of the class volunteered, it is possible that this self-selection may have contributed to less diversity of learning styles, thereby inadvertently affecting the results. The students' interest in participating may reflect a more self-directed learning approach. Further investigation of how learning style preferences are related to use of, and comfort with, computer-assisted programs and virtual reality systems should be initiated as administrators and faculty incorporate technology into their curriculum.

Previous didactic GPA generally predicts future didactic GPAs,[37-39] although few studies have identified good predictors for clinical skills.[40] In this study, those with superior Dental Anatomy Laboratory scores performed well, while those with lower scores did not perform as well. It is interesting to note, however, that the "Good" students in the VR group scored higher, although not significantly, than the "Excellent" students. While this phenomenon may be peculiar to the study group that consisted of a small number of subjects, it might warrant further investigation.

Any technology that enables novice students to learn the mechanics of tooth preparation with significantly less supervision from faculty and in less time than using traditional methods could have major implications for preclinical/clinical dental education. Two of the most pressing issues facing dental schools today are a faculty shortage and an overloaded curriculum. The use of this technology has the potential to address both of these issues. If students can learn the requisite skills more efficiently using VR technology with significantly less supervision, fewer instructors would be needed to guide the students in the preclinical courses. In addition, the potential for a more efficient use of a student's time, with more time learning skills and less time waiting in line for faculty feedback, could shorten the amount of time spent in preclinical laboratories. In addition, students could use the VR technology to review procedures and practice their skills prior to executing preparations on patients. This is consistent with the Dental Education's Response to Curriculum Reform Initiatives, which among many recommendations includes a call to "increase learning of clinical skills at chairside and decrease time spent in preclinical laboratories" and to "utilize technology . . . including informatics and operatory simulations."[41] In addition, if fewer instructors are required for preclinical teaching, more faculty could supervise students' treatment of patients. This would not only allow students to increase their clinical knowledge and skills prior to graduation; it would also be another step in improving the community's oral health. We see the implementation of this system as beneficial to all stakeholders. Furthermore, the decreased curriculum time might allow students (and faculty) the flexibility to pursue additional scholarly activity or clinical experiences. The VR system has the potential to provide a predominantly self-training format for pre- and postdoctoral students, faculty, and graduates in a relatively low-stress and objective environment.

In summary, dentistry has made great strides during the past decade with the development of new materials and innovative technologies. Today, it is not unusual to find computerized dental practices using intra-oral imaging devices, digital radiographic equipment, and digital tooth apex locators, along with computer-aided design/computer-assisted manufacturing (CAD-CAM) systems. These advances are also being introduced into dental schools. The contemporary dental simulation systems are making mannequin heads mounted on metal rods obsolete. Technological advances are helping change the way students learn. The DentSim technology allows students not only to "treat a virtual patient," but also to receive objective feedback about the procedure during and after the "treatment session." It also allows faculty to evaluate all aspects of the procedure at any time, either on site or off site. One of the major advantages of virtual reality technology is that students can be in charge of their psychomotor learning. Students can immediately access information regarding their preparations, review their techniques in real time, determine where their weaknesses are, and take steps to improve. In addition, they can use the unit for review (and remediation) during non-scheduled times (after hours and on weekends).

While we embrace the potential of this technology, the limitations of the study include the small number of volunteer students and the artificial environment. Additional studies in preclinical laboratory environments are clearly needed, as well as an increase in the repertoire of preparations. Nevertheless, the results of this study suggest that virtual reality technology has the potential to provide an efficient and more self-directed approach for learning clinical psychomotor skills. It is imperative that dental educators, administrators, and researchers continue to evaluate this new technology. As major stakeholders, the dental education community should be promoting technological change and actively participating in shaping the technological advances that will revolutionize all of dental education, not just preclinical psychomotor training.

Acknowledgments

A sincere expression of thanks to DenX of Israel and DenX Ltd., Australia for their continued support as well as the loan of two additional DentSim units for the study. We also thank the following individuals: Dr. S. Lehavi, Dr. E. Arani, and Mr. D. Baruch for technical and educational support; Mr. J. DeMark and Mr. J. Langeloh of KaVo America for their technical support and loan of the KaVo simulators for the study; the CWRU Restorative faculty, Drs. I. Bekeny, P.J. Goyal, A. Graves, I. Halim, J. Love, T. Markarian, and Chair Dr. L. Castellarin; and Dr. S. Dhaliwall and Ms. A. Degesys for entering much of the data. This work was supported by the Walter Nord Grant from Case Western Reserve University, University Center for Innovation in Teaching and Education.

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