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Faculty Impressions of Dental Students' Performance With and Without Virtual Reality Simulation

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Abstract: This study compared faculty perceptions and expectations of dental students' abilities using virtual reality simulation (VRS) to those who did not use virtual reality simulation (non-VRS) in an operative dentistry preclinical course. A sixteen-item survey with a ten-point rating scale and three open-ended questions asked about students' abilities in ergonomics, confidence level, performance, preparation, and self-assessment. The surveys were administered three times to a small group of preclinical faculty members. First, faculty members (n=12, 92 percent response rate) gave their perceptions of non-VRS students' abilities at the end of their traditional course. Secondly, faculty members (n=13, 100 percent response rate) gave their expectations of the next incoming class's abilities (VRS students) prior to the start of the course with traditional and VRS components. Finally, faculty members (n=13, 100 percent response rate) gave their perceptions of VRS students' abilities after completion of the course. A Tukey's test for multiple comparisons measured significance among survey items. Faculty perceptions of VRS students' abilities were higher than for non-VRS students for most abilities examined. However, the faculty members' expectations of VRS training were higher than their perceptions of the students' abilities after VRS training for most abilities examined. Since ergonomic development and technical performance were positively impacted by VRS training, these results support the use of VRS in a preclinical dental curriculum.

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Mannequin simulation is becoming the standard of preclinical teaching in dental schools.[1] The concept is based on creating an environment similar to that of a dental clinic, with a mannequin replacing the patient, including all the ergonomic aspects of clinical dentistry.[2,3] Over a decade ago, a computerized dental simulator was developed by DenX Ltd. (presently owned by Image Navigation Ltd.).[4] This new virtual reality simulator allowed students to receive immediate, three-dimensional, audio and written feedback on their work on artificial teeth (such as cavity, crown, and endodontic access preparations) and review their work following completion in a movie media player.

The computerized simulator can be installed using an existing traditional mannequin simulator, with the addition of a computer, camera, special handpiece, and a reference body. With the virtual reality simulator, students' work is recorded and compared to an ideal preparation that is predesigned and/or selected by the course director from the software database. The students can view an accurate image and detailed measurements of the ideal preparation, as well as their own preparation, in several dimensions and cross-sections (the system's accuracy level is estimated at one hundred microns).

Several studies have been conducted to test the validity of this technology. In her 2004 report, Buchanan demonstrated that when trained with the virtual reality simulator, students learned faster, arrived at the same level of performance, accomplished more practice procedures per hour, and requested more evaluations per procedure or per hour than in the traditional preclinical laboratories.[5] Jasinevicius et al. suggested that virtual reality technology had the potential to provide an efficient and more self-directed approach for learning clinical psychomotor skills. Their study found that students using only traditional instruction received five times more instructional time from faculty than did students who used the virtual reality simulator, and there were no statistical differences in the quality of the preparations.[6] Other studies have found an improvement in course performance through higher examination and course scores,[7-9] as well as a decrease in overall course failure rate and student remediation by more than 50 percent.[8,9]

These studies have identified advantages to using virtual reality simulation as dental students learn psychomotor skills; however, none of them examined faculty members' attitudes towards using this relatively new technology. The faculty's perceptions of what the simulator offers in terms of preparing students for patient care are essential for enhancing curricular development and its implementation. Welk et al., in an article focusing on the utilization of new technologies in dental education, argued that in the long run faculty attitudes are critical to educational success.[10] Therefore, the purpose of our investigation was, first, to explore faculty members' perceptions and expectations of students' abilities in a preclinical operative dentistry course with and without virtual reality simulation training. We hypothesized that their perceptions of students' abilities with virtual reality simulation training would be higher than their perceptions of students' abilities without it. Second, we investigated faculty members' expectations of students' abilities as a result of virtual reality simulation training as compared to students without this training. Knowledge of faculty attitudes towards virtual reality simulation training was used to plan and develop a preclinical operative course at the onset of curricular change.

Methods

The traditional preclinical curriculum at the University of Pennsylvania offered a preclinical operative dentistry course during the second semester of the first year. This curriculum consisted of didactic instruction and bench-top and mannequin laboratory practice without any virtual reality simulation (non-VRS). There were eighty-four hours of didactic instruction, and 304 hours of laboratory that included practice time and practical examinations. The new preclinical curriculum was introduced in the first semester of the first year and utilized DentSim (Image Navigation Ltd.) virtual reality simulation (VRS) training. Students were required to practice preparations and complete competency assessments on the simulator. Each student spent approximately sixty hours of course time within the VRS component of the course before transitioning into the non-VRS simulation laboratory during the second semester of the first year for continued instruction in operative preparations and restorations. Although the new curriculum spanned two semesters of the first year, the laboratory component of the traditional course was reduced by seventy hours (approximately 23 percent of the time previously spent in the preclinical lab).

This investigation was conducted at the time VRS was introduced into the first-year dental curriculum. The study received the university's Institutional Review Board approval. Study participants were recruited from preclinical faculty members who taught in the operative dentistry course. Faculty members who participated in the study had from three to fifteen years' teaching experience in the preclinical operative course and were familiar with student assessment, course goals, and design. They had not had any previous experience with VRS units, nor had they had any exposure to the incoming students.

Surveys administered as part of this study were developed by an interdisciplinary team of faculty members, including two of the authors (R.G., J.B.), experienced in traditional and dental simulation instruction who were not study participants. Surveys were circulated among the four-member faculty team for review with the goal of ensuring clear and consistent interpretation of directions and items given.

Preclinical faculty members (n=12, 92 percent response rate) offered their perceptions of non-VRS students' (n=97) abilities at the end of the preclinical course (non-VRS) using a nineteen-item survey. This is referred to as administration of Survey 1. Sixteen of the items used a ten-point rating scale, while the remaining items were open-ended. The participants were directed to give their general perceptions of non-VRS students' abilities in five categories after completing the traditional operative course: ergonomics, confidence, performance, preparation, and self-assessment (Table 1). The items were randomly presented at the time the survey was given. Participants were also directed to provide narrative comments about their perceptions of the average student's strengths and weaknesses after completion of the course. Additionally, they were directed to

Table 1. Survey items grouped into categories by theme

Category and Item Number	Students' Abilities
Ergonomics	
1	The students' control of the high-speed handpiece
2	The students' ability to use good finger rests
3	The students' positioning
4	The students' ability to use a mirror when performing operative procedures
Confidence	
5	The students' confidence level with operative procedures
6	The students' overall confidence level in the lab
7	The students' lack of apprehension in performing operative procedures
8	The students' stress level with operative procedures
Performance	
9	The students' ability to prepare teeth for simple operative procedures
10	The students' ability to prepare teeth for complex operative procedures
11	The students' psychomotor skills
12	The students' general performance in the course
Preparation	
13	The students' ability to choose the correct burs for operative procedures
14	The students' ability to prepare the operatory for operative procedures including having appropriate instruments, equipment, and supplies
Self-assessment	
15	The students' ability to critique preparations using hand instruments
16	The students' ability to evaluate their work
Open-ended	
17	In relationship to operative procedures, what is the average student's biggest strength?
18	In relationship to operative procedures, what is the average student's biggest weakness?
19	What would you suggest to improve the abilities of students when they enter the preclinical lab?

provide narrative comments about how the average student's abilities could be improved when he or she enters the preclinical lab.

The same preclinical faculty instructors (n=13, 100 percent response rate) attended a one-day lecture and hands-on course in the VRS laboratory about two weeks prior to beginning the preclinical operative course utilizing non-VRS training. Upon completion of this course, they completed a survey with the same items as before, but were directed to give their general expectations of the *incoming* students' (n=105) abilities in the five categories. This is referred to as administration of Survey 2.

These same faculty members (n=13, 100 percent response rate) were surveyed again four months later, at the end of the preclinical operative course (with students who used VRS in the previous semester), and were directed to give their general perceptions of the VRS students' abilities in the five categories. They were also directed to provide narrative comments about their perceptions of the average student's strength, weakness, and ways to improve before entering the preclinic. This is referred to as administration of Survey 3.

The survey items were grouped into five categories: ergonomics, confidence level, performance, preparation, and self-assessment (Table 1). Items were listed in no particular order on the surveys so the sequences would not influence the responses. Responses were on a ten-point scale. The scale for all but one ability ranged from 1=least desirable to 10=most desirable. The students' lack of apprehension in performing operative procedures was rated as 1=most desirable to 10=least desirable to maintain the credibility of the responses. The number response was treated as a continuous variable in the analysis due to the central limit theorem.[11] Parametric statistics were used for description and testing of survey item means for statistical differences.[12] Analysis of variance was used to test whether the three survey administrations had dissimilar means. Tukey's test for multiple comparisons was used to determine which surveys were different from each other. No adjustment was made for multiple testing due to the number of survey items. Faculty members responded to open-ended questions for both the non-VRS and VRS students. Narrative comments were read by two authors (R.G. and S.L.), who agreed on themes. Comments related to each theme were tallied and percentages calculated based on the number of comments within each theme compared to the total number of comments offered per category. The first two open-ended items related to a student's biggest strength or weakness, respectively. Narrative comments for these items demonstrated similar themes as those described for survey items 1–16, yet the narrative comments for the item asking for ways to improve students' abilities before entry into the preclinic either related to student preparedness or curriculum and teaching.

Results

Faculty perceptions and expectations of students' abilities are reported in Table 2. Faculty perceptions of VRS students' abilities were generally higher than those given for non-VRS students (Surveys 1 and 3). Two of these comparisons reached significance ($p<0.05$). Faculty expectations of VRS students' abilities compared to faculty perceptions of non-VRS students' abilities were numerically higher for all but one survey item (Surveys 1 and 2). Six of these comparisons reached significance ($p<0.05$). Faculty expectations of VRS students' abilities

Table 2. Faculty perceptions and expectations of students' abilities reported as means and standard deviations for survey items 1–16

Category and Item Number	Survey 1 n=12		Survey 2 n=13		Survey 3 n=13	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Ergonomics						
1	6.41	2.57	8.00	1.29	7.76	1.48
2	5.41*	2.67	8.38	0.76	7.23	2.01
3	4.16*†	1.85	8.76	1.03	7.76	1.83
4	4.83*†	1.94	8.69	1.03	7.23	1.83
Confidence						
5	6.25	2.56	7.76	1.16	7.07	1.18
6	6.58*	2.02	8.07	0.76	7.00	1.15
7	5.75	2.26	7.15	1.72	5.92	2.39
8	5.66	2.05	5.69	2.46	6.30	1.75
Performance						
9	6.91*	2.19	8.46	0.77	7.53	0.96
10	6.16	2.28	7.69	1.43	6.84	1.28
11	6.00*	2.26	8.00	0.95	7.15	1.07
12	6.75	2.01	7.92	1.03	7.07	1.03
Preparation						
13	6.83	2.17	7.61	1.76	6.84	1.57
14	6.00	1.95	7.46	1.45	6.69	1.60
Self-assessment						
15	6.58	2.49	5.76	2.74	6.15	1.51
16	5.83	2.20	7.07	2.22	6.38	1.85

Survey 1: Faculty perceptions of non-virtual reality simulation students' abilities.
Survey 2: Faculty expectations of virtual reality simulation students' abilities.
Survey 3: Faculty perceptions of virtual reality simulation students' abilities.

*Significant differences at $p<0.05$ between survey 1 and 2.
†Significant differences at $p<0.05$ between survey 1 and 3.

were numerically higher for fourteen out of sixteen abilities compared to faculty perceptions of non-VRS students' abilities (Surveys 2 and 3). None of these comparisons were statistically different.

Faculty perception of ergonomics made up the main difference between non-VRS and VRS students. For non-VRS students (Survey 1), three of the four items received the lowest faculty ratings of the entire survey (Table 2). Faculty expected great improvement in students' abilities in this area as ratings of Survey 2 were almost twice that of Survey 1. The survey items "ability to use good finger rests" (item 2), "students' positioning" (item 3), and "students' ability to use a mirror when performing operative procedures" (item 4) remained significantly higher when faculty perceptions were compared for non-VRS and VRS students.

The faculty members generally expected that VRS training would enhance students' abilities of confidence and performance (Table 2). Survey items that reached statistical difference were "students' overall confidence in the lab" (item 6), "students' ability to prepare teeth for simple operative procedures" (item 9), and "students' psychomotor skills" (item 11). Also of interest is item 8, which asked respondents to rate the students' stress level. The rating for VSR students was slightly higher than for non-VRS students.

The faculty members seemed to expect that simulation training would slightly enhance students' preparation and self-assessment abilities, for all except item 15 (Table 2). Item 15 asked about "students' ability to critique preparations using hand instruments." The faculty perception of students' using hand instruments for self-evaluation of their own work was lower with VRS than without VRS, yet higher than what was expected.

Theme analysis of faculty comments for open-ended items can be found in Tables 3–5. Faculty comments for the students' biggest strength appear in Table 3. Around half of the comments were related to performance in which "use of a high-speed handpiece" and "outline form" were identified for both dental school classes. Twenty-seven percent of the faculty comments for the VRS students' biggest strengths were related to ergonomics.

For the question on the students' biggest weakness, over half of the narrative comments were related to ergonomics (56 percent) for the non-VRS group (Table 4). Thirty-nine percent of the respondents' comments were on performance-related issues as the biggest weakness for the non-VRS students and 64 percent for the VRS students. Faculty members identified specific technical aspects of tooth preparation as problematic for the non-VRS students, while

Table 3. Selected faculty comments for students' biggest strength and percentage of comments by theme

	Non-Virtual Reality Simulation Students	
	Percentage	Select Quotes
Performance	50%	"Mastering the highspeed by the end of the lab course" "Placement of restorative material" "Outline form"
Other	25%	"Ability to learn" "Standard of excellence required"
Self-assessment	17%	"Ability to critique restorations using hand instruments" "Evaluation of work"
Confidence	8%	"Confidence"
	Virtual Reality Simulation Students	
	Percentage	Select Quotes
Performance	47%	"Using high speed" "Outline form"
Ergonomics	27%	"Positioning"
Other	19%	"Motivation" "Try hard"
Self-assessment	7%	"Ability to evaluate work"

Table 4. Selected faculty comments for students' biggest weakness and percentage of comments by theme

	Non-Virtual Reality Simulation Students	
	Percentage	Select Quotes
Ergonomics	56%	"Use of the mirror" "Positioning"
Performance	39%	"Proximal box (axial and gingival walls)" "Judgment of relations and dimensions" "Bur parallel to long axis of tooth"
Confidence	5%	"Fear of doing things wrong"
	Virtual Reality Simulation Students	
	Percentage	Select Quotes
Performance	64%	"Inability to plan out dimensions of prep" "Understanding operative procedures" "Comprehension"
Self Assessment	17%	"Using hand instruments"
Ergonomics	10%	"Using a mirror"
Other	9%	"Lack of time" "Reading the manual"

Table 5. Selected faculty comments for improving students' abilities when they enter the preclinic and percentage of comments by themes

	Non-Virtual Reality Simulation Students	
	Percentage	Select Quotes
Student Preparedness	57%	"Prepare before starting clinical work" "More neat and organized" "More practice"
Curriculum/Teaching	43%	"Constant reinforcement of procedures" "More consistency from instructors" "Close the gap between lab and clinic"
	Virtual Reality Simulation Students	
	Percentage	Select Quotes
Student Preparedness	80%	"Make the students read the manual before lab" "Know more about the instruments and outline form; be more prepared"
Curriculum/Teaching	20%	"Integrate more preclinic with DentSim" "Not to have dissection lab and preclinic at the same time" "Give more background lectures before DentSim"

comments for the VRS students were related to "comprehension" and "understanding of operative procedures." Comments for the item on suggestions for improving the abilities of students when they enter the preclinic can be found in Table 5. Fewer curricular issues were identified by the respondents for ways to improve students' abilities when VRS was employed. Faculty comments focused on the need for greater student preparation.

Discussion

Virtual reality simulation training in the dental curriculum is a relatively new adjunctive teaching tool. Shah and Cunningham pointed out that the use of technology "can encourage constructive learning on the part of the student and a change in the role of the teachers and students."[13] As such, knowing faculty members' perspectives of VRS is essential for the development of educational programs in which this type of technology is featured. Thus, it was our purpose to determine faculty members' perceptions of students' abilities with and without VRS training and use this information to help guide preclinical curriculum design.

Generally, faculty perceptions of VRS students' abilities were higher than non-VRS students. We also found that faculty members' perceptions of VRS students' abilities were lower than they anticipated yet were still higher than non-VRS students' abilities. It may be that the study participants, without significant prior experience with VRS, had heightened expectations of VRS training on skill development and student learning. With this knowledge and greater exposure to VRS training, curricular changes have been made to better incorporate this new technology into the course with the ultimate goals of enhancing teaching effectiveness and student outcomes. Specific modifications to the preclinical operative course are described in the paragraphs that follow.

Our results found that faculty members anticipated that VRS training would enhance students' positioning and use of mirror and finger rest in the preclinical setting. Additionally, according to our qualitative and quantitative data, faculty members perceived students' ergonomics after completing VRS instruction to be better than students' abilities without VRS training. This is an important feature of VRS that is clearly presented to the operator working with the simulator.[14] The VRS immediately alerts students to hand and bodily positions that are not adequate.[15] Another advantage of the VRS-associated preclinical laboratory is a more realistic clinical environment with an ergonomically correct work space.[16] It has been found that students feel more prepared for clinical practice after participating in VRS training.[17] Item 1 in our survey was the only item associated with ergonomics that was not statistically different; however, we believe that the respondents may have misinterpreted the term "control of the handpiece." Our intent was to gather faculty perceptions of students' ability to position and properly grasp the handpiece, and if we had made that clear, we believe the improvement would have been significant. From the standpoint of curricular planning, we have been able to devote less faculty time to assessing and correcting students' ergonomics with the use of VRS training.

The faculty members expected students with VRS training to have greater psychomotor skills and ability to prepare teeth for simple operative procedures, yet their perceptions of these students' abilities were lower than anticipated but numerically higher than the non-VRS students. This same pattern was seen when they rated the students' confidence level. Our findings complement others that reported students accomplish more practice procedures per hour[5] and experience an improvement in course performance[7,18] with VRS training. In other areas of health care training, greater practice in technical procedures leads to further development of psychomotor skills resulting in greater operator confidence and skills.[19] Narrative comments suggested that VRS students had greater technical skills than non-VRS students, yet struggled with comprehension of operative procedures. A study by Koch et al. suggested that the development of technical skills can be enriched by active learning as compared to didactic training alone.[20] Further evaluations are needed to identify if performance of the technical parts of operative dentistry requires explicit knowledge of the science behind preparation design. With VRS, the students often rely on the computerized feedback and instructions for completing a preclinical procedure. They may develop strategies that allow them to "beat" the computer and receive a higher score rather than truly understanding the nature of the problem and working towards a solution. Nevertheless, based on this study's results, curricular modifications were made to include additional lectures and written information, as well as individual assessment throughout the VRS course to emphasize the importance of understanding operative concepts as the students develop their psychomotor skills.

The faculty members in our study perceived that VRS students experience greater stress with operative procedures than the traditionally taught students. This could have been attributed to the implementation of VRS training as a new teaching modality rather than VRS training itself.[21,22] Faculty members seemed to be apprehensive about the "newness" of the VRS training and its effect on students' skill development and grading. Polychronopoulou et al. reported that students often perceive performance pressure as a main source of stress in dental school.[23] With VRS, students work at their own pace, preparing multiple teeth while receiving feedback from a computer. As such, our students were not required to discuss their performance with the faculty and could have relied solely on computer-generated feedback. This may have felt "safer" to students hesitant to show faculty members a product that was less than ideal. However, as students transitioned away from VRS to the more traditionally taught component of the course, it could have been stressful to receive face-to-face faculty feedback. Moreover, this feedback may have been more subjective and based less on predetermined measurable evaluation criteria.[24] Mandernach evaluated different types of feedback while learning new skills using simulation and found an advantage to objective goal-directed feedback over feedback about the reasoning for an error that was not immediately relevant to the problem.[25] With greater exposure to VRS training, faculty members will likely learn to work more effectively with this technology, easing apprehension. This, in turn, has the potential to positively impact students' experiences and attitudes.

It was expected that VRS training would impact students' ability to select burs or set up for operative procedures. The DentSim forces students to select the specific bur; otherwise, the computer generates an obvious error. In an attempt to enhance students' selection of appropriate burs and readiness to set up for operative procedures, an additional teaching module has been developed in the preclinical operative course to place more emphasis on bur identification, measurement, and the selection process.

The faculty members expected VRS training to enhance students' abilities to evaluate their own work, yet did not expect it to improve their abilities to critique preparations with hand instruments. The VRS gives students elaborate feedback, which eliminates their need to use hand instruments to evaluate their preparations. Following this study, the students' self-evaluation of preparations, specifically with hand instruments, has been increased, and self-evaluation exercises were added to the course followed by student-faculty discussions. Also, the faculty members perceived VRS-trained students were slightly better able to evaluate their own work, suggesting that the feedback gained from the simulator encouraged overall self-assessment. Work by Jasinevicius et al. supports this finding, indicating that VRS has the potential to foster self-directed learning.[6]

This descriptive study had limitations. First, it was based on faculty perceptions of abilities attributed to all students collectively in two dental school classes; however, our research design supported our main interest of determining faculty members' perceptions of VRS students' abilities compared to non-VRS students' abilities. The long-term success of educational programs has been attributed to faculty familiarity with and positive attitudes towards the use of new technologies in dentistry.[10] We opted not to collect data on every individual student's performance since this would have been very cumbersome and time-consuming for the participants, ultimately taking away efforts devoted to their other professional obligations. We also decided to compare abilities of two dental school classes as there was no reason to believe that the students' abilities differed prior to initiation of preclinical training. Secondly, our study had a relatively small sample size, which would have contributed to the lack of statistical significance found for some survey items. However, our response rates were much higher than other investigations gathering faculty opinions.[26-28] Additionally, we were able to capture twelve or thirteen faculty members' perceptions of student abilities longitudinally at three separate time points. Our sample size is consistent with others reporting the attitudes of one program's faculty.[29,30] To decrease potential bias towards the positive impact of VRS training on student performance, the time interval between survey administrations 2 and 3 was four months, and it would have been difficult for the participants to recall how they rated students' abilities in the past.

This investigation sought to identify faculty perceptions of VRS training as compared to non-VRS training. It appears that the participants felt that the students' performance was better with VRS, particularly in the areas of ergonomics and technical performance. Nevertheless, the faculty members had higher expectations of the students' abilities with VRS in comparison to their perceptions after completion of VRS training.

Knowledge of faculty opinions and students' skill development most and least positively impacted by VRS are critical to building successful educational programs. Our findings suggest that VRS-trained students may have an advantage in the clinical setting as compared to non-VRS trained students. However, studies are needed to determine students' clinical performance following the use of VRS training and their attitudes towards this new type of technology.

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