Simulation training for ceramic crown preparation in the dental setting using a virtual educational system

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Abstract

Objectives: The aim is to evaluate the effectiveness of a preclinical training of ceramic crown preparation using the Virtual Educational System for Dentistry.

Material and Methods: Fifty-seven dental students were recruited to prepare a ceramic crown under the guidance of the Real-time Dental Training and Evaluation System (RDTES) in order to collect pre-learning data. They participated in the online virtual learning course independently on the Virtual Learning Network Platform (VLNP). One week later the students were invited to complete their post-learning crown preparation with the RDTES. A questionnaire survey explored students' perceived benefits or drawbacks of the virtual educational system. Students were allocated into Group A (n = 15), B (n = 24) and C (n =18) based on their pre-learning performance. Differences of assessment results among different groups were evaluated by ANOVA and Kruskal-Wallis tests. The pre- and post-learning assessment results in all groups were compared using Paired t-tests or Wilcoxon signed rank tests.

Results: The error scores for four assessment items (instrument selection, preparation section, preparation reduction, preparation surface and profile) and total score of outcome assessment after the virtual learning were significantly different with those before the virtual learning ($p < 0.05$). There were significant interactions between time and student group in the mean scores of

process and outcome assessments ($p < 0.001$), except for the assessment item "damage of adjacent teeth".

Conclusion: The application of a Virtual Educational System for Dentistry with the VLNP and RDTES in preclinical operative training helps students improve their clinical skills.

Key words: dental education, preclinical practice, virtual reality, simulation, crown preparation

Introduction

Clinical training is one of most important components in medical education with a direct relevance to patient safety (1). Many approaches and courses are set for dental students to enhance their clinical skills and problem-solving ability. With the technological breakthroughs, 3D computer-assisted medical simulation using Virtual Reality (VR) technology has been widely applied in many areas of healthcare professional trainings including dental education. In dentistry, due to the invasive and irreversible nature of most operative procedures, students are required to have adequate skills for the safe delivery of patient treatment (2). The major benefits of Virtual Reality Simulation (VRS) include skill acquisition before patient exposure, which allow dental students to repeatedly practice procedures to develop adequate skill levels. VRS can also provide standardized feedback which will give students independence from direct supervision (2, 3). Recent advancements in VRS have been embedded in dental education, particularly in the field of preclinical training (4-6). Virtual Reality Simulation enhances effectiveness of preclinical crown preparation training in comparison with traditional simulation teaching techniques, which provides improved learning objectives and reproducible feedbacks, unlimited training hours, and enhanced cost-effectiveness for dental schools (7-11). Various VR dental training simulators are applied to procedures such as caries removal, cavity restoration, crown and bridge preparation, wisdom tooth extraction, pocket probing, calculus detection and calculus removal. It provides the opportunity to integrate clinical case scenarios into the operative teaching environment (12-16). It is beneficial to students as it allows them to operate in optimal practice conditions. Additionally, the student's operation can be compared with the ideal

standard by overlaying the two virtual reality images at any time during the operational procedure. This could help them to improve their dental preclinical skills. The VR assists a smooth transition from pre-clinical to the clinic which is identified by students as a stressful period (17).

In this study, we use the Virtual Educational System for Dentistry consisting of the Virtual Learning Network Platform (VLNP, Affiliated Stomatological Hospital of Nanjing Medical University, Nanjing, China) and Real-time Dental Training and Evaluation System (RDTES, Suzhou Digital-health Care Company, Suzhou, China), which is designed and implemented by Nanjing Medical University. This educational system based on the VRS is designed for the preclinical training of dental education. It helps students to grasp operational essentials and improve technical skills of dental practice via the real-time interactive virtual environment. Dental students use the VLNP to complete the online virtual learning course independently via their own online student accounts. This course includes three parts. First, the students are invited to familiarize themselves with the operation of the system through reading the pre-defined criteria of the dental practical tasks. Second, the students watch a series of videos which demonstrate how to perform the practical steps of crown preparation. Last, the students perform the practical procedure via an online interactive virtual platform, which is instructed by the VLNP in a stepwise approach. The students can undertake unlimited practice of all the procedures on the virtual learning environment in their own time.

The RDTES is similar to the DentSim system (Image Navigation, New York, NY), which is a preclinical simulator that provides real-time images processing with the use of three-dimensional graphics and VRS (18). However, the RDTES has lower cost and was more compatible with our current educational system compared with DentSim system. The practice videos generated by the student are captured by the RDTES. This includes the extraoral view via the camera and the intraoral view via the optical position sensor system (NDI Polaris). The system will automatically analyze the parameters of students' work based on the predefined tooth preparation criteria and generate real-time through the computer screen animation. Hence students are able to visually compare their own procedures and results with the pre-defined assessment criteria. The RDTES provides the students with accurate and objective feedback on their procedures compared with the traditional method of visual inspection of their work.

The aim of this study was to evaluate the effectiveness of a preclinical training of ceramic crown preparation using the Virtual Educational System for Dentistry with the VLNP and RDTES.

Materials and Methods

- ***Participants and setting***

In China, the 7-year dental undergraduate education programme is comprised of 5 years of preclinical training (year 1-5, including theoretical courses and practical courses) and 2 years of clinical training (year 6-7). All the students enrolled in the fifth year of a 7-year Undergraduate Dental Programme were invited to participate in the evaluation of the preclinical training course at the School of Stomatology of Nanjing Medical University, China. All the Year 5 dental students consented and took part to complete the pre-clinical training and to fill out the questionnaires in the study which was conduct to evaluate their performance of a ceramic crown preparation of the upper left central incisor.

The participants provided informed written consent, and the study followed the Declaration of Helsinki and the guidelines of the Ethics Review Committee of Affiliated Stomatological Hospital of Nanjing Medical University with regard to medical protocols and ethics (PJ2018-021-001).

- ***Study design and procedures***

All fifty-seven students had attended the didactic lecture series of preparing the ceramic crown before attending the practical course. First, they were requested to prepare the ceramic crown of upper left central incisor on the phantom models under the guidance of the RDTES with a standardized online instruction (Figure S1). Their baseline data of practical skills of ceramic crown preparation was collected via the RDTES under the same conditions. Following completion of the practical work on the phantom head, the RDTES assessed the results based on the pre-defined assessment criteria (7, 19, 20). Then, the students were requested to perform the online virtual learning course on the VLNP, involving reading the operational instructions and

pre-defined criteria of preparing a ceramic crown. It also included watching the standard teaching videos and practicing the interactive virtual operation in their own time. Successful completion of each task enables the student to access to the next step of the programme. When the virtual learning course was completed, the student's practical result was collected and analyzed by the VLNP. The students and the tutors were provided with formative feedback of their practical work generated by the system based on the pre-defined criteria in terms of process and outcome indicators. One week later the students were requested to complete a practical test for the ceramic crown preparation of an upper left central incisor on the phantom head with the RDTES under same conditions in terms of operative armamentarium and phantom heads. The process of the practical course using the virtual educational system was shown in Figure 1.

The results of the tooth preparation were assessed by the RDTES based on the pre-defined assessment criteria (7, 19, 20), which included two parts: process and outcome assessments of the practice (Table 1). The process assessment consisted of the preparation sequence and instrument selection. The outcome assessment involved (i) preparation section, (ii) preparation reduction, (iii) preparation of surface and profile, and (iv) any damage to the adjacent teeth. The process and outcome assessments took account of each category for students' crown preparation performance in terms of their performance errors (i.e. component error score). Therefore, the final score of the process or outcome assessment was achieved according to the formula 'Total score =100 – Total sum of every component error score'. The total score of process or outcome assessment >= 60 was specified as an acceptable grade, and the total score < 60 was regarded as a poor grade in the evaluation system.

The participating students were allocated into four groups based on their performance in the process and outcome assessments for the ceramic crown preparation before the online virtual learning (Table 2). These assessment results were regarded as the students' baseline performance results.

- ***Questionnaire***

A questionnaire was conducted with the students after they finished ceramic crown preparation training. The questionnaire was comprised of five items for the participating students, which were used to demonstrate their responses and feedbacks towards the Virtual Educational System

for Dentistry with the VLNP and RDTES (Table 3). A modified Likert scale was used in this questionnaire, with four instead of five possible degrees to prompt a stated opinion rather than a neutral response (21). The degrees ranged from 'I disagree', 'I partially disagree', 'I agree' to 'I strongly agree', which were respectively marked with the points of -2, -1, +1 and +2. The sum of the questionnaire points per subject was obtained.

- ***Statistical analyses***

Data was analyzed using the statistical software program SPSS ver.16.0 (IBM Corporation, Armonk, NY). The scores of the practical assessment results before and after the online virtual learning course were tested for normal distribution and variance homogeneity (Kolmogorov–Smirnov test, Levene test). Paired t-tests and Wilcoxon Signed Rank tests were conducted based on whether or not the data was normally distributed. This was to compare the assessment results before and after the virtual learning course in every student group, including the total scores and component error scores. Differences of the assessment results of the crown preparation and the questionnaire points among the different groups were evaluated by two-way ANOVA (if the data was normally distributed and had variance homogeneity) and Kruskal-Wallis tests (if the data was not normally distributed or had no variance homogeneity). P values < 0.05 were considered to indicate statistical significance.

Results

Fifty-seven Year 5 dental students (13 males and 44 females) aged from 22 to 26 years (average age of 24), participated in the study. They were divided into four groups: Group A (n = 15), Group B (n = 24), Group C (n = 18) and Group D (n = 0) based on their baseline performance of the ceramic crown preparation before the online virtual learning course. We did not include Group D in the evaluation as there were no students fulfilling the inclusion criteria (total score of process assessment <60 and outcome assessment score >=60) (Table S1). There were no statistically significant differences among the students of three groups in terms of demographic parameters ($p > 0.05$).

- ***Comparison of the assessment results before and after the virtual learning among different groups via VLNP***

A two-way ANOVA was conducted to examine the effect of time (pre-learning vs. post-learning) and student group (based on students' pre-learning performance of crown preparation) on their process and outcome assessment scores. There were statistically significant differences in the mean total scores and component error scores of process and outcome assessments between different student groups ($p < 0.05$, Table S2), except for the assessment item "damage of adjacent teeth". Meanwhile, the interaction of time (pre-learning vs. post-learning) and student group level was also statistically significant on their mean total scores and component error scores of process and outcome assessments ($p < 0.05$).

The mean total score of the practical outcome assessment after the virtual learning was statistically significantly higher compared with that before the virtual learning [$F (1, 108) = 132.42$, $p < 0.001$, Table 4 and Table S2]. Among the four items of outcome assessment, the mean error scores of three items were significantly lower in the post-learning than the pre-learning, including preparation section [$F (1, 108) = 39.37$, $p < 0.001$], preparation reduction [$F (1, 108) = 64.10$, $p < 0.001$], and preparation surface and profile [$F (1, 108) = 48.00$, $p < 0.001$]. In terms of the process assessment item "instrument selection", the mean error score of post-learning assessment was also significantly lower than that of pre-learning assessment [$F (1, 108) = 3.96$, $p = 0.049$]. There were no statistically significant differences between the mean total score of process assessment [$F (1, 108) = 3.36$, $p = 0.07$] and the mean error score of preparation sequence [$F (1, 108) = 2.11$, $p = 0.15$] before and after the virtual learning. Although this was not significant, the total score was higher in the post-learning than the pre-learning, with lower error score of preparation sequence in the post-learning.

Paired t-test compared the mean scores of crown preparation assessment between before and after the online virtual learning in all groups (Table 5). In Group A, the assessment results of the ceramic crown preparation did not statistically differ between the pre- and post-online virtual learning ($p > 0.05$). The mean total scores of the post-learning assessment were significantly higher than those of the pre-learning in Group C, with lower component error scores of the post-learning ($p < 0.001$) except for the assessment item "damage of adjacent teeth". The mean total

score for outcome assessment after the virtual learning was also significantly higher compared with those before the virtual learning in Group B, with lower error scores for preparation section, preparation reduction, preparation surface and profile after the virtual learning ($p < 0.001$).

- ***Students' attitudes towards the Visual Educational System for Dentistry***

Nearly 97% (n=55) of the students agreed or strongly agreed that they could improve their ability of their preclinical practice via the Virtual Educational System for Dentistry (Figure 2). Fifty-six (98.25%) out of 57 students agreed or strongly agreed that performing the practical procedures on the VLNP made it easy for them to understand the essentials of the practical task, and the online virtual learning via the VLNP was convenient and efficient to improve their operational skills of the preclinical practice. Only one (1.75%) partially disagreed with this statement. The results showed the students strongly agreed that the Virtual Educational System for Dentistry with VLNP could improve their operational skills in the process with 43.86% (n=25) of the sample and their final outcome with 77.19% (n=44) of the sample of the practical task (Table 3).

Although all students approved the benefits of the Virtual Educational System for Dentistry, there were significant differences among the questionnaire points of three groups (Kruskal-Wallis test, $p < 0.001$). Students from Group C seemed more positive towards the effect of the Virtual Educational System for Dentistry (Figure S2).

Discussion

Preclinical dental training experiences were important for students to gain familiarity with the operational procedures, to acquire knowledge of anatomical structures within the oral cavity and to master dexterous psychomotor skills (22). The VR dental simulator applied to preclinical dental training, allowed the students to practice dental procedures in an interactive environment, whilst providing augmented visual computerized feedback about a student's preparation compared to an ideal standard (23-25). The human-computer interface facilitates interactive visualization and control of computer-generated three-dimensional images and their related environment. This is done with sufficient detail and speed so as to evoke a sensorial experience close to that of a real experience (26).

In this study, our aim was to evaluate the effectiveness of an interactive, multimedia educational system named the Virtual Educational System for Dentistry in a crown preparation preclinical training of dental undergraduate students. This system based on the VRS made it more accessible for students to grasp the operational essentials and technical skills of dental practical tasks. The VLNP provided an interactive and virtual learning environment, in which the students could utilize an interface including a mouse or a keyboard to control virtual operational instruments to accomplish various practical tasks. With the RDTES, a real-time computerized evaluation system, the students were allowed to observe and receive instant and objective visual feedback based on pre-defined assessment criteria. They could also review their progress and identify the mistakes to improve their skills. Teachers could evaluate students' learning progress through digital reports to further strengthen students' learning objectives. This was potentially an ideal approach for the education of dental students at preclinical training.

The results of this study revealed that the Virtual Educational System for Dentistry may significantly improve the operational outcome of the ceramic crown preparation, including preparation section, preparation reduction, and preparation surface and profile. This system offered the real-time guidance and feedback via the computed-interactive visual operation. It also provided objectively precise evaluation reports to the students. Practical mistakes were pointed out immediately. There was accurate disparity feedback given to the learner between the actual and standard outcomes attained. All these factors helped the students recognize and correct their shortcomings of the practical tasks in a timely and accurate approach. There was no significant increase in the process assessment of the ceramic crown preparation, as the operational process skills were relatively simpler and easier to grasp for students compared with the operational outcome skills.

Among three student groups of this study, the interaction of time (pre-learning vs. post-learning) and student group level was statistically significant on their process and outcome assessment results. In Group B and C, the post-learning assessment results of ceramic crown preparation were significantly higher than the pre-learning results. However, the mean total scores and component error scores of process and outcome assessments had no differences between the pre- and post-online virtual learning in Group A. This suggested that the Virtual Educational System for Dentistry might be more sensitive to students who performed less well at

the baseline level in the crown preparation. Previous studies have confirmed this view, which suggested that the VR technology maybe more beneficial for the students at the lower ability of psychomotor skills rather than more gifted students (4). It could provide a simulated practical environment for the students to exercise in a safer and more effective learning environment than the traditional learning method via the textbook or teacher instruction. This may explain why the students with poor performance in their baseline assessment have improved their operational skills significantly after using the Virtual Educational System for Dentistry. In addition, the surveyed feedbacks towards this system from the different student groups were significantly different. The students with the poorer pre-scores of the practical assessments rated the effectiveness of the virtual educational system higher. Gluch et al. noted the differences in responses and skill development from the students with different learning styles (27). The students with less emphasis on independent learning appeared to have more enthusiasm for the VRS (27). It implied that the virtual educational system should be selectively applied to the preclinical dental practice based on the student's ability and learning styles.

Although the Virtual Educational System for Dentistry was beneficial for students to improve their operational skills in the dental practical education, it was a semi-immersive VRS system using a high-performance graphics computing system to display the virtual environment and interact with the user through keyboards, mice or other three-dimensional interaction devices. A haptic-enhanced VRS system with a fully immersive display system will provide the most direct experience of virtual environments (28-30). The interaction between the virtual object and reality could accurately be expressed via the haptic system, which was an essential step in enhancing the sense of presence and immersion in VR applications (31-35). Therefore, future investigations will involve an updated Virtual Educational System for Dentistry with a haptic-enhanced VRS system (Shanghai Jiao Tong University, Shanghai, China) (36, 37).

Conclusions

The results of this study suggested that the Virtual Educational System for Dentistry with the VLNP and RDTES was suitable for the preclinical course of dental practice. The virtual educational system could improve the dental students' abilities in tooth preparation, particularly

the practical outcomes such as preparation section, preparation reduction, and preparation surface and profile. This might be due to its advantages including more objective assessment and feedback, unlimited training time and space, and enhanced cost-effectiveness, compared with the traditional crown preparation training (7).

Conflict of interest

The authors received no financial support and declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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Table 1. The pre-defined criteria of ceramic crown preparation on RDTES.

Items of the assessment criteria	Error Score		
Process Assessment	**Standard**	**Additional**	**Total**
[1] Preparation sequence ● **Guiding order:** Incisal edge → labial surface → proximal surface → lingual surface → cervix → refinement ● **Operating procedure:** Preparing guidance grooves → grinding off dental hard tissue between the grooves → opening the contact area between the adjacent teeth	60	0	60
[2] Instrument selection ● **Burs:** Preparing the contact area by TR11, the axial surface by TR13, the cingulum by flame-shaped bur	40	0	40
Total	100	0	100
Outcome Assessment			
[1] Preparation section ● **Section:** Cusp, labial, lingual and proximal surfaces ● **Tooth surface reduction**: Incisal reduction with 2.0 mm; labial, lingual and proximal reduction with 1.5-2.0 mm. Maintaining the lingual form of the crown.	60	0	60
[2] Preparation reduction ● **Left volume of tooth:** Positive volume/negative volume	15	15	30
[3] Damage of adjacent teeth ● **No damage to adjacent teeth**	10	0	10
[4] Preparation surface and profile ● **Various degree of surface:** Continuous and smooth surfaces; smooth and obtuse line angles; ideal taper of axial surfaces (2-5°)	15	19	34
Total	100	34	134

Table 2. Students' baseline performance of crown preparation based on their total scores of process and outcome assessments before the online virtual learning.

Groups	Baseline performance grade	
	Process assessment	**Outcome assessment**
A	Total score >= 60	Total score >= 60
B	Total score >= 60	Total score < 60
C	Total score < 60	Total score < 60
D	Total score < 60	Total score >= 60

Table 3. Students' attitudes towards the benefits and drawbacks of the Virtual Educational System for Dentistry.

Attitudinal items	Number of students			
	Disagree	**Partially disagree**	**Agree**	**Strongly agree**
[1] I have improved the ability of the preclinical practice via the Virtual Educational System for Dentistry.	0	2	27	28
[2] The Virtual Educational System for Dentistry with VLNP helps me improve my operational process of the practical task.	3	13	16	25
[3] The Virtual Educational System for Dentistry with VLNP helps me improve my operational outcome of the practical task.	0	2	11	44
[4] Performing the practical procedure on VLNP makes it easy for me to understand the essentials of the practical task.	0	1	12	44
[5] The online virtual learning via VLNP is convenient and efficient for me to improve the operational skills of the preclinical practice.	0	1	20	36

Table 4. Comparison of the assessment results of the ceramic crown preparation before and after the virtual learning via VLNP.

Scoring items		Pre Mean (SD)	Post Mean (SD)	Difference [b] Mean (SD)
Process assessment	[1] Preparation sequence	14.0 (2.0)	11.67 (1.55)	-2.37 (2.26)
	[2] Instrument selection	12.77 (1.41)	10.11 (1.07)	-2.67 (1.64)
	Total [a]	73.19 (3.19)	78.23 (2.52)	5.04 (3.65)
Outcome assessment	[1] Preparation section	11.68 (1.25)	3.49 (0.46)	-8.19 (1.28)
	[2] Preparation reduction	16.17 (0.55)	10.40 (0.54)	-5.77 (0.69)
	[3] Damage of adjacent teeth	2.22 (0.19)	1.94 (0.15)	-0.28 (0.23)
	[4] Preparation surface and profile	22.41 (1.17)	12.48 (1.05)	-9.93 (1.56)
	Total [a]	47.51 (2.33)	71.60 (1.26)	24.09 (2.40)

[a] Total score = 100 – Error score of scoring items

[b] Difference score = Post score – Pre score

Table 5. Comparison of the pre- and post-learning assessment results of the ceramic crown preparation in Group A, B and C.

Scoring items	Student groups	Pre Mean (SD)	Post Mean (SD)	Difference [b] Mean (SD)	t value	P value
Process Assessment						
[1] Preparation sequence	Group A	5.33 (7.90)	9.00 (10.89)	3.67 (11.09)	1.28	0.221
	Group B	6.25 (8.37)	11.46 (11.65)	5.21 (15.43)	1.65	0.112
	Group C	31.67 (10.00)	14.17 (12.51)	-17.50 (13.42)	-5.53	<0.001*
[2] Instrument selection	Group A	6.93 (7.92)	9.07 (5.95)	2.13 (5.63)	1.47	0.164
	Group B	7.67 (7.64)	9.67 (9.13)	2.00 (12.97)	0.76	0.458
	Group C	24.44 (5.80)	11.56 (8.33)	-12.89 (9.56)	-5.72	<0.001*
Total [a]	Group A	87.73 (14.35)	81.93 (15.74)	-5.80 (12.23)	-1.84	0.087
	Group B	86.08 (14.10)	78.88 (20.31)	-7.21 (27.13)	-1.30	0.206
	Group C	43.89 (12.09)	74.28 (19.93)	30.39 (19.67)	6.56	<0.001*
Outcome assessment						
[1] Preparation section	Group A	3.63 (2.56)	3.16 (2.75)	-0.47 (4.25)	-0.43	0.673
	Group B	13.60 (10.03)	3.30 (3.12)	-10.30 (10.35)	-4.88	<0.001*
	Group C	15.83 (8.34)	4.03 (4.54)	-11.81 (8.59)	-5.83	<0.001*
[2] Preparation reduction	Group A	13.21 (3.87)	10.71 (4.27)	-2.49 (5.10)	-1.89	0.079
	Group B	15.31 (2.45)	10.52 (4.13)	-4.79 (3.92)	-5.99	<0.001*
	Group C	19.79 (3.76)	9.98 (3.95)	-9.81 (4.49)	-9.26	<0.001*
[3] Damage of adjacent teeth	Group A	2.23 (1.44)	2.16 (1.16)	-0.073 (1.27)	-0.22	0.826
	Group B	1.93 (1.38)	1.82 (1.05)	-0.12 (1.91)	-0.30	0.768
	Group C	2.61 (1.39)	1.93 (1.22)	-0.68 (1.73)	-1.66	0.114
[4] Preparation surface and profile	Group A	11.06 (5.99)	10.74 (6.38)	-0.32 (8.09)	-0.15	0.88
	Group B	25.86 (4.26)	13.71 (8.38)	-12.15 (10.98)	-5.42	<0.001*
	Group C	27.27 (6.98)	12.29 (8.53)	-14.98 (11.12)	-5.72	<0.001*
Total [a]	Group A	69.87 (6.00)	73.23 (9.47)	3.36 (10.48)	1.24	0.235
	Group B	43.30 (11.07)	70.65 (9.12)	27.36 (12.11)	11.07	<0.001*

	Group C	34.51 (13.46)	71.51 (10.42)	37.01 (14.91)	10.53	<0.001*

* P < 0.05

[a] Total score = 100 – Error score of scoring items

[b] Difference score = Post score – Pre score

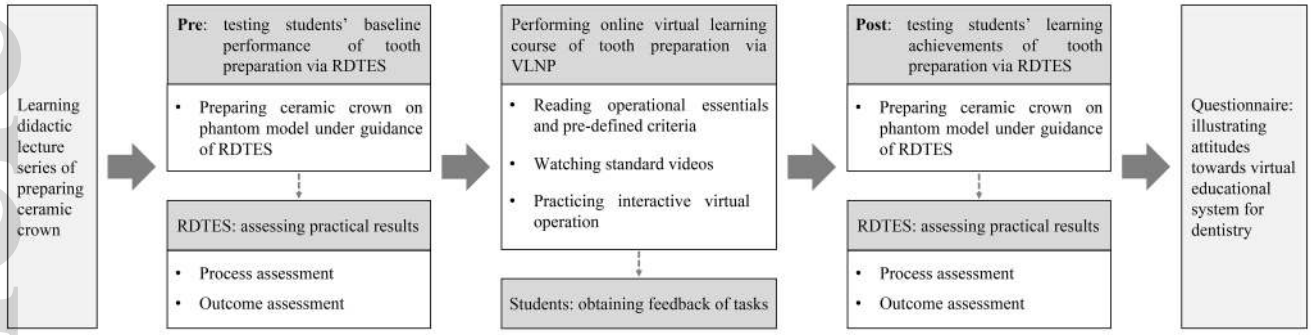

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Figure 1. The flow diagram of the practical process using the Virtual Educational System for Dentistry.

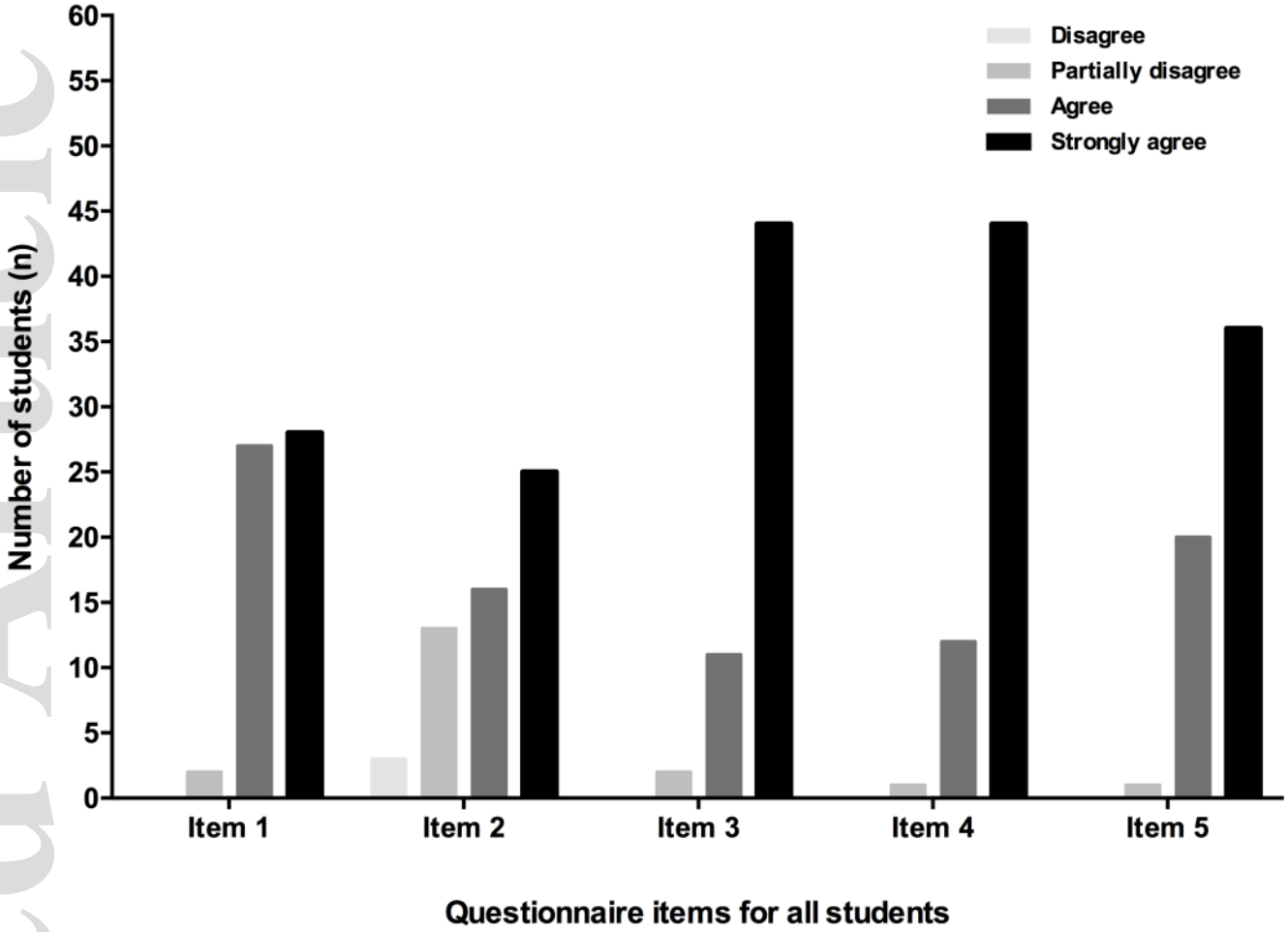

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Figure 2. Students' attitudes towards the Virtual Educational System for Dentistry with the VLNP and RDTES.