Virtual Patient Simulator for Skill Training in Dentistry

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***Abstract*—Diagnostic errors represent a significant source of harm throughout the healthcare profession. Similarly, in dentistry, these could lead to missed diagnoses, wrong or unnecessary therapies, loss of patient's trust, and even the loss of the life of a patient. Therefore, it is important to improve the education of future healthcare professionals by optimizing their cognitive and practical skills by minimizing or avoiding errors that can happen during skill training. For this, virtual simulators are introduced as a further step to help students grow and advance the required clinical skills in a representative virtual environment. This is supported with the educational approaches such as problem-based learning with an increased amount of guided practice at a relatively low cost. These models encourage students to practice problem-solving skills individually with the involvement of many forms of media and materials that stimulate students' interest in learning and result in higher satisfaction. Current implementations mostly include virtual patient simulators with different approaches as haptic-based, web-based, etc. This research is based on the development of such Virtual Patient Simulators for dental students including intelligent tutoring systems for improving decision-making skills in dentistry.**

***Index Terms*—problem-based learning, dentistry, virtual patients, game engines AND virtual simulation**

I. Introduction

During the last two decades, information and computer technologies have had a considerable impact in general as well as in education. Together with other educational sectors, dental education generally has also started to use a blend of different teaching methodologies for their students. But much of the teaching of skill training, clinical problem solving and therapy planning have traditionally been undertaken during clinical courses while students attend their clinical sessions [1]. Paper-based educational systems have been used for many years to enable students to self-assess their clinical reasoning abilities. Even the feedback was only provided for certain scenarios when presented during scheduled case seminars.

But, in the process of becoming professionals, the students have to improve their skills to meet satisfactory levels. For this, appropriate patient assessment is a basic skill that would be required in any clinical discipline. It includes proper history taking, adequate examination of the patient and the decision on the required investigations. Therefore, the need for appropriate patient assessment and proper clinical reasoning methods has become one of the main necessities for dental students [2]. In addition to that, adequate training in problem-based decision-making of students has been identified as another area that needs to be improved. Also, because of the fewer chances for a real-time tutoring system to improve skill training, it has not motivated the students to improve their skill training and decision-making in their clinical sessions.

As a solution for this, effective computer-assisted learning in undergraduate clinical dental programmes has been identified, as it can be used as an adjunct to traditional education or as a means of self-instruction. Computer-assisted learning will benefit the students in self-paced and self-directed learning with increased motivation [3]. Now they have become one of the most commonly used Case-based learning or Problem-based learning types [4] in modern medical education [5]. These are interactive computer programs that simulate real-life clinical scenarios in which the student acts as a health-care professional. In these scenarios, the student obtains a history, performs physical examinations, orders and interprets lab and/or imaging tests and finally makes diagnostic and therapeutic decisions. Also, it enables training on diagnostic reasoning and systematic patient approach and treatment, resulting in a comprehensive treatment plan before actually treating the virtual patient in the simulator. This virtual patient simulator is used for skill training in dentistry which contains the real dental skill training procedure in a virtual platform.

II. Literature Review

A. Problem Based Learning

Virtual patient skill training often uses problem-based learning approaches to train students [6]. In problem-based learning

(PBL), students learn about a subject by attempting to solve an open-ended problem. PBL is a student-centered approach. PBL is also an active way for students to learn basic problem-solving skills and acquire knowledge through interaction with others, a key skill demanded by nearly every work environment. PBL [7] is intended to test students' knowledge and help them develop their clinical reasoning abilities by presenting real-world patient problems as challenges.

The learning in PBL is driven by the problem. In medical PBL settings, students are exposed to "real-life" scenarios that call for collaborative problem definition, hypothesis generation, data collection and analysis, and evaluation or justification of solutions [8]. The patient's problem is designed to challenge students to develop reasoning, problem-solving, and team skills. In our virtual patient system, we have designed such questions covering two different scenarios.

B. Existing Virtual Patient systems

Haptic-based simulators and non-haptic based simulators are both used in dentistry for skill training and development.

Haptic-based simulators provide a realistic sense of touch and force feedback, allowing students to practice procedures with a level of tactile sensation similar to that experienced during actual dental procedures. These simulators usually include a hand-held tool that mimics the appearance and feel of dental instruments, and it can be connected to a computer program that simulates the experience of working on a virtual patient. Haptic-based simulators provide students with a high level of realism and sensory input, allowing them to refine their motor skills and hand-eye coordination. Some of the existing applications are, DentSim [9], MOOG Simodont Dental Trainer, PerioSim haptics [10], Virtual reality training simulator (VRTS) [11] etc.

On the other hand, non-haptic-based simulators typically use computer graphics and animation to simulate dental procedures. These simulators offer a lower level of realism in terms of tactile sensation and force feedback, but they can still provide valuable training for students in a safe and controlled environment. Non-haptic simulators are typically less expensive than haptic-based simulators, making them more accessible for educational institutions with limited budgets. Some of non-haptic simulators in dentistry are, Web-based Simulation of Patients (Web-SP)[cite] , Virtual World(VW) [12], COllaborative MEdical Tutor (COMET) [8], Virtual Patient Collection (VPC) [13], Virtual Learning Environment (VLE) [14], Virtual Patient via an Artificial Intelligence Chatbot(AI chatbot) [15], Artificial Interface for Clinical Education(ALICE) [16] etc.

In dentistry, both haptic-based and non-haptic-based simulators are used to train students in a variety of procedures, such as restorative dentistry, oral surgery, and endodontics. While haptic-based simulators offer a more realistic experience, non-haptic-based simulators are still useful for providing students with valuable experience and feedback. Ultimately, the choice of which simulator to use depends on the specific needs and resources of the educational institution.

1) Feature comparison of related systems: Several types of research are done to categorize Virtual patient systems [17]. Table VI shows the feature comparison of several virtual patient systems which have been identified during the literature review. All of these applications are web-based applications with different kinds of features and techniques. According to the table, combinations of features can be identified in each and every implementation where they have led the system to be successful in various approaches. As an example, some systems (VW and VRTS) have consisted of attractive representations for the users with their graphical representation. They even contain medical instrument selection in 3D mode. On the other hand, some of the systems including COMET and Web-SP cover many theoretical areas including intelligent evaluation criteria. Web-SP has tried to cover the actual clinical procedure as it is through information with 2D graphics while COMET has been introduced as a specific implementation which provides a collaborative learning tool. However, as COMET is good at teamwork, it is important to consider doctor-patient interaction. At that point, communication methods are necessary. This can be provided to the system as chatbots. Textual chat systems have been implemented in VW, VLE and AI-chatbot systems. Furthermore, diagnosis evaluation and feedback systems can be considered as another important aspect that virtual patients should have within their implementation. Most of the systems have diagnosis evaluation and feedback systems in different forms. Some systems have access to previous records of the student. As an example, in VLE there is case feedback to the tutor as well which is a supportive approach when improving the system.

Overall, when considered with the implementations discussed above, it can be identified that the virtual learning systems can be effective for dentistry, particularly when used in conjunction with traditional in-person instruction.

III. Methodology

The virtual patient web interface was designed including the main three phases of patient assessment in dentistry (History taking, Examination and Investigation, Diagnosis), so that it equals a main theoretical topic of the practical skills training in terms of content and learning objectives. React redux was used for the web interface implementation while firebase firestore was used as the database. Furthermore, Firestore cloud storage was used for the deployment.

Two completed VP cases were created following the above phases in order according to the design principles for VP cases, the figure 1 shows the architecture of the system.

After a successful login a student is given the chance for the case selection from the given cases.The design principles contained the relevanceness to the case, an adequate level of difficulty for the student, possessing a high level of interactivity and providing detailed feedback tailored to the individual. Here the main focus was given for making optimal use of media, highlighting on relevant learning points and offering recapitulation. In addition, each VP scenario presented

an authentic web interface and included the questions and clarifications customized to the process of clinical reasoning.

Each case contained a 3D graphic of the intra-oral view representing the defects providing the zoom in zoom out and 360 degree rotation. Furthermore, they consisted of numerous elements including drop-down menus, multiple choice selections, text boxes, etc helping to create an efficient learning environment including multimedia. The construction of the cases followed a linear and non-dichotomous approach, but the students could freely navigate back to previous case slides to look up relevant findings within the cases. In order to compensate for the absence of in-person guidance from a supervised physician at the clinic, the diagnostics and treatment options were provided in additional text boxes (glossary), and multiple-choice questions were used. Correct answers were rewarded with positive marks while wrong answers led to negative marks followed by constructive feedback and detailed explanations regarding the various choices.

A. History Taking

This phase mainly includes obtaining the patient's history by allowing the students to ask questions from the VP regarding the selected case. A student was provided with a list of sections as History of the presenting complaint, Medical history, Habits, Plaque control, Dietary history, Previous dental treatments and Social history. A drop-down menu and once a section was selected the relevant questions were displayed on another drop-down menu. Once a question was chosen, the VP displayed the answers following the selected question.

Here the marks were allocated for choosing the correct order of selecting the sections to ask the questions from the patient. The wrong orders were given negative marks. In addition, the questions in each section included both relevant and irrelevant questions to the selected case and selecting only the relevant questions were given positive marks while the choosing of irrelevant questions carried negative marks.

B. Examination

Examination phase allowed the students to examine the patient using the intra oral view, extra oral view. The extra oral section described the physical appearance while the intra oral section consisted with the Intra Oral view, Periodic Screening, Soft Tissue Assessment, Hard Tissue Assessment and Gingival Assessment. The intraoral view was provided as a 3D model representing the defects of the teeth of the patient providing the zoom in zoom out and 360 degree rotation features so that the student can examine the tooth in a preferred scale and angles.

1) 3D modeling: 3D modeling implementation for the intra-oral view representation was first considered using game engines and the research was done to identify the most suitable approach for the web interface.

The 3D model was created using Blender with all the relevant features which should be included in a teeth set of different kinds of teeth, gum, tongue etc. According to a case restorations, cavities and discolorations were created in the 3d model using Blender features. A mirror tool was also created using Blender which is needed to get a better view of the front teeth set. After creating the 3d model we exported it as a .glb file for further implementation.

Unity was used for further implementation of the 3d model. The 3d model was imported to unity as a .glb file and then implementation of zoom in and zoom out feature was started. But due to some resolution issue, clear lessness of the 3d model was observed and since that issue, further implementation of the 3d model was carried away using Blender. However for the zoom in and out feature implementations, React three.js library was used.

The evaluations were done in Soft Tissue Assessment and Hard Tissue Assessment according to the answers provided by the student in the relevant assessment regarding the patient examination. The questions included tool selections, caries status and restorations status and plaque scores and bleeding scores calculation using the given charts.

C. Investigation

This phase provided the students with various types of sources to investigate the patient. They included Radiograph, Haematological assessments and Sensibility recordings. Here the radiographs contained the types of Dental Panoramic Tomogram (DPT), intraoral periapical(IOPA), Bitewing and Cone-beam computed tomography (CBCT). Students could choose any given category and do their investigations accordingly.

D. Evalution and Feedback

Evaluation of the student was carried out using the criteria of Students' individual behavior. The system evaluates the ability to choose adequate history questions, examination behavior including tools selection, identifying caries status and restorations status and calculating plaque scores and bleeding scores, investigation method selection and Providing the correct answers for the questionnaire for diagnosis. In the investigation phase, the student has to choose the correct lab tests and types of radiographs. Incorrect selections lead to negative marks This gives a sense of a real scenario since in a real scenario, students should not take unwanted investigation methods. Other than that, in the evaluation weight-based marking criteria were used.

This system contains a real-time feedback system. It gives detailed feedback on the student's behavior with suggestions and comments so that students can do self-assessments and improve their skills.

IV. Testing evaluation with students

Thirty three third year dentistry students in a four-year program were assigned randomly in a VP (18) and a Small Group Teaching (SGT) group (15) which was regarded as a control group. The study was conducted on a voluntary basis, and a written informed consent was obtained prior to the participation with the right to withdraw at any time. Throughout the instructional approaches, the students were

unaware of their study group affiliation. Basic information as age, sex and study duration were gathered via a questionnaire. Figure 2 shows the study design for the feedback evaluation.

V. Analysis

A. Study participation

Prior to the test, a questionnaire was given to get the user characteristics of the students and do a self-assessment. Asked questions are in the table I. The first aim was to identify each student separately. For that students were assigned random codes. All the students were in the same semester. It was semester 6. Using students from the same semester helped to avoid the bias that may happen due to the technical knowledge difference in a clinical case during the experiment. For the experiment, 21 Female students and 14 Male students participated. Due to technical issues, 2 students' records can not be used for future investigation. So the usable sample count is 33. According to the questionnaire none of the students had good exposure to these types of virtual patient systems. The average history-taking rate is 3.486. The average rate of confidence in patient assessment according to the patient's presentation is 3.429.

B. Outcome measures

The Objective Structured Clinical Examination (OSCE) is a widely used assessment method in the field of dentistry. This type of examination evaluates a candidate's clinical skills and ability to apply their theoretical knowledge in a practical setting. Two OSCE exams were held before and after the experiment. The exam was graded from 1 to 100. Then the mean values, standard deviations and p-values were calculated. The table IV shows the values obtained for mean and standard deviation.

In the case initial we decide our null hypothesis as our designed virtual patient system can perform well as the traditional clinical procedure. To prove that it can not be neglected, the p-values were calculated and it is in table V.

According to these statistical values, both the control group and the VP group have performed in a similar manner. Their mean and standard deviation values do not have any significant difference in both pre and post-OSCE. Moreover, p-values are greater than 0.5. This means that the initial hypothesis, that the VP system can perform well as the traditional clinical procedure is not neglectable. Moreover, the average time student spent in the Virtual patient system is 53 minutes. It is a reasonable time period compared to the traditional clinical time frame.

VI. Students' feedback review

After the test, two questionnaires were given to get user feedback about the system and user feedback about the overall experience.

After the test, these questionnaires were only given to the students who interacted with the Virtual Patient Simulator.

Overall, students felt better prepared to diagnose (mean = 2.78, SD = 2.78 ± 1.166125) as shown in Table II shows. Students felt that working on the VP cases is better and more enjoyable than learning with real patients (mean = 2.93, SD = 2.93 ± 1.197377) and found this motivates further self-learning (mean = 2.81, SD = 2.81 ± 1.46745). In Table III the direct feedback that was given within the VP cases was felt to be sufficient (mean = 3.68, SD = 3.68 ±1.138347). Students also found that case completion develops skills in decision making (mean = 2.72, SD = 2.72 ± 1.206045). In particular, the detailed structure, the multi-media environment, the individual learning pace and the option to repeatedly work on cases was commended. However, students only partially found that working on the VP cases felt like making real life clinical decisions (mean = 3.12, SD = 3.12 ±1.078193). As the overall case work up students have given mean of 3.12 in Table III.

VII. Discussion

This study was conducted to evaluate the effectiveness of the developed virtual patient system. These types of learning platforms have several benefits for the students when compared with other approaches. One of the key benefits of VP is its flexibility in terms of learning rate and time. It has already been discussed in prior studies and changes the learning experience from a teacher-centered to a more learner-centered approach [18], [19].

The final study design and evaluation were done in a controlled environment after getting ethical clearance. Both VP and control groups were tested at the same time to make the results more accurate. Throughout the session, there is no interruption from outside and students engage well with the system. According to the statistical data gained from the results of the study, there is no significant difference in the OSCE exam result of both control and intervention (VP) groups. Also, positive student feedback was given by participating students. Students in the VP group assessed the VP's comprehensibility, quality, design, and substance. Hence the application has a good rating.

VIII. Limitations and strengths

While evaluating the findings of this study, several limitations were taken into account. First, the statistical power of this pilot study is constrained by the sample size (n = 33 students). With the time limitations, one case was selected for the study in order to simulate through a virtual patient system. However, this may lead to bias in the obtained results. Also, the system contained a limited number of clinical cases due to the unavailability of relevant datasets. Within the implementation, sources such as radiographs, and intraoral views have been reproduced regarding the same case. Most of the available radiographs did not perfectly match the chosen case. Sometimes it contains extra defects too.

The study has a number of other strengths as well. One major strength is simulating one clinical scenario including all the details. This was a challenging procedure to achieve due to the unavailability of the necessary data. Also, the current study was randomized and controlled in comparison to prior studies

to evaluate the use of VP as an alternative to conventional clinical training in dentistry at various levels where it can also be identified as an important approach regarding the overall implementation.

IX. Final Conclusion

Virtual patient systems for dentistry are virtual learning platforms that replicate various aspects of real-world dental practice. These systems can be used to train dental students, assess the competency of dental professionals, and provide patients with a realistic preview of dental procedures. This study shows how successful the development of our virtual patient simulator. The system evaluation was done in a controlled environment.

TABLE I
User characteristics questionnaire

Questions	Input
Your code	This code was given to the student prior to the test in randomly chosen order
What is your level of training?	Semester of the student
Sex	Male/Female
No. of semesters engaged in clinical dentistry	Rate from 1 to 5
Have you ever used an interactive electronic learning module before? , if yes details	yes/no
How would you rate your history-taking skills?	Scale from 1 to 5. 1 for very bad. 5 for very good
How would you rate your confidence in patient assessment according to the patient's presentation?	Scale from 1 to 5. 1 for very bad. 5 for very good

TABLE II
User feedback about the overall experience

Question	Mean out of 5	Standard Deviation
This learning experience helps to develop skills in decision making	2.72	2.72 ± 1.206045
This learning experience helps to build up the confidence in patient assessment	2.66	2.66 ± 1.266557
This learning experience helps to build up the confidence in diagnosis	2.69	2.69 ± 1.185455
This learning experience helped to learn in my pace of learning	2.78	2.78 ± 1.293193
This way of learning is better and enjoyable than learning with real patientss	2.93	2.93 ± 1.197377
This motivates further self-learning	2.81	2.81 ± 1.46745
This learning experience improved my understanding on the patient assessment process	2.81	2.81 ± 1.309927
After completing the case, I feel overall better prepared for patient care in a real-life practice setting	2.78	2.78 ± 1.166125

TABLE III
User feedback about the system

concept	Mean out of 5	Standard Deviation
Authenticity of patient encounter and the consultation . While working on this case, I felt I had to make the same decisions a doctor would make in real life	3.12	3.12 ±1.078193
Professional approach in the consultation Your idea on Intra-oral view (3D view)	3.12	3.12 ±1.352467
Coaching during consultation What do you think of the feedback received at the end?	3.68	3.68 ±1.138347
Overall judgment of case workup The system is user-friendly	3.12	3.12 ±1.258306

TABLE IV
Mean score and standard deviation for pre-questionnaire and post-questionnaire

		Mean(1-100)	Standard Deviation
Pre questionnaire(OSCE)	Control	44.64	4.64±9.90
	VP	44.21	44.21±13.77
Post questionnaire(OSCE)	Control	58.93	58.93±9.64
	VP	58.95	58.95±11.85

TABLE V
p-value for pre-questionnaire and post-questionnaire

	p-value
Pre questionnaire(OSCE)	0.818235
Post questionnaire(OSCE)	0.666375

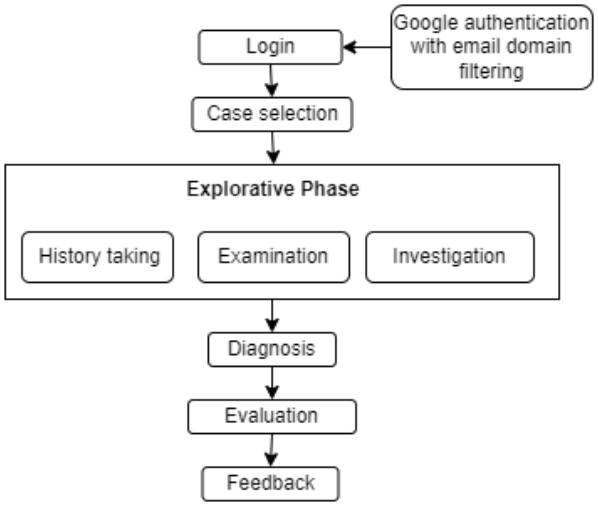

Fig. 1. The Virtual Patient System Architecture

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TABLE VI
TABLE 1.0 ANALYSIS : FUNCTIONAL COMPARISON

Features	Techniques	Web-SP	COMET	VW	VPC	VRTS	VLE	ALICE	AI chat-bot
Haptic-based						yes			
Introduction to the system	Instruction in text					yes			yes
	Instruction in video			yes				yes	
History taking	Textual	yes		yes	yes	yes	yes	yes	yes
Examination and investigation	Textual		yes	yes	yes		yes	yes	yes
	Selecting from drop-down list	yes							
	Providing resources with 3D images			yes		yes			
	Providing resources with 2D images	yes	yes				yes	yes	
	Proving resources with videos							yes	
PBL			yes	yes					
Chat System (with the patient)	Textual			yes			yes		yes
Tool Selection	3D images			yes		yes			
Diagnosis	Only diagnosis		yes	yes					
	Diagnosis with treatment instructions	yes				yes	yes	yes	
Feedback System	Textual	yes	yes	yes		yes	yes		yes
	Access to the previous diagnosis	yes							
	Case feedback for the tutor						yes		
Individual Supervision	Tracking log	yes					yes		
	Evaluation					yes	yes	yes	yes

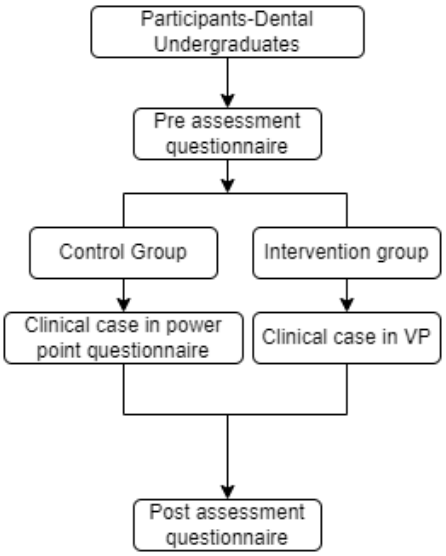

Fig. 2. The Study Design for Feedback Evaluation

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