An Overview of Virtual and Augmented Reality in Dental Education

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Abstract

Introduction: Clinical dentistry is a complex area for education. This is because the development of clinical competence requires the assimilation of knowledge combined with the acquisition of clinical skills and problem-solving ability. In recent years, a variety of computer-based modalities—including intelligent tutoring systems, medical simulation, and virtual reality techniques and the development of Web 2.0 collaborative authoring and social networking tools—has become available. ***Aims:*** The aims of this paper are to provide an overview of the use of one of these modalities—virtual and augmented reality systems—in dental education and to discuss the strengths and weaknesses of these systems. ***Methods:*** A literature review was performed, using the search terms "virtual reality" and "dental education". Secondary literature searching was then performed. Results: The review suggested that the use of virtual and augmented reality technologies offers the advantages of the reinforcement of theoretical dental knowledge, correct use of dental instruments, ergonomic positioning, students' self-evaluation, faster acquisition of skills and positive student perception. In general, any disadvantages arise because most of the dental simulators that use virtual and augmented reality are in an early/experimental stage. ***Conclusions:*** It can be concluded that virtual and augmented reality systems will play an increasing role in dental education. These technologies are likely to change clinical training and encourage the use of reflective forms of assessment, which involve students in a self-assessment process to identify individual learning needs and self-directed learning. These innovations promise not only lower costs of the educational process, but also an increase in quality by providing a new set of pedagogical tools for dental schools.

Key Words: Quality, Higher Education, Virtual Reality, Augmented Reality, Technology, Innovation

Introduction

Clinical dentistry is one of the most demanding areas for education. The development of clinical competence requires the assimilation of large amounts of knowledge combined with the acquisition of clinical skills and problem-solving ability. Clinical skills include skills in patient consultation and physical examination, as well as skills in performing a clinical procedure. Clinical problem solving requires the ability to synthesise the information obtained from interaction with a patient, possibly special tests, such as radiographs, and integrate this information with the dentist's knowledge and experience in order to diagnose and manage the patient's problem.

Currently, training in clinical competence follows an apprenticeship approach, which consists of close supervision of students while they interact with patients. Unfortunately, sometimes, this method of training can subject patients to discomfort, risk of complications, and prolonged treatment times. There may also be limited access to professional training in more complex scenarios with a corresponding difficulty of training in a time-effective manner.

Classically, pre-clinical operative training for dental students has consisted of a combination of theoretical teaching and practical exercises in the laboratory. This method is costly, time-consuming, and inexact. On completion of such pre-clinical

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training, the student inevitably faces the patient without the proper development of his/her skills.

New technology-based approaches to address these problems have emerged in recent years through the development of a wide range of computer-based tools and systems. These include intelligent tutoring systems [1], medical simulation [2,3], virtual reality techniques [4,5], the development of Web 2.0 [6], collaborative authoring and social networking tools [7-12]. The field of intelligent tutoring systems has come a long way since its start in the 1980s [13]. There is now well-accepted standard architecture for such systems and a number of well developed and tested user-modelling techniques such as Bayesian networks [14]. The field has matured to the extent that Carnegie Mellon University is now using intelligent tutoring as a key technology in its ambitious open learning initiative [15].

Recent work, in which artificial intelligence has been incorporated into intelligent tutoring systems [16] and—as in the Unified Medical Language System (UMLS)—used to improve the quality of feedback to students, holds promise for the future [17]. These new tools may well provide wider access to learning, improve the quality of interaction and decrease the cost of producing such systems [17].

In all areas of human activity, virtual and augmented reality technologies can provide one answer. These technologies can be used to:

- Enhance information technology and communication and thus sustain society and the knowledge-based economy.
- Improve the competitiveness of and creativity in a nation's economy, in public administration, in research, in education and in health care.
- Optimise disease prevention methods and public health systems and help the development of medical therapies [18].

Virtual reality has been used for several years to train military and civilian pilots and more recently in medicine [3]. It has been defined as electronic simulations of environments experienced via head-mounted goggles and wired clothing, enabling the end-user to interact in realistic three-dimensional situations [19]. There has been some discussion about the definition of augmented reality and its relationship to virtual reality [20]. One view is that augmented reality is a form of virtual reality where the participant's head-mounted display is transparent, allowing a clear view of the real world [20]. Both virtual and augmented learning can be incorporated within e-Learning, which is defined as "learning in a way that uses information and communication technologies" [21].

The technologies of virtual and augmented reality available for education and training in dentistry have the ability to create virtual reality that enables simulation of practical procedures in three dimensions. Virtual and augmented reality technologies can be used to simulate and assess clinical techniques. They provide unlimited access to practice sessions, the immediate feedback needed for learning, and allow a standardised assessment of the skills acquired by students [12].

During the past decade, pre-clinical and clinical training have witnessed a significant increase in the use of simulation technology for teaching and assessment [22]. The use of virtual and augmented reality techniques to create realistic simulations of the physical aspects of the clinical environment is attracting increasing attention, due to the promise of creating high-quality training environments, and to the rapid development and decreasing cost of software and hardware. Advances in technology are enabling advances in clinical training and the challenges of the clinical training environment are driving the development of new technology.

The influence of new technology on dental education and the dental curriculum is already evident in some dental schools. However, the assimilation of these techniques into the dental curriculum has been slow [23]. Integration of innovative systems, based on new technology, into dental curricula should be a goal to improve the quality in dental and medical education [24].

Aims

Against this background, the aims of this paper are to provide an overview of the use of one of these modalities—virtual and augmented reality systems—in dental education and to discuss the strengths and weaknesses of these systems.

Methods

The authors performed a literature review on the topic. The initial review was of PubMed for English-language studies published from 1 January 2000 to 1 February 2011, using the search terms "virtual reality" and "dental education". Further literature was identified from the reference lists of the papers accessed via PubMed and by searching the

World Wide Web. It included conference abstracts, books and online publications as well as papers in journals.

Results

Early uses of virtual and augmented reality

Two papers and one set of conference proceedings detail early but incomplete work in the use of virtual and augmented reality in dental education:

- Kim *et al.* (2005) proposed a dental training system with a multi-modal workbench providing visual, audio, and haptic feedback. Haptics has been defined as the science concerned with studying the sense of touch [25]. This system uses volume-based haptic modelling which represents a tooth as a volumetric implicit surface. It allows drilling a tooth, but it is limited to a spherical tool [26].
- Wang *et al.* (2003) developed a simulator that allows probing and cutting of a tooth model, but the virtual tool implementation is limited to a spherical shape, as with Kim et al.'s 2005 system [27].
- Yau *et al.* (2006) developed a dental training system employing material stiffness and a spring force function. This simulation uses an oriented bounding box for the boundary of the cutting tool. Yau *et al.* (2006) introduced different cutting tool shapes but did not provide details on how forces are rendered for irregular-shaped cutting tools [28].

DentSim

DentSim [29] was one of the first, if not the first, virtual reality system for teaching restorative dentistry. It enables students to practise clinical procedures on a simulated patient with on-screen visual tracking of the procedure concerned, real-time feedback and evaluation of their performance. Since the early 2000s, the system has been used in a number of dental schools in North America and Europe [30-32]; reports of its evaluations [31,32] indicate that it is effective in enabling students to work without the need for a supervisor (teacher), to assess their performance critically, and to monitor their performance [32,33].

The Geneva System

For the past six years, the Geneva Dental School, Department of Cariology, University of Geneva, Switzerland, has been developing innovative concepts using computer three-dimensional simulation for the teaching of dental anatomy. The aim was to validate the added value of information technology (IT) integration into curriculum. The results showed that 70% of the students were satisfied or very satisfied with this module and that the simulation boosted their motivation to learn dental anatomy. It also became evident that IT did not introduce a supplemental complexity that reduced teaching efficiency. Currently, a second-generation virtual reality dental simulator with improved tactile features to teach drilling procedures is being developed [34].

The Virtual Dental Patient

AIIA Laboratory Computer Vision and Image Processing Group, Department of Informatics, Aristotle University of Thessaloniki Greece, developed the Virtual Dental Patient (VDP) application [35]. The VDP was designed to aid students to become acquainted with tooth anatomy, the handling of drilling instruments and the challenges associated with the drilling procedure. The VDP simulator allows the user to:

- View/manipulate a three-dimensional head and oral cavity model constructed using anatomical data, adapt the model to the characteristics of a specific patient using either facial photographs or three-dimensional data, and animate it using an MPEG-compatible facial animation player. The model consists of oral cavity tissues, teeth and head/neck tissues (external surface).
- Perform virtual tooth drilling within the oral cavity using a Phantom haptic device (SensAble Technologies Inc) [36] to control the drilling tool. The user, sensing contact/resistance the stylus of the haptic device, controls the position of the dental bur while drilling. The application makes use of the internal dual surface/volumetric representation of the tooth. Removal of tooth tissue during drilling is implemented as a series of morphological operations on the volumetric (voxel-based) representation of the tooth. The virtual tooth drilling is performed on three-dimensional volumetric dental models from a database that has been constructed by digitising and post-processing (alignment and segmentation) cross-sections of extracted teeth, viewed through an optical microscope. Apart from being used as a training tool for students, the system can also assist

experienced dentists in planning a real-life tooth drilling by familiarising them with individual patient anatomy, identifying landmarks and planning their approach.

Virtual Reality Dental Training System

Virtual Reality Dental Training System (VRDTS), developed by Novint Technologies in collaboration with the Harvard School of Dental Medicine, is a dental simulator that uses virtual reality technology for cavity preparation [31]. The software simulates a set of dental instruments (low-speed drill, an explorer, two carvers, a carrier and a packer), amalgam material, and a single molar. The VRDTS allows for the virtual restoration of teeth. However, it has the disadvantage that it does not enforce or support correct positioning or hand/finger rests because the student holds the interface in the air [37].

Iowa Dental Surgical Simulator

The Iowa Dental Surgical Simulator (IDSS) has been developed by the College of Dentistry at the University of Iowa, U.S.A., which also has a Graphical Representation of Knowledge (GROK) Laboratory. In the IDSS, students can feel enamel, healthy dentine and carious dentine when they touch a virtual tooth. IDSS consists of three hardware components: the computer, a monitor, and a force feedback device, which has customised software. Participants interact with the computer by grasping a joystick or explorer handle attached to the force feedback device. Teeth are displayed on the monitor, and the student can manipulate the joystick or explorer in such a way as to "feel" enamel, healthy dentine, and carious dentine. Different haptic responses are received when the joystick or explorer is manipulated over the appropriate areas of the tooth. Initial development has emphasised the clinical virtual assessment of dental margins for the simulation and detection of dental caries. The original task was changed to the assessment of the small gaps between dental crowns and the prepared tooth. The IDSS's major disadvantage is that it focuses more on tactile skill development and less on psychomotor skill development [38].

PerioSim©

The C. J. Luciano College of Dentistry at University of Illinois at Chicago (UIC) invented PerioSim©, a prototype of a dental simulator for training in periodontal procedures. It allows trainees to learn how to diagnose and treat periodontal diseases by visualising a three-dimensional virtual human mouth and experiencing tactile sensations while touching the surface of teeth, gingivae, and calculus with virtual dental instruments. PerioSim© is a part of the curriculum of the Department of Periodontics at UIC. It has the advantage that it does not require tooth surface alteration, but the disadvantage that tactile sensations for the gingival tissues are not realistic [39,40].

HapTEL

The HapTEL system has been developed as a collaboration between the King's College London Dental Institute and Reading University, U.K. It is based on a haptic unit, which has been adapted from a computer gaming device [41]. It includes two screens that enable the user to look down onto a simulated jaw as if they were treating a real patient, specifically designed software that gives flexibility to the drilling position and lightness of touch, and a foot pedal to control the speed of the bur. Users are able to replay the procedure that they have performed and to assess their skills. The percentage of caries removed and the percentage of hard tissue removed are fed back to them as a score. The scores are stored so that students and their teachers can monitor progress. A range of simulations is available, starting with simple caries in a tooth and progressing to more complex caries [42]. Over a two-year period, 300 pre-clinical dental students have used the hapTEL system [43].

VirDenT system

The Faculty of Dental Medicine, University Ovidius of Constanta, Romania, has developed VirDenT system. The VirDenT uses technologies based on virtual and augmented reality to simulate the preparation of fixed dental prostheses (crowns and bridges) [44].

VirDentT consists of a virtual drill, teeth and patient, with a haptic interface that allows dental students or other users to practise restorative dental procedures in a virtual environment. It allows a student simultaneously and proactively to follow the procedures demonstrated by an intelligent tutor. The virtual and augmented reality simulator simulates the tooth preparation procedure both graphically and haptically, using a video display and haptic device.

VirDenT is non-invasive and provides feedback to students, enabling them to recover if an error is made. Like hapTEL, it records and evaluates students' progress. It is hoped that students

will learn tooth preparation more quickly than when taught by classical methods and tooth preparation time needed by students will be reduced [45].

The first phase of the VirDenT development process consisted of the construction of a model of the system in which the VirDenT software would operate in [46]. In the second phase one, the domain ontology that formally describes the knowledge needed in all-ceramic restorations was developed by clinicians and informaticians [46]. A prototype was then developed and tested in June 2010.

Moog Simodont Dental Trainer

Most recently, in The Netherlands, the Academic Centre for Dentistry Amsterdam (ACTA) has installed Moog Simodont dental trainers [47] in its new premises. These haptic devices provide multiple dental procedures that can be practised in a virtual environment, including manual dexterity exercises with automatic evaluation, diagnosis and treatment planning, cavity preparation, and crown and bridge preparations [48].

The Forsslund System

The Forsslund system has been designed to provide virtual reality training in third molar extraction. It has also recently been installed at ACTA [49].

Other Uses of Virtual and Augmented Reality in Dentistry

In head and neck surgery

In the field of oral and maxillofacial surgery, head and neck reconstruction requires multidisciplinary communication. Virtual surgical planning using computed tomographic imaging and virtual and augmented reality technology allow oral and maxillofacial surgeons to perform virtual surgery and generates templates and cutting guides that allow for the precise and expedient recreation of the plan in the operating room [50]. A recent development is the Voxelman system for planning and training in paranasal surgery [51]

In implantology

In the field of oral implantology, treatment planning has been based on the interpretation and mental reconstruction of cross sectional two-dimensional image data. Because the clinician concerned has to imagine how the two-dimensional images are in three dimensions, this is very difficult, and it hampers treatment planning [29]. To overcome these problems, a virtual reality environment for treatment planning in oral implantology that provides a three-dimensional view has been developed [29]. It enhances diagnosis and treatment planning as the true position and orientation of implants can be assessed in three dimensions. The virtual world in which treatment planning takes place allows the clinician to move and interact with the individual patient's anatomy simultaneously with three degrees of freedom. The design and placement of implants are interactively controlled by the clinician and are simulated in real-time. Thus the results of actions become immediately visible and provide feedback for interactive adjustment. In addition, the virtual reality environment for oral implant treatment planning enables the detection of inappropriate implant placement with regard to the quantity and quality of a patient's bone [50].

As a method of pain control

In the field of pain management, usually achieved with anaesthesia, alternative methods suggest that the use of immersive virtual reality distraction may be an effective method of pain control during periodontal scaling and root planing procedures [52].

Discussion

This overview has been limited to one area of e-Learning with dentistry. It has not considered others or the use of virtual and augmented reality in other areas such as aviation and medicine. It is noticeable how few studies have been published to compare the effectiveness of the new virtual and augmented reality systems in dental education. However, from this study it is apparent that their use in dental education has increased over the last decade [53]. Many of the systems that have been described are very new and require in-depth long-term evaluation. For a variety of reasons, there has been resistance to change in several dental schools [12]. This is unfortunate because use of the technology concerned has the potential to improve the quality of dental education and the clinical skills of both medical and dental undergraduates before they apply these skills to the care of live patients, thus minimising the risk of iatrogenic damage to patients.

Many advantages of the use of virtual and augmented reality in dental education were apparent from the literature review. They included:

- Reinforcement of learned dental concepts: students can apply theoretical concepts from previous courses to a simulated clinical experience [1,3,54].

- Correct use of dental instruments: students learn how to use the high-speed hand piece, rotary cutting instruments, mirror, explorer, and periodontal probe correctly [54].
- Correct ergonomic positioning: incorrect operator and/or patient positioning can result in blocking the camera from reading the LED sensors. When this happens, a warning signal prevents the user from continuing. This encourages the students to practise good ergonomic habits [37].
- Psychomotor skills: training in direct and indirect vision and spatial orientation in a controlled setting are incorporated very early into the dental curriculum [2].
- Self-evaluation: students have immediate, unlimited, and objective access to detailed feedback of their work. The imaging available in this system includes three-dimensional graphics, cross-sections, measurements, and zoom features [28,41].
- Standardised evaluation: unlike those of a number of clinical supervisors, the assessments are objective and consistent [42,43].
- Faster acquisition of skills: studies published so far indicate that students attain a competency-based skill level at a faster rate than with traditional simulator units (phantom heads). This can result in changes in dental curriculum and earlier entrance into the predoctoral clinic [28,35,53].
- Positive student perception: the majority of courses in the freshman curriculum relate to basic biomedical sciences. Students enjoy the opportunity to have what they perceive as a more dentally related course [34,54].
- Availability over many hours: It is not essential for large numbers of Faculty to supervise students while they are using the systems, thus saving staff costs.

Against these advantages, there are a number of disadvantages. These include:

- Many of these virtual of augmented reality dental simulators are at an early or experimental stage [26,27,40].
- A system limitation with the current design: many of the systems are programmed for and evaluate tooth preparations only. Tooth restoration is rarely included. In addition, hand instrumentation cannot be performed (with the exception of a cavity for an amalgam filling). However, haptic devices will solve that problem in the future [37].
- Many systems are limited to using spherical tools that are simple to implement, but it also limits very much realism in a simulated dental clinic, where several types of instruments are needed in different shapes and sizes [26,40].
- The initial cost of this advanced technology simulation can be substantial [43].
- Difficult equipment to maintain and repair: technology-based systems require faculty/ engineering staff to be available for training and supervision of the laboratory.

Future virtual reality systems will provide precise representations of many other procedures and will be valuable training simulators. However, it is essential that they meet the requirements of the real world and that their design is driven accordingly "The educational needs must drive the development of the appropriate technology" [53]. They should not be viewed as toys for enthusiasts. Nevertheless, the human element must never be dismissed. Patients are real and verbal communication and clinicians' attitudes are as important as their knowledge and skills. Also, dental educators and clinicians will need to adapt, by supporting the best science, embracing new avenues of inquiry and welcoming the expertise of people in other disciplines. Training for new faculty members in teaching skills, curriculum design, and assessment methods are critical for supporting future innovation.

Scientific research will continue to offer exciting technologies and effective treatments. For the profession and the patients it serves to benefit fully from modern science, new knowledge and technologies must be incorporated into the mainstream of dental education.

The technologies of modern science have astonished and intrigued our imagination. This review provides only a glimpse of the coming wave.

Conclusions

- Virtual reality is the next step in dental education. The technologies of virtual and augmented reality innovate how clinical training takes place.
- Unlike existing systems for clinical courses, such as using plastic models of teeth, virtual reality systems overcome the limitations of phantom head systems and provide standardised case, objective assessment, and interactivity.

- They encourage the use of reflective forms of assessment with methods that involve students in a self-assessment process to identify individual learning needs and self-directed learning. These can then lead to the development of a realisation of the need for lifelong learning.
- Although these innovations can be expensive initially, they promise not only lower costs for the educational process, but also increased quality by providing a new set of pedagogical tools for dental schools (Faculties of Dental Medicine).
- To bring these innovations into widespread use, a close collaboration between dental teachers, experts in pedagogy, IT scientists and entrepreneurs is needed.

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Contribution of each author

MD carried out the baseline searches, drafted the past (relevant) projects section, contributed to the VirDenT section, and edited the paper.

CIA supervised the review, drafted the discussion and the conclusions.

CMB and DMP contributed to the VirDenT section.

NI carried out the baseline searches.

CIN contributed to the introduction and edited the paper.

Statement of conflict of interests

As far as the authors are aware, there are no conflicts of interest associated with this work.

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