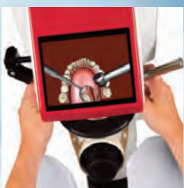
VR as Innovation in Dental Education

Validation of a virtual reality environment: collecting evidence 'on-the-fly' during development and implementation



Ilse R. de Boer

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I.R. de Boer

Paranimfen: Martin de Boer
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Copromotor:	dr. J.M. Vervoorn	Vrije Universiteit Amsterdam
Overige leden:	prof. dr. F. Lobbezoo	Universiteit van Amsterdam
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General introduction and thesis outline

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VIRTUAL REALITY IN DENTAL EDUCATION

The history of dental education is marked by both change and continuity.[1] The first marked dental education dates to the year 1530, in which the earliest dentistry textbook was published in Leipzig.[1] This thesis enhances "change" in dental education, and reflects on the developmental processes. For the continued development, growth, and broadening of future dental professionals' knowledge and possibilities, innovation and the continued enhancement of knowledge are paramount. The new possibilities afforded over time, by technical innovations and knowledge should be used to shape the academic and professional development of dentists.

Innovation in dental education encompasses many areas. A current major pillar of innovation in medical and dental education is the introduction of virtual reality (VR) and virtual reality environments (VRE).[2] The use of simulation has been proposed as the next major step in the evolution of health science education.[3] VREs have a very wide operational capability.

Advantages of VR often discussed in (dental) education:

<u>Patient care:</u>
- Patient safety: procedures can be practiced in a VRE and mistakes corrected before the patient receives the actual treatment.

<u>Environmental:</u>
- The possibility to practice without wasting (disposable) materials and water.
- Avoidance of the use and waste of human tissue (e.g. extracted teeth).
- Hygiene: no contact with possible contaminated (human) tissues or fluids.

<u>Educational:</u>
- As procedures are undertaken in a computer environment, each step is traceable. This enables users to go back in time and re-analyse specific difficult aspects of procedures or practices. For teachers, this option presents the opportunity to judge the complete process of a treatment, rather than just the end-product or result.
- Objective assessment by the computer: no subjectivity is introduced by examiners during assessment and the computer calculates the score.
- Overcoming the disconnection between the classroom/pre-clinic and clinic.
- Cost: reducing the waste of practice materials (e.g. disposables, plastic teeth for students, etc.).

Possible *disadvantages* of VR education:

<u>Patient care:</u>

- Privacy of digital patient data needs to be guaranteed.
- Lack of human interaction.

<u>Environmental:</u>

- The use of extracted human teeth for dental education remains the ‘gold standard’. Virtual teeth are not (yet) available as a complete replacement.

<u>Education:</u>

- Cost: the development, maintenance and acquisition of a VRE can be very costly.
- The level of realism achieved in a trainer or simulator: how real should a (dental) trainer or simulator be to enable students to acquire clinical skills? Managing the expectations of users in this matter can be of high importance.
- Implementation in a curriculum can be challenging, as a completely new environment is added to existing teaching methods.

At many dental schools, including the Academic Centre for Dentistry Amsterdam (ACTA), educational challenges were experienced due to the shortage of extracted human teeth with the desired pathologies to train students in simulated clinical problem solving. Additionally, there is a lack of patients with the proper dental diseases for the development of all clinical competences. The use of extracted teeth and the variety of patients also alter students’ circumstances; student experiences were difficult to compare due to different circumstances during learning and testing. Plastic teeth, used as a substitute for human teeth, differ considerably to human teeth in terms of their colour and hardness. Moreover, they are either sound or contain unrealistic simulated caries.

ACTA was searching for a solution to overcome these challenges in dental training, and secure a ‘future proof’ curriculum that offered a training environment in which students could become competent professionals within the timeframe to graduation, whilst also meeting the increasingly high ethical standards pertaining to learning on patients. Additionally, renewing and improving the quality of dental education is a constant agenda. Therefore, an exploration of the possibilities of VR simulation in dental training was carried out.

THE DAWN OF THE SIMODONT DENTAL TRAINER

The beginning

To sustain dental training, ACTA tested since 2000 almost all new dental training technologies available on the market, varying from augmented reality to virtual reality. Based on the testing outcomes, an important requirement for a new VRE was identified. VREs should enable students to perform entire procedures or exercises in the virtual world, thereby embracing the opportunities provided by VR and avoiding the complexities of combining VR with reality. ACTA was looking for a learning environment to enhance competency based learning and to introduce a better integration of theory with practice. In 2002, ACTA made first contact with Fokker Control Systems (a few years later known as Moog Inc.) [4], a company specializing in precision motor control products and systems.[5] In 2007, ACTA sought to form a partnership with FCS (now Moog Inc.), following proof of concept of the proposed solution to meet the educational needs (i.e. a learning environment in which students' could work safely and independently to learn at their own pace). Development of an entirely new simulator was planned by cooperation between ACTA and FCS. A subsidy from the Ministry of Education of the Netherlands (the Hague, the Netherlands) was received by ACTA to invest in the development of the educational courseware in the Moog Simodont dental trainer. In 2007, the first contract was signed with Moog to co-develop 50 machines that would be installed in the preclinical lab of ACTA by September 2010.

Designing the Simodont dental trainer

The first sketch of the Simodont dental trainer was created in 2005 (Figure 1).

The operator hands and the field of view (FOV) were positioned in accordance with real-life scenarios of a working dentist. The working area was restricted by the FOV, and thus, the operator was unable to move around the 'patient'. However, the position of the "patient"

Figure 1. The first draft of the Simodont dental **trainer.**

could be changed during 'treatment', enabling the work to be conducted from realistic positions respective to the patient.

Many prototypes followed until 2009 (Figures 2a & 2b). In 2010, the latest version was installed at ACTA (Figure 3). To achieve future proof education, the Simodont dental trainer was intended to offer the possibility for use in both pre-clinical and clinical settings. The transition between these learning environments should be effortless for users; therefore, the development of haptics in the Simodont dental trainer was a major focal point, meaning that the force feedback (FFB) or 'feeling' during drilling needed to be as life-like as possible. Additionally, the final design of the Simodont dental trainer was required to be 'student proof', meaning that the machine should facilitate independent student use without the need for constant teacher or technician supervision.

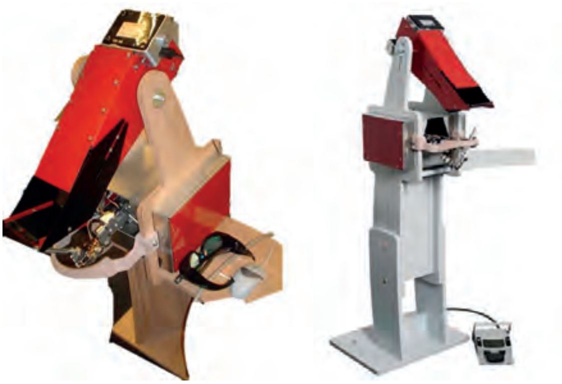

Figure 2a. Prototypes of the Simodont dental trainer.

Figure 2b. Prototypes of the Simodont dental trainer.

Figure 3. The Simodont dental trainer installed at ACTA in 2010.

Continuous development

The Simodont dental trainer is still currently under development, and its software and hardware specifications are continuously being improved. The Simodont dental trainer can now be used for manual dexterity exercises, treatment of virtual patients including treatment planning, as well as for basic cavity preparation and crown preparations. Future applications for the VRE are aimed at bridge preparation, paedodontics, endodontic access cavity preparation, and periodontal examination of virtual patients. To validate the Simodont dental trainer, multiple studies have been performed.[5-9]

In this thesis, the academic circumstances of simultaneous development, implementation, and evidence collection have been described. Development and stepwise implementation enables the creation of evidence, and several components of the Simodont dental trainer are evaluated for improvement and future development of the technology. During this study the Moog Simodont dental trainer (Moog Inc., Nieuw-Vennep, the Netherlands) was incorporated stepwise into the curriculum, in addition to contemporary teaching methods.

OUTLINE OF THIS THESIS

To be able to treat virtual patients and offer educational training on teeth with realistic anatomy in a virtual world, the development and evaluation of virtual teeth are required. In the first part of this thesis, these topics are described. **Chapter 2** describes the development and origin of virtual teeth, with and without pathology. **Chapter 3** evaluates the opinions of dental professionals and students on the learning possibilities and appearance of virtual teeth compared to contemporary educational means, such as plastic teeth and extracted human teeth.

The second part of this thesis describes the validation of assumptions for the development of a virtual reality learning environment and evaluation of the experiences of working in the Simodont dental trainer VRE. **Chapter 4** discusses the evaluation of working with three-dimensional (3D) versus two-dimensional (2D) vision in the Simodont dental trainer, and their impact on the satisfaction of users. **Chapter 5** describes the evaluation of working with and without force feedback in the VRE, and the consequences for dental students on their performance and experiences. **Chapter 6** describes the effects on performance when working with a variation in force feedback, during a test on the Simodont dental trainer.

The final part of this thesis, **Chapter 7**, describes the 'on-the-fly' method, which was applied during all previous studies of this thesis. It describes the simultaneous innovation, development, and execution of research in an academic environment while implementing the system in education.

REFERENCES

1. Book: Institute of Medicine. Dental Education at the Crossroads: Challenges and Change. Committee on the Future of Dental Education. The National Academies Press ISBN 9780309051958. Washington, DC, 1995.
2. Okuda Y, Bryson E, DeMaria S, et al. The utility of simulation in medical education: What is the evidence? Mt Sinai J Med 2009; 76:330-343.
3. Suebnukarn S, Phatthanasathiankul N, Sombatweroje S, Rhienmora P, Haddawy P. Process and outcome measures of expert/novice performance on a haptic virtual reality system. J Dent 2009: 37:658–665.
4. http://www.moog.com
5. Wang D, Li1 T, Zhang Y, Hou J. Survey on multisensory feedback virtual reality dental training systems. Eur J Dent Educ. 2016. Epub ahead of print. doi: 10.1111/eje.12173
6. Mirghani I, Mushtaq F, Allsop MJ, Al-Saud LM, Tickhill N, Potter C, Keeling A, Mon-Williams MA, Manogue M. Capturing differences in dental training using a virtual reality simulator. Eur J Dent Educ. 2016 Nov 19. doi: 10.1111/eje.12245. [Epub ahead of print]
7. Koopman P, Vervoorn JM. Innovations in education for the digital student. Ned Tijdschr Tandheelkd 2012; 119:286–90.
8. Bakker DR, Lagerweij ML, Wesselink PR, Vervoorn JM. Transfer of manual dexterity skills acquired on the Simodont, a dental haptic trainer with a virtual environment, to reality, a pilot study. Bio-algorithms Med-Systems 2010;6:21–4.
9. De Boer IR, Bakker DR, Wesselink PR, Vervoorn JM. The Simodont in dental education. Ned Tijdschr Tandheelkd 2012; 119:294–300.

Part I

Virtual teeth in a virtual reality environment

Creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education

I.R. de Boer
P.R. Wesselink
J.M. Vervoorn

2

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ABSTRACT

Purpose
To describe the development and opportunities for implementation of virtual teeth with and without pathology for use in a virtual learning environment in dental education.

Material and methods
The creation of virtual teeth begins by scanning a tooth with a cone beam CT. The resulting scan consists of multiple two-dimensional greyscale images. The specially designed software program ColorMapEditor connects these two-dimensional images to create a three-dimensional tooth. With this software, any aspect of the tooth can be modified, including its colour, volume, shape and density, resulting in the creation of virtual teeth of any type.

Results
This article provides examples of realistic virtual teeth with and without pathology that can be used for dental education. ColorMapEditor offers infinite possibilities to adjust and add options for the optimisation of virtual teeth.

Discussion
Virtual teeth have unlimited availability for dental students, allowing them to practise as often as required. Virtual teeth can be made and adjusted to any shape with any type of pathology. Further developments in software and hardware technology are necessary to refine the ability to colour and shape the interior of the pulp chamber and surface of the tooth to enable not only treatment but also diagnostics and thus create a greater degree of realism.

Conclusion
The creation and use of virtual teeth in dental education appears to be feasible but is still in development; it offers many opportunities for the creation of teeth with various pathologies, although an evaluation of its use in dental education is still required.

INTRODUCTION

The use of virtual reality (VR) is becoming increasingly common, as illustrated by the extensive use of computer games and use of VR software in fields such as architecture to create 3D (three-dimensional) designs.[1] VR was first used in medical education approximately 15–20 years ago.[2,3] In dentistry, for example, VR combined with haptic feedback was used to simulate drilling in a jawbone and to insert an oral implant.[4] Since 2003, the ACTA (Academic Centre for Dentistry Amsterdam) has experimented with VR. VR was introduced to the dental education programme at ACTA in 2010.

In the contemporary pre-clinical simulation laboratory, students practise on extracted human teeth combined with plastic teeth in a typodont and a phantom head. The accuracy and precision of non-clinical testing of dental students' proficiency in crown preparation on a typodont has been evaluated. This analysis showed that performance on typodonts is a poor predictor of clinical performance on patients. Students performed worse on the clinical crown examination than the typodont examination.[5] Experience has shown that in many countries, the number of suitable extracted teeth available for dental education is insufficient. In most dental schools, extracted teeth must be sterilised before use, which may cause potential hazards and negatively affect their quality. Plastic teeth look and feel very different from natural extracted teeth and usually have no simulated pathology; those that do exhibit some pathology are very expensive.[6–8] Furthermore, typodonts may easily become contaminated, putting students and teachers with airway problems at risk.[9]

Virtual teeth in a virtual learning environment can offer many solutions and opportunities in dental education. For example, pre-surgical practice in a virtual environment using a 3D model of a virtual tooth generated from an original CBCT was shown to improve endodontic microsurgery performance.[10] The availability of virtual teeth is unlimited, they can be more realistic than plastic teeth, there are no costs for the students as there are with plastic teeth, and they are safe to work with in terms of hygiene and patient safety. Virtual teeth can be created in any quantity and can display any type of dental pathology for a virtual patient case.

Virtual teeth can be used in a simulation learning environment, such as the haptic dental trainers Simodont®, PerioSim™ (University of Illinois, Chicago, USA) or hapTEL™ (Kings College London, University of London, UK). Together with Moog Inc. (Nieuw-Vennep, the Netherlands), the ACTA developed the Moog Simodont dental trainer (Simodont), a device used to train dental students (Fig. 1). The Simodont consists of a training console and a computer. The training console consists of two instruments and a small screen (800 × 600 pixels) located in the position of the patient's head. Under this screen, two instruments are attached to the simulator. One instrument is shaped as a dental handpiece and provides haptic feedback, and the other serves as a dental mirror. Thus, when a virtual tooth is cut, visual, audio and tactile feedback are received simultaneously. 'Haptic' means relating to or proceeding from the sense of touch.[11] The amount of force feedback received depends on the dental tissue being 'treated'; enamel feels harder than carious tissue. A 3D view is created using special glasses. A separate computer connected via an interface to the training console contains the lesson program for the students (i.e. the courseware). The courseware contains a 'waiting room' of virtual patients with virtual teeth and manual dexterity assignments.

This study describes the development, creation and uses for virtual teeth with and without pathology in dental education. It provides dental educators with insight into the procedures involved and in the development and possibilities offered to help them develop their own ideas about creating a virtual learning environment and virtual teeth.

Fig. 1. Moog Simodont® dental trainer

MATERIALS AND METHODS

Figure 2, step 1

The creation of a virtual tooth begins by scanning an extracted tooth with a cone beam computer tomography (CBCT) scanner. In this case, a NewTom 5G (QR SLR, Verona, Italy) was used. The resolution was 0.2-mm isotropic voxels. The scan data were processed using Amira software (Visage Imaging, San Diego, CA, USA), version 4.2, to produce a Digital Imaging and Communications in Medicine (DICOM) file containing data describing one tooth. The complete file consists of multiple 2D (two-dimensional) grey-scale images.

Figure 2, step 2

The software program ColorMapEditor® (CME), which was developed by Moog based on the Sensegraphics (Stockholm, Sweden) toolbox H3D, was specially designed to display and edit the file representing the scanned tooth. CME is an application used to create and edit a 'lesson' for the Simodont simulation software. In a lesson, many files and different volume data are combined to specify, for example, a virtual jaw with a virtual tooth (Fig. 3). With CME, a user can create and modify volume data and colour data, load a tooth, place the tooth in a jaw and build a virtual mouth, that is, a virtual patient, for dental education.

To begin creating and editing a virtual tooth, the DICOM of the scanned tooth file must be loaded in CME and saved as density data. The density data represent the hardness of the various tooth materials (enamel, dentine, pulp, etc.). The next step is to derive a colour data file from the density data. This is a separate file in which colour is added to a certain voxel (a volumetric pixel), saved in three dimensions and shown in 2D slices or as a 3D image when the complete tooth is shown. The third file needed to load the tooth is the iso volume file, a separate file that determines the shape of the outside surface of the tooth using an iso value. 'Iso' is a term used to define a value that connects voxels with the same grey value on the 3D volumetric model.

The colour data, density data and iso volume are saved as nrrd files (nearly raw raster data[12]). The combined iso volume and density data form a snapshot, a separate file that is saved to allow the simulator to read both files to create a single complete image. All of these files (density, colour and iso) are separately saved to create many possibilities for editing the tooth; for instance, the density of the tooth can be edited without deforming the surface and thus the shape of the virtual tooth.

Fig. 3. Virtual lower jaw

Figure 2. Six steps for creating a virtual tooth (27) with pathology in CME.

1. Scan a tooth (CBCT)

Figure 2a

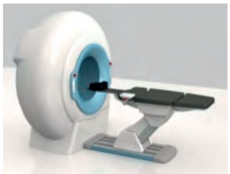

Figure 2b

2. Start editing in ColorMapEditor

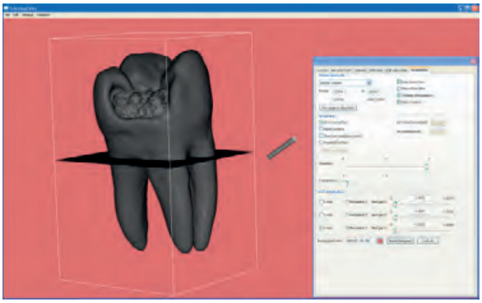

Figure 2c

3. Select a (normalised) iso value to create the surface of the tooth

Too high (0.49) Too low(0.49) Iso value selected (0.33)
Figure 2d

4. Edit the file in 3D by changing the density and adding mass

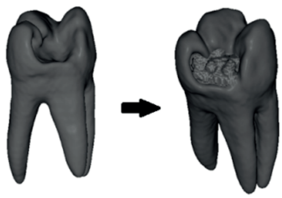

Figure 2e

5. Colour the inside of the tooth

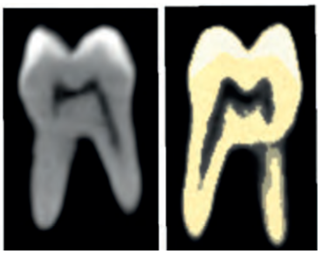

Figure 2f

6. Colour the outside of the tooth	 Figure 2g
7. Finish	 Figure 2h

Figure 2, step 3

The file representing the scanned tooth contains more density data than exclusively the data of the tooth. Some of the reflections of the x-rays are also read as density data. When defining the shape of the tooth, the boundary between 'air' and 'tissue' must be determined; this is based on the iso value, a normalised value between 0 and 1. Before determining the iso value, the range of the density data in the file should be set to the limits of the data to ensure that all of the density data in the file can be used. The value is selected by trial and error. If the iso value is too high, many voxels from the scan will be excluded from the surface of the tooth, and the projected image will contain 'holes'. If the iso value is too low, too many voxels from the scan will be included, the shape of the tooth will be deformed, and the pulp space will not be hollow. Once the correct iso value is selected, the surface of the tooth can be edited.

Figure 2, step 4

The iso surface is derived from the density data file. To edit the surface, virtual mass must be added to the density data file of the tooth, and the iso surface (shape of the tooth) must be derived from this file.

When the surface and shape of the tooth are established, the iso surface can be saved. After determining the iso surface, the density data can be adjusted. These adjustments make it possible to create soft, virtual carious tissue with a value below the normalised iso value. Very soft virtual tissue can be added to the tooth without altering its outside shape. A haptic device, the PHANTOM Omni (SensAble Technologies, Inc., MA, USA) was used to add virtual 3D mass to the tooth. The Omni makes it possible to feel the outside surface of the tooth and the cavity using force feedback.

During the scan of the tooth, faults or artefacts can occur in the scan file. These virtual voids in the density data can be corrected by adding virtual tissue.

Figure 2, step 5
When the shape of the tooth is determined, pathology is added at the correct density (which translates into a specific hardness); adding colour to the tooth completes the 3D image and adds more realism. The nrrd file for the colour data consists of grey values that show the different tissues (i.e. enamel, dentine, pulp, caries) for colouring. The colour is added to the tooth in both the 3D and 2D images. In the 2D image of the virtual tooth, colour is added on three axes: the x-axis, y-axis and z-axis. The tooth is divided into thin slices that are 0.2 mm thick, which makes it possible to select a very specific voxel in the tooth and add or adjust the colour. The selected RGB (red, green and blue) value defines the colour; this value is between 0 and 255. The RGB value must be determined for every tissue that is coloured (enamel, dentine, pulp and caries). Two different sets of RGB values for one specific colour, that is, two different shades of one colour, are used. This gives more depth to the colour and thus the different tissues of the tooth. The tooth is coloured by filling individual voxels or a set of voxels with the selected colour.

Figure 2, step 6 and 7
To finish the outside surface of the tooth, the PHANTOM Omni, a pencil with force feedback, is used. This makes it possible to colour the tooth very precisely. The outside surface of the tooth can be made 'magnetic' so that the pen gives constant force feedback.

When the virtual tooth file has been completed, the virtual tooth can be placed in a virtual jaw. This complete lesson, consisting of a virtual jaw and virtual teeth, is used in the simulator to enable the treatment of a virtual patient (Fig. 3).

RESULTS

The procedure described above offers many possibilities for the creation and editing of virtual teeth to be used in a virtual learning environment for dental education. CME is a new software application and is easy to use, to create and edit virtual teeth. The virtual teeth can then be used to execute a treatment in, for instance, Simodont. The creator of the virtual teeth can decide what shape, hardness (density), colour or pathology will be added to the virtual tooth. To date, a digital library (Fig. 4) of 55 virtual teeth, including both adult and deciduous teeth with and without pathology (Fig. 5), is available at ACTA and accessible to any school upon request.

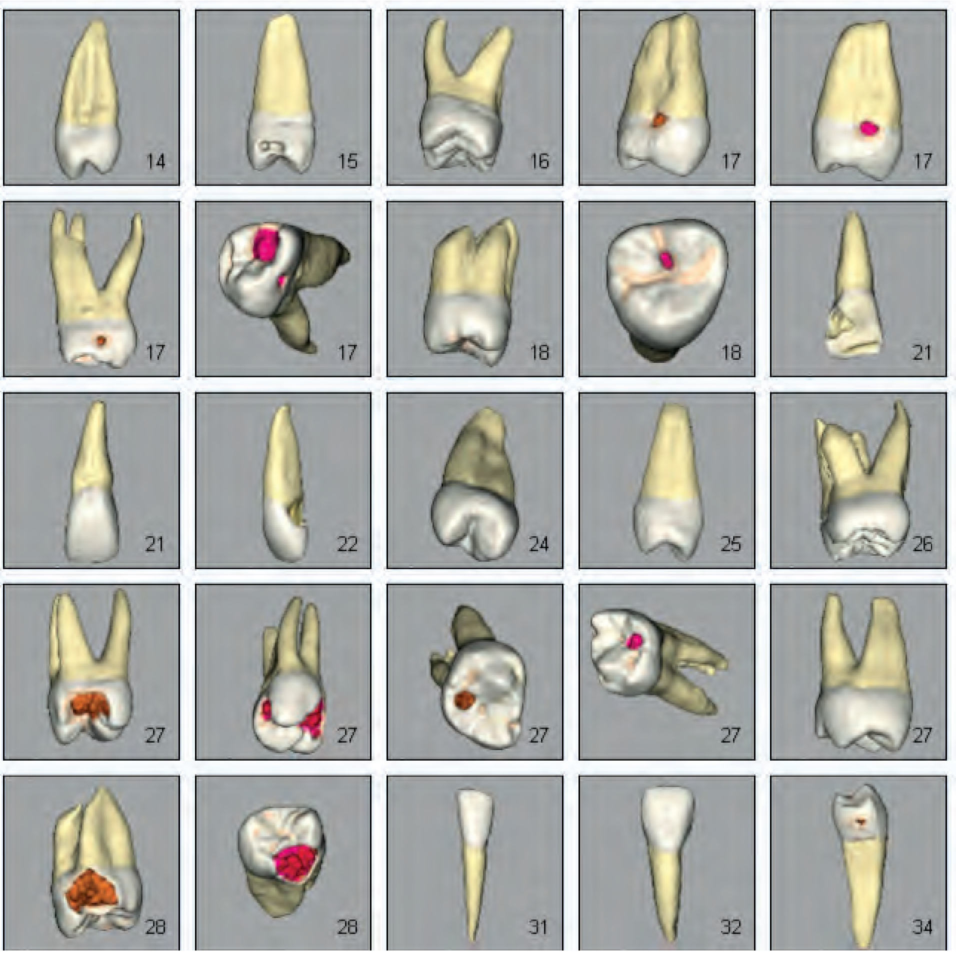

Fig. 4. Examples of virtual teeth in the digital library.

Figure 5. Examples of virtual teeth

Sound teeth

Figure 5a

Tooth with extensive decay

Figure 5b

Deciduous tooth

Figure 5c

Maxillary Incisor

Figure 5d

DISCUSSION

The use of CME to create virtual teeth allows the adjustment of the appearance, shape, mass and hardness of the tooth in a scan. A portion of the tissue of a scanned tooth with caries may be missing in the file because the cone beam CT does not detect all of the caries, which has a low density, in a large cavity. In this study, virtual teeth are obtained from a scan made with a CBCT device. Another study demonstrated the possibility of obtaining data using micro-computed tomography.[13] This possibility was also tested in this study, but micro-CT provided a file containing too many data, with a resolution that could not be used in the computer of the simulator. Additionally, this high resolution did not improve the level of realism of the virtual tooth when projected in the Simodont. With CME, it is possible to build up the density, reshape the surface and create virtual caries in the tooth. Students can learn to remove caries while using the colour or staining of the caries, if a tool such as the caries detector is applied or the hardness of the decay is used as a guide. Dentists feel the hardness of the tooth to locate the region in which they are cutting. The model of the density data is therefore very important when the tooth is used for cutting or removing caries to increase the realism of the treatment.[14] In a virtual tooth, a composite or amalgam restoration can be designed with the required shape, colour and hardness, which allows dental students to practise how to shape, finish and remove a restoration.

Further development of CME is necessary to optimise the image of the virtual tooth. For example, to make the appearance of the tooth more realistic, it will be necessary to add texture to the surface, that is, change the light reflection of the surface to make the enamel and root appear different. Additionally, the option to create white spot lesions on the virtual teeth contributes to a realistic appearance and enables additional diagnoses. Developing an option to colour the inside of the pulp chamber in virtual teeth will create the opportunity to practise preparation of an endodontic access cavity and locate the canal orifices. Further research is recommended to evaluate the use of virtual teeth in dental education. The introduction of a new virtual learning environment with virtual teeth raises questions, such as whether the teeth appear sufficiently realistic to serve its purpose in dental education, which must be answered before acceptance in the curriculum can be possible.

The use of extracted human teeth in dental education remains the optimal basis for the clinical training of dental students in many aspects, for example, to provide the realistic feeling of drilling and instrumentation. However, the difficulties in accessing a sufficient number of suitable extracted teeth for all students, issues with hygiene and the ethical questions involved in using human material for educational purposes without written consent make the use of virtual teeth very attractive. Virtual teeth offer many advantages and opportunities to overcome these problems and can be used as an additional learning environment in contemporary dental education. The impact of the use of VR on the performance of endodontic microsurgery was evaluated in a previous study. These authors used virtual teeth based on CBCT scans from a cadaveric porcine mandible.

The virtual teeth provided different force feedback in various tissues based on their density values. The virtual teeth in this study were not coloured, and they were not created to be a substitute or addition to actual clinical settings, which is the purpose of the current study.[10] The creation of realistic looking virtual teeth with and without pathology offers the opportunity to present students in an early stage of education in the simulation laboratory with a realistic clinical problem, a patient with diseased teeth, instead of only plastic teeth or extracted natural teeth. Using a virtual learning environment with virtual teeth offers the chance to practise in a highly realistic and safe environment. In contemporary dental education, every student practises on his or her own collected extracted teeth. This makes it almost impossible for the university to ensure that every student receives the same pre-clinical education and acquires the same practical experience. Plastic teeth are expensive for students and universities to buy, and the hardness of the material is usually not comparable to that of real teeth. However, this is not the case with virtual teeth. Moreover, when using virtual teeth, assignments for students are standardised, which makes it possible for teachers to provide standardised feedback and for students to exchange treatment plans and discuss patient cases. In addition, during clinical simulation tests with the use of virtual teeth, the testing environment is identical for every student, which eliminates differences in the difficulty of the tests; this standardisation is impossible when extracted teeth are used. In virtual cases, every student treats the same patient and treats the same virtual tooth and pathology.

The projection of the virtual teeth by the two beams in Simodont produces an image with a limited resolution. Thus, in addition to the virtual teeth, photographs of the scanned teeth are still necessary for accurate diagnosis and should be incorporated in the courseware and lessons. At the moment, it is not possible for every tooth in the virtual jaw to be haptic and fully rendered. The computer that secures the haptic rendering has limited memory. Additionally, the graphics card of the computer limits the number of triangles that can be displayed to create the 3D image of the virtual tooth. The solution to this problem is to use Accutrans® 3D (version 2.12.1) to create a low-resolution model of all the teeth in the jaw that are not involved in the treatment of the virtual patient. Low-resolution models are made for both the haptic and colour models. A low-resolution haptic model consists of approximately ± 1000 triangles, while a low-resolution image of the graphic model consists of approximately ± 10 000 triangles. These low-resolution models project the image of a virtual tooth, and when touched with instruments, they give haptic feedback. However, it is not possible to make a preparation in the low-resolution teeth. It is currently possible to create a jaw with three or four haptically rendered teeth. When creating a lesson in the simulator, the CME user can decide which teeth should be fully rendered and haptic and which teeth should be visible in a low resolution format, depending on the virtual patient case.

The aim of using virtual teeth in a virtual learning environment in the curriculum, in addition to the use of plastic teeth and human extracted teeth, is to make the transition from the contemporary pre-clinical laboratory (with phantom heads) to the clinic (where real patients are treated) more natural.

CONCLUSION

The use of VR has become an important and permanent component of medical and dental education. The creation and use of virtual teeth in dental education has contributed to this development. The creation of virtual teeth with and without pathology offers many opportunities and advantages for dental education in terms of safety, cost and usability. CME is a very versatile and useful application for creating and editing virtual teeth. It is continually updated to improve and expand the possibilities for creating virtual teeth. This enables the opportunity to let students work on a variety of pathologies in virtual teeth and even to develop complete patient settings with varying degrees of complexities, allowing dental students to develop competencies and skills that would otherwise require patients or extracted teeth, which may not be sufficiently available in many dental schools. Further research is necessary to evaluate and validate the application of virtual teeth in dental education.

REFERENCES

1. http://www.buzzle.com/articles/virtual-reality-in-architecture.html Accessed: 12 February 2012
2. Quinn F, Keogh P, McDonald A, Hussey D. A pilot study comparing the effectiveness of conventional training and virtual reality simulation in the skills acquisition of junior dental students. Eur J Dent Educ 2003;7:13-19.
3. David Ota, Bowen Loftin, Tim Saito, Robert Lea, James Keller. Virtual reality in surgical Education. Comput. Biol. Med. 1995;25:127-137.
4. Kusumoto N, Sohmura T, Yamada S, Wakabayashi K, Nakamura T, Yatani H. Application of virtual reality force feedback haptic device for oral implant surgery. Clin. Oral Impl. Res 2006;17:708-713.
5. Nunez DW, Taleghani M, Wathen WF, Abdellatif HM. Typodont versus live patient: predicting dental students' clinical performance. J Dent Educ 2012;76:407-413.
6. Dominici JT, Eleazer PD, Clark SJ, Staat RH, Scheetz JP. Disinfection/sterilization of extracted teeth for dental student use. J Dent Educ 2001;65:1278-1280.
7. Pantera EA, Schuster GS. Sterilization of extracted human teeth. J Dent Educ 1990;54:283-5.
8. Douglas E. Parsell, Leslie Karns, William T. Buchanan, Roger B. Johnson. Mercury release during autoclave sterilization of amalgam. Eur J Dent Educ 1996;60:453-458.
9. Jeffrey E. Aycock, Edward E. Hill. Should preclinical typodonts be disinfected prior to grading? J of Dent Educ 2009;73:133-136.
10. Suebnukarn S, Rhienmora P, Haddawy P. The use of cone-beam computed tomography and virtual reality simulation for pre-surgical practice in endodontic microsurgery. Int Endod J. 2012;45:627-632.
11. Suebnukarn S, Phatthanasathiankul N, Sombatweroje S, Rhienmora P, Haddawy P. Process and outcome measures of expert/novice performance on a haptic virtual reality system. J Dent. 2009; 37:658-665.
12. http://teem.sourceforge.net/nrrd/ Accessed: 10 December 2011
13. Kato A, Ohno N. Construction of three-dimensional tooth model by micro-computed tomography and application for data sharing. Clin Oral Invest 2009;13:43-46
14. Yoshida Y, Yamaguchi S, Kawamoto Y, Noborio H, Murakami S, Sohmura T. Development of a multi-layered virtual tooth model for the haptic dental training system. Dent Mat J 2011;30:1-6.

Evaluation of the appreciation of virtual teeth with and without pathology

I.R. de Boer
M.D. Lagerweij
P.R. Wesselink
J.M. Vervoorn

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3

ABSTRACT

Aim

Virtual teeth with and without tooth pathology have been developed for use in a virtual learning environment in dental education. The objective of this study was to evaluate the appearance of these virtual teeth for use in dental education and to compare them with contemporary educational models, such as plastic teeth and extracted human teeth.

Material and methods

Six sets of photographs representing six different teeth were shown to dentists, teachers (dentists) and dental students (bachelor's and master's degree students). Each set consisted of 15 pictures showing five views of the extracted human tooth, the similar virtual tooth and the plastic tooth. The five views represented the mesial, distal, occlusal, buccal and lingual surfaces. The virtual tooth was the same as the extracted tooth (scanned with a cone beam CT, coloured and edited in ColorMapEditor®), and the plastic tooth presented the best possible match to the extracted tooth. The participants were asked to rate the appearance of the virtual teeth (overall and in terms of caries, restoration and colours), whether the virtual or plastic teeth resembled the extracted teeth better and from which teeth they expected to learn the most (extracted, virtual or plastic).

Results

Each group of participants found that the virtual teeth resembled the extracted teeth more than they resembled the plastic teeth; 71% of the participants expected to learn more from the virtual teeth than from the plastic teeth.

Conclusion

The results show that the appearance of the virtual teeth was considered more realistic than the appearance of the plastic teeth. The expectation was that the learning opportunities of the virtual teeth are better than of the plastic teeth.

INTRODUCTION

With on-going developments in technology and the increasing availability and use of computer products such as smartphones, tablets and e-books, contemporary students are well acquainted with the use of computer technology in everyday life. This development makes educational computer technology and simulation accessible for students. The use of simulation in medical and dental education is expected to be the next major step in the evolution of health science education.[1] Simulation in medical education has led to improvements in medical knowledge, increased comfort in procedures and improvements in performance during retesting in simulated scenarios. Simulation is defined as an instructional process that substitutes real patients, encounters with artificial models, live actors, or virtual reality patients.[2]

At the Academic Centre for Dentistry Amsterdam (ACTA), a virtual learning environment, the Moog Simodont dental trainer (Simodont dental trainer®), has been integrated into the dental curriculum to train dental students. A variety of published studies on medical simulation indicate that students who have trained with virtual reality simulators demonstrate better skills and performance compared with those who have not been trained on these simulators.[3,4,5] Virtual teeth with and without tooth pathology have been developed for the Simodont dental trainer®, in which virtual patients are treated. These virtual teeth are developed with a special software program ColorMapEditor® (CME). CME was developed by Moog Inc. (Nieuw-Vennep, the Netherlands) in collaboration with ACTA, based on the Sensegraphics (Stockholm, Sweden) toolbox H3D.[6] CME is a software application designed to edit and colour the image of a tooth which is scanned using a cone beam computer tomography (CBCT) scanner.[6]

Students need to acquire technical skills and develop competencies to treat patients in the clinic. In the traditional preclinical laboratory, students practise on extracted human teeth to gain knowledge about pathology (e.g., to diagnose, remove caries and create a filling) and on plastic teeth to acquire manual dexterity skills (e.g. standard cavity- and crown preparations). This implies the separation of developing skills in manual dexterity and clinical decision making. By using a virtual tooth model, which can contain more similarities to the clinical situation than plastic teeth, the opportunity can be offered to students to make decisions related to the clinical situation during skills training and therefore enables students to combine skills-based and competency-based learning.

In addition to extracted human teeth, plastic teeth with pathology are available for training purposes. These teeth bear very little resemblance to reality due to a lack of disease distribution, detail and physical properties needed to accurately simulate real teeth.[7] For these reasons, plastic teeth do not offer the opportunity to carry out various clinical procedures realistically such as excavation of caries (Fig. 1). Additionally, plastic teeth are expensive for dental schools and students. Suitable extracted teeth, with the required pathology, are often difficult to obtain in sufficient numbers. An important advantage offered by virtual teeth is that a task can be repeated where the distribution and size of pathology within the tooth is exactly the same as in the original attempt and for all class members. This offers significant advantages for learning to manage a case correctly when a repeated attempt is needed and in assessing cohorts of students on a standard case. Furthermore, the issues of needing ethical approval and patient approval to acquire the extracted teeth and then manage infection control of the human tissue are avoided.[8]

Figure 1. Plastic tooth 36, with simulated caries.

The use of virtual reality (VR) has been applied via *Second Life* and the use of virtual patients in dental education.[9] Models of virtual teeth can be used to train clinicians and dental students in dental morphology.[10] To treat virtual patients or to acquire manual dexterity (for instance, in cutting a crown), a virtual jaw with virtual teeth is required. To ensure that virtual teeth can be used and accepted in the curriculum by students and faculty, their appearance should be sufficiently realistic. The level of realism of the virtual teeth was investigated by questioning four different groups of participants with varying levels of experience in dentistry.

The objective of this study was to evaluate and compare by the use of a paper questionnaire the appearance and learning possibilities of the virtual teeth created with the CME and used in a virtual learning environment with that of plastic teeth and extracted human teeth. The extracted teeth are considered as the 'gold standard' throughout this whole study. (Fig. 2).

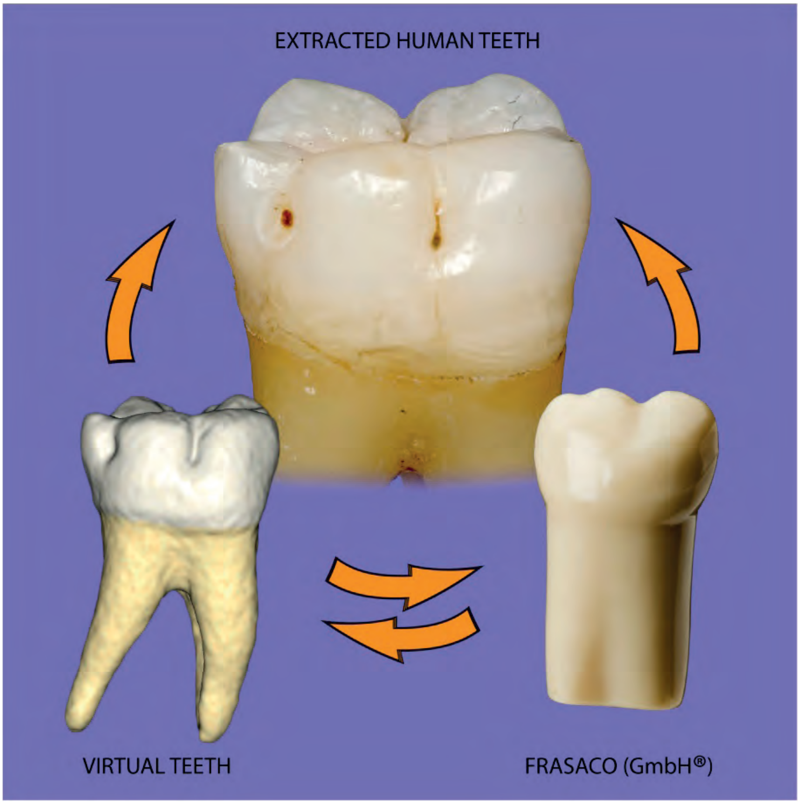

Figure 2. Scheme illustrating the various comparisons that were made in this study.

MATERIALS AND METHODS

Participants

The participants were selected from four different groups of clinicians varying in experience:

- Dentists working in general practice.
- Dentists working in general practice who are also members of the dental school faculty.
- Master's-level dental students (fourth through sixth year) with clinical experience.
- Bachelor's-level dental students (first through third year) with limited clinical experience but extensive experience with plastic teeth (Frasaco GmbH).

The participants who qualified as dentists were asked to report when they had graduated from dental school to estimate their level of experience in general practice. Furthermore, the ages and genders of all of the participants were recorded (Table 3). All participants were informed prior to participation in the study that the results of the questionnaires would be used for research and all the participants gave their informed consent. The study design and developed questionnaire were reviewed and approved by the ethical committee of the faculty.

Questionnaire

To compare and evaluate the virtual teeth created for dental education, a questionnaire was presented to the four different groups of participants. The questionnaire consisted of multiple-choice questions, comparative rating scale questions, open-ended questions and questions that asked the participants to mark their opinions on a visual analogue scale (VAS).

Table 1 provides an overview of the questions and statements used in the questionnaire. To analyse the 'position' of virtual teeth and plastic teeth in dental education in relation to extracted human teeth, the participants were asked to rate the extent to which the virtual teeth resembled the extracted teeth and the extent to which the plastic teeth resembled the extracted teeth on a VAS. On the questions that used a 5-point Likert scale, the participants could select a value from 1 ('completely disagree') to 5 ('completely agree'). The participants rated the *colour*, *shape* and *overall appearance* of the teeth, the caries and the restoration and the expected learning possibilities.

Table 1. Statements used in the questionnaire.

Category A	**Comparisons of appearance**
Design	Visual analogue scale (0% resemblance - 100% resemblance)
Number	Question
1	To what extent do the virtual teeth resemble the extracted human teeth?
2	To what extent do the Frasaco GmbH teeth resemble the extracted human teeth?

Category B	**Expectations of learning possibilities**
Design	Multiple-choice question
Answer model	- 3 points (more) - 2 points (an equal amount) - 1 point (less)
Number	Question
1	Do you expect to learn more/an equal amount/less from virtual teeth than from human extracted teeth?
2	Do you expect to learn more/an equal amount/less from plastic teeth than from human extracted teeth?
3	Do you expect to learn more/an equal amount/less from virtual teeth than from plastic teeth?

Category C	**Overall appearance**
Design	Comparative rating scale question
Subcategory	Colour/shape/in general
Answer model	5-point Likert scale: 1 (completely disagree) – 5 (completely agree)
Number	Statement
1	I consider the overall appearance of virtual teeth concerning the colour/shape/in general to look sufficient to replace extracted human teeth in dental education.
2	I consider the overall appearance of virtual teeth concerning the colour/shape/in general to look sufficient to replace plastic teeth in dental education.
3	I consider the overall appearance of plastic teeth concerning the colour/shape/in general to look sufficient to replace extracted human teeth in dental education.

Category D	**Appearance of the caries**
Design	Comparative rating scale question
Subcategory	Colour/shape/in general
Answer model	5-point Likert scale: 1 (completely disagree) – 5 (completely agree)
Number	Statement
1	I consider the colour/shape/general overall appearance of the caries in the virtual teeth sufficient to replace extracted human teeth in dental education.
2	I consider the colour/shape/general overall appearance of the caries in the virtual teeth sufficient to replace plastic teeth in dental education.
3	I consider the colour/shape/general overall appearance of the caries in the plastic teeth sufficient to replace extracted human teeth in dental education.

Category E	**Appearance of the restoration**
Design	Comparative rating scale question
Subcategory	Colour/shape/in general
Answer model	5-point Likert scale: 1 (completely disagree) – 5 (completely agree)
Number	Statement
1	I consider the colour/shape/general appearance of the restoration of the virtual teeth, sufficient to replace extracted human teeth in dental education.

Category F	**Suggestions to improve the appearance of the virtual teeth**
Design	Open-ended
Subcategory	General

Evaluation scheme with photographs

Six sets of photographs were presented to each participant. Each set consisted of five views of the selected extracted human tooth, five views of the similar virtual tooth and five views of the plastic tooth, which represented the closest representation to the extracted tooth that was available. The six human extracted teeth are a part of a school collection made up out of patients' teeth who gave their permission to ACTA to use them for research and educational purposes. The views represented the buccal, lingual, mesial, distal and occlusal surfaces. Tooth 47 is shown in Fig. 3. The other five sets of photographs consisted of the teeth mentioned in Table 2; tooth 11 was sound, tooth 37 contained a large distal cavity, tooth 47 contained an occlusal amalgam restoration with mesial cavity, tooth 16 was sound and tooth 43 contained a small buccal cavity. For each of six natural teeth selected and identified using the FDI World Dental Federation notation, a virtual tooth was created by initially scanning it with a CBCT (NewTom 5G; QR SLR, Verona, Italy). The collected data were then edited and coloured with the CME software to create the virtual representation of the original tooth. Six plastic Frasaco teeth that most closely resembled the extracted teeth were selected as well (Table 2). The participants completed the questionnaire alongside the sets of photographs.

Table 2. Selected teeth for this study.[11]

Selected virtual teeth and extracted teeth	Frasaco registration number
11	Tooth 11 (type number: ANA-4 Z 11)
37	Tooth 36 (type number: ANA-4 ZK 36)
47	Tooth 46 (type number: ANA-4 ZK 46)
16	Tooth 16 (type number: ANA-4 Z 16)
47	Tooth 46 (type number: ANA-4 ZK 46)
43	Tooth 43 (type number: ANA-4 Z 43)

Figure 3. Example set of photographs.

Statistical analysis

The data collected with the questionnaire were statistically analysed with SPSS 18.0 (SPSS, Chicago, IL, USA). The data were analysed for normal distribution through Q-Q plots. Based on the outcome of the Q-Q plots, the data were tested either parametrically (normal distribution) or non-parametrically (no normal distribution). Different tests were used according to the different types and nature of data. In the result section, the type of analysis is noted alongside each result.

RESULTS

A total of 163 participants completed the questionnaire. We found 84 dentists, 16 teachers of our faculty, 27 Master's students and 36 Bachelor's students willing to participate in this study (Table 3). The dentists had an average of 22 years (range 5–37 years, median 25) of experience in general practice, and the teachers had an average of 24 years (range 9–35 years, median 25).

Table 3. General information about the participants.

	Number of participants	Males	Females	Gender unknown	Average age (years) + SD
Dentist	84	49	32	3	48 ± 10
Dentist (teacher)	16	10	6	0	51 ± 9
Master's student	27	11	16	0	26 ± 3
Bachelor's student	36	16	20	0	22 ± 3
Total	163	86	74	3	37

Results for Category A (Comparisons of appearance)

A total of 156 participants answered Category A of the questionnaire. Figure 4 shows the mean percentage of the score given by the participants from each group on the VAS and the standard error of the mean. In a paired samples t-test, a statistically significant difference ($P < 0.05$) was found. For each of the four participant groups, the differences were 0.000, 0.005, 0.000 and 0.000, respectively.

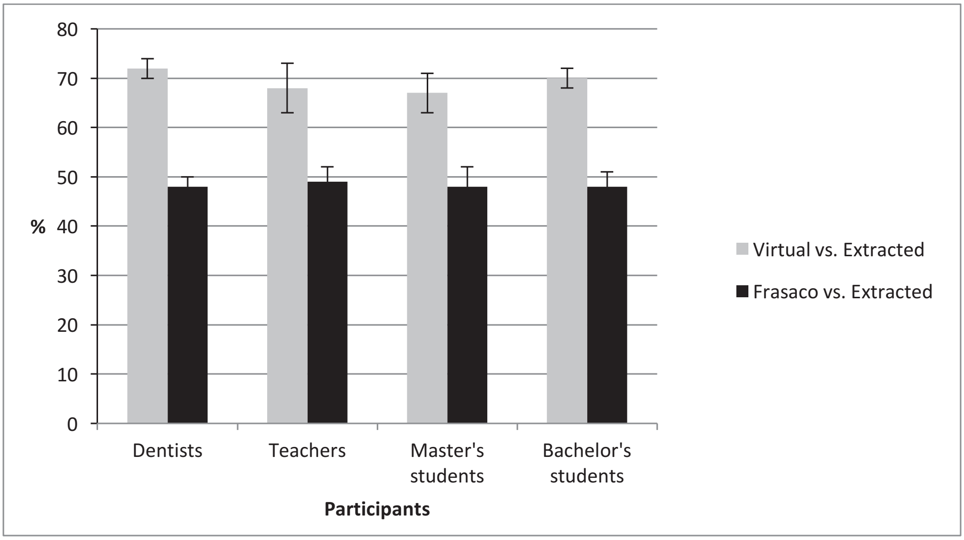

Figure 4. This figure shows the mean percentage of the score given by all participants on a VAS, rating the resemblance of the appearance of virtual teeth compared to extracted teeth and to plastic teeth), including the standard error of the mean.

Results for Category B (Expectations of learning possibilities)

Table 4 shows the results of Q1, Q2 and Q3 with subdivision of the groups. The ANOVA test (Table 5) executed in SPSS showed no significant differences between the means within the groups. The t-test indicated that the answers differed significantly ($P < 0.05$) amongst the questions (1–2, 2–3 and 1–3).

Table 4. Mean and Median and standard deviation scores per group. (1=less, 2= equal, 3=more)

	N	Mean + SD Q1	Mean + SD Q2	Mean + SD Q3	Median Q1	Median Q2	Median Q3
		Virtual - extracted	Plastic - extracted	Virtual - plastic	Virtual - extracted	Plastic - extracted	Virtual - plastic
Dentist	79	1.43 ± 0.620	1.11 ± 0.371	2.72 ± 0.594	1	1	3
Teacher	15	1.54 ± 0.768	1.07 ± 0.277	2.53 ± 0.650	1	1	3
Master's student	27	1.19 ± 0.408	1.11 ± 0.332	2.33 ± 0.712	1	1	3
Bachelor's student	35	1.26 ± 0.452	1.03 ± 0.174	2.60 ± 0.659	1	1	3

Table 5. Results of the ANOVA test for Question 1,2 and 3

		Mean square	F	P value
Q1	Between groups Within groups	0.679 0.315	2.157	0.095
Q2	Between groups Within groups	0.066 0.096	0.688	0.561
Q3	Between groups Within groups	1.047 0.421	2.486	0.630

Table 6 shows the global mean values from paired t-tests ($P < 0.05$) for Q1, Q2 and Q3. The comparison between plastic and extracted teeth (Q2) received a lower rating than did the comparison of virtual and extracted teeth (Q1). Virtual teeth compared with plastic teeth (Q3) had the highest mean score. Figure 5 shows percentages of participants that answered less, equal or more on questions 1, 2 and 3 (Category B: the expectations of learning possibilities). The results show that over 70% of the participants expected to learn more from virtual teeth compared with plastic teeth. However, slightly less than 70% of participants indicated that they expected to learn less from the virtual teeth compared with natural teeth. When considering decreased expected learning from plastic teeth compared with natural teeth, this figure rose to over 90%.

Table 6. Paired samples statistics for Q1, Q2, Q3; no division between groups.

Question	N	Mean + Std. deviation	Std. error mean
Q1	156	1.36 ± 0.567	0.045
Q2	156	1.09 ± 0.308	0.025
Q3	156	2.61 ± 0.658	0.053

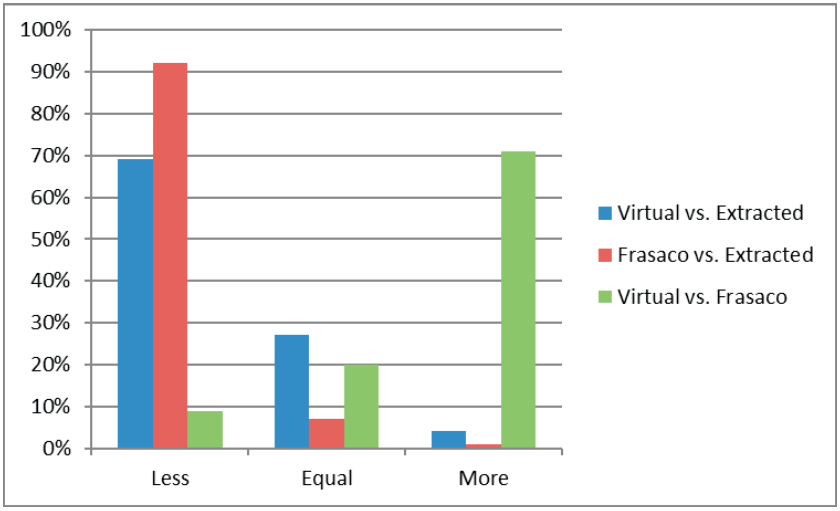

Figure 5. Percentages of participants that answered less/equal/more on Questions 1, 2, and 3 in Category B.

Results for Categories C, D and E (Overall appearance, appearance of the caries, appearance of the restoration)

Table 7 shows the results of the chi-square test of the scores for category C, D and E. This shows there are no significant differences in the scores between the four groups.

Tables 8–10 show results of all participants, without subdivision in groups.

Table 8 shows the means of the scores of category B, which represents the comparison of the overall appearance. Table 9 shows results of the appearance of the caries and Table 10 of the appearance of the restoration.

Table 7. Paired samples statistics for Q1, Q2, Q3; no subdivision of the groups.

Pair	Question pair	N	Mean (paired differences)	Sig. value (P<0.005)
Pair 1	Q1 – Q2	156	0.269	0.000
Pair 2	Q1 – Q3	156	-1.250	0.000
Pair 3	Q2 – Q3	156	-1.519	0.000

Table 8. Chi-square test between groups Category B, C, and D

No.	Test	N	Value	P-value	No.	Test	N	Value	P-value
Q 1	Chi-square test	163	8.733	.726	**Q 12**	Chi-square test	161	10.765	.549
	Likelihood ratio	163	13.151	.358		Likelihood ratio	161	12.649	.395
Q 2	Chi-square test	163	7.928	.541	**Q 13**	Chi-square test	160	24.101	.063
	Likelihood ratio	163	8.656	.470		Likelihood ratio	160	18.344	.245
Q 3	Chi-square test	163	11.437	.492	**Q 14**	Chi-square test	160	12.761	.387
	Likelihood ratio	163	14.435	.274		Likelihood ratio	160	12.924	.375
Q 4	Chi-square test	162	17.280	.139	**Q 15**	Chi-square test	161	13.347	.344
	Likelihood ratio	162	14.399	.276		Likelihood ratio	161	12.732	.389
Q 5	Chi-square test	162	17.782	.122	**Q 16**	Chi-square test	161	18.138	.112
	Likelihood ratio	162	17.488	.132		Likelihood ratio	161	21.890	.039
Q 6	Chi-square test	162	16.615	.165	**Q 17**	Chi-square test	162	17.862	.120
	Likelihood ratio	162	19.593	.075		Likelihood ratio	162	17.983	.116
Q 7	Chi-square test	163	26.158	.010	**Q 18**	Chi-square test	162	12.381	.416
	Likelihood ratio	163	24.075	.020		Likelihood ratio	162	13.439	.338
Q 8	Chi-square test	163	28.357	.005	**Q 19**	Chi-square test	155	11.888	.455
	Likelihood ratio	163	24.125	.020		Likelihood ratio	155	12.396	.414
Q 9	Chi-square test	163	8.557	.740	**Q 20**	Chi-square test	156	5.884	.922
	Likelihood ratio	163	11.198	.512		Likelihood ratio	156	6.426	.893
Q 10	Chi-square test	162	22.228	.035	**Q 21**	Chi-square test	156	7.439	.827
	Likelihood ratio	162	19.763	.072		Likelihood ratio	156	8.307	.761
Q 11	Chi-square test	161	15.231	.229					
	Likelihood ratio	161	14.973	.243					

Table 9. Mean scores and Standard Deviation in Category B (overall appearance) (no subdivision in groups)

	Mean (colour) + SD	Mean (shape)	Mean (in general)
Virtual vs. extracted	3.17 ± 1.014	3.86 ± .848	3.40 ± .992
Virtual vs. plastic	3.91 ± .849	4.01 ± .826	3.85 ± .918
Plastic vs. extracted	2.35 ± .913	2.91 ± 1.008	2.56 ± 1.006

Table 10. Mean scores and Standard Deviation in Category C (appearance of the caries) (no subdivision in groups)

	Mean (colour)	Mean (shape)	Mean (in general)
Virtual vs. extracted	2.90 ± 1.019	3.46 ± 1.045	3.25 ± 1.049
Virtual vs. plastic	3.79 ± .938	3.95 ± .830	3.88 ± .995
Plastic vs. extracted	1.97 ± .945	2.08 ± .929	1.94 ± .896

Table 11. Mean scores and Standard Deviation in Category D (appearance of the restoration) (no subdivision in groups)

	Mean (colour)	Mean (shape)	Mean (in general)
Virtual vs. extracted	2.99 ± .940	3.17 ± .972	2.94 ± .955

Results for Category F

In the final section of the questionnaire, the participants recorded their personal remarks and recommendations to improve the realism of the virtual teeth. The following comments were mentioned frequently: the enamel should be translucent, the colour transitions should be more gradual and white spot lesions and stains on the teeth would improve the realism. The participants also mentioned creating a structure on the surface of the different tissues. The bachelor's degree students mentioned that a notable difference was the fact that they could hold plastic and human teeth in their hands during the inspection, whereas this is not possible with virtual teeth.

In general, most of the participants mentioned that virtual teeth are a good addition to dental education but cannot completely replace extracted human teeth.

DISCUSSION

In this study, the appearance of newly developed virtual teeth was evaluated and compared with that of extracted human teeth and plastic teeth. The responses to the questions in Category A, which were related to appreciation of the appearance of the teeth, clearly showed that the participants considered the virtual teeth to resemble the extracted teeth more closely than the plastic teeth ($P < 0.05$). This result marks a step forward in simulation towards the replacement of extracted teeth, which are increasingly difficult for students and dental schools to collect. The second important aim of the study was to investigate the expected learning opportunities, Category B, using virtual teeth in a virtual learning environment. Virtual teeth are intended to be a valuable learning tool that can be used in addition to or instead of extracted teeth and they are anticipated to represent an improvement over plastic teeth. All groups of participants expected to learn more from the virtual teeth than from the plastic teeth but less from the virtual teeth than from the extracted teeth, which remain the 'gold standard'. These results indicate that virtual teeth can expand learning opportunities for students when they are used in addition to extracted teeth.

The statements in Categories C, D and E concerning the colour, shape and general appearance of the virtual teeth were used to strengthen the results found in Categories A and B and were extended to investigate whether the appearance of the virtual teeth was sufficient to replace extracted human teeth or plastic teeth in dental education.

The participants were reasonably positive about the possible replacement of the extracted human teeth with virtual teeth. They were also reasonably positive about the possible replacement of plastic teeth with virtual teeth [the virtual teeth received higher scores than the plastic teeth did in all of these subcategories (Table 11)]. They were negative about replacing extracted human teeth with plastic teeth. These results emphasise the added value of virtual teeth in dental education alongside extracted and plastic teeth. In particular, the properties of general shape and colours of the virtual teeth were considered very similar to those of the extracted teeth. Regarding caries, the participants negatively evaluated the appearance of the caries in the plastic teeth, whereas the virtual caries were rated much more positively. They were more critical about the colour of the caries, but they still rated the virtual teeth higher than the plastic teeth. The results for the statements in Category E concerning the resemblance of the restoration were ambiguous. A possible explanation could be that only one tooth with an occlusal amalgam restoration was shown and no teeth with composites or fillings with other shapes or material. This may have made it difficult for the participants to make a clear judgement or recommendation. In a future study, more restorations in different teeth should be rated to study the feasibility of replacing extracted restored teeth in dental education. One limitation related to the statements in Categories C, D and E is that is it very difficult to define exactly what the 'replacement' of reality is. In this study, the teeth were considered feasible replacements in dental education as long as the resemblance of the different parts was 'sufficient for learning'.

In another study, a multilayered virtual tooth model was developed for a dental training system.[12] In that study, the authors mainly focused on creating a model (by Micro-CT) with realistic force feedback. They managed to create a virtual tooth with two different degrees of hardness (dental tissue and pulp), but no attention was devoted to improving the realism of the virtual teeth by adding colours. The authors state that the sense of reality should be increased. In the current study, the appearance of the virtual teeth was the sole focus. An evaluation of the hardness of the teeth will be included in a future study. In addition to evaluating the 'look' and 'feel', a virtual tooth should be placed in the complete context of a learning environment to evaluate its potential for replacing extracted human teeth.

In general, the dentists were very positive about the virtual teeth and certainly saw their potential for replacing plastic teeth. The teachers, although more critical, were still cautiously positive about the virtual teeth. They emphasised the importance of using extracted human teeth because they show more 'history', such as demineralised enamel or occlusal wear. The master's degree students were critical in their comments; the results of the questionnaire showed that they incorporated other experiences they had encountered using the Simodont dental trainer during their earlier education. These negative experiences of the students were acquired during the early 'test implementation' of the Simodont dental trainer. When the virtual learning environment was still in full development, the students had a few sessions on the Simodont dental trainer and in Category F some students referred to this experience. The negative experiences consisted mainly of 'the feeling is not realistically enough yet to replace extracted teeth'. In this study, their experience on the dental trainer was not questioned. The bachelor's degree students indicated in their comments that the virtual teeth might be useful in addition to human and plastic teeth. They considered learning experiences with plastic teeth relevant as well, which could be a result of the fact that the students were working with plastic teeth in their curriculum at the time of the study. Therefore, they may have viewed the future learning possibilities from a different perspective.

Instead of presenting photographs to the participants for this study, it was considered to present the actual models of the human extracted teeth, the virtual teeth and plastic teeth in three dimensions. Meaning, the real extracted tooth, a Simodont dental trainer in which the virtual tooth could be viewed in 3D and the real matching plastic tooth. This procedure was tested and was considered to be impractical for a large number of participants. It was decided that it was preferable to use a large group of participants rather than a small group with seemingly more realistic teeth.

The participants were not divided equally amongst the groups. Dentists working in general practice were present in a large number during the execution of the study. The number of faculty members is limited in a dental school, and therefore, that group was much smaller; however, the participants in the 'teacher' group represent a relatively large percentage of the pre-clinical teacher's group at our school. Nonetheless, the difference in size compared with the other groups makes the probability of finding differences between groups smaller. Bachelor's degree students and master's degree students were more evenly divided and available in sufficient numbers.

The participants were selected and grouped according to their level of experience in dentistry. Dentists in general practice have extensive clinical experience. The teachers, in addition to their clinical experience, have experience in traditional education and may be comfortable with the contemporary situation. With the introduction and application of new technologies, they might offer a different (more critical) appraisal. Master's degree students have (limited) clinical experience, in addition to their extensive experience with plastic teeth. Bachelor's degree students have extensive experience working with plastic teeth, so they can note their advantages and shortcomings easily.

An advantage of using virtual teeth, which appear realistic, is that students directly learn to deal with carious lesions in the same way that they would in a patient instead of learning skills on plastic teeth in a phantom head. Therefore, the preparation design is based on the patient's history and the extent of the dental caries instead of the shape of a standardised preparation.[13] In addition, all of the students can work with the same case or tooth, which makes standardisation possible.

Conclusion

This study showed that the virtual teeth resembled the extracted human teeth more closely than the plastic teeth did and therefore were considered more realistic.

All of the participants expected to learn more from the virtual teeth than from the plastic teeth, but less from the virtual teeth than from the extracted human teeth. They all stated that the virtual teeth, although not (yet) suitable for replacing extracted teeth, are a useful additional learning asset. Further research on haptic feedback in virtual teeth is necessary before they can completely replace extracted human teeth in (pre)clinical dental procedures.

REFERENCES

1. Suebnukarn S, Phatthanasathiankul N, Sombatweroje S, Rhienmora P, Haddawy P. Process and outcome measures of expert/novice performance on a haptic virtual reality system. J Dent 2009: 37: 658–665.
2. Okuda Y, Bryson EO, DeMaria S Jr, et al. The utility of simulation in medical education: what is the evidence? Mt Sinai J Med 2009: 76: 330–343.
3. Aggarwal R, Tully A, Grantcharov T, et al. Virtual reality simulation training can improve technical skills during laparoscopic salpingectomy for ectopic pregnancy. BJOG 2006: 113: 1382–1387.
4. Francis HW, Malik MU, Diaz Voss Varela DA, et al. Technical skills improve after practice on virtual-reality temporal bone simulator. Laryngoscope 2012: 122: 1385–1391.
5. Burden C, Oestergaard J, Larsen CR. Integration of laparoscopic virtual-reality simulation into gynaecology training. BJOG 2011: 118 (Suppl 3): 5–10.
6. De Boer IR, Wesselink PR, Vervoorn JM. Creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education. Eur J Dent Educ 2013: 17: 191–197.
7. Kim L, Park SH. Haptic interaction and volume modelling techniques for realistic dental simulation. Vis Comput 2006: 22: 90–98.
8. Dominici JT, Eleazer PD, Clark SJ, Staat RH, Scheetz JP. Disinfection/sterilization of extracted teeth for dental student use. J Dent Educ 2001: 65: 1278–1280.
9. Philips J, Berge ZL. Second life for Dental Education. J Dent Educ 2009: 73: 1260–1264.
10. Kato A, Ohno N. Construction of three-dimensional tooth model by micro-computed tomography and application for data sharing. Clin Oral Invest 2009: 13: 43–46.
11. http://www.frasaco.de/fileadmin/epaper-Lieferprogramm_2014_deutsch/#/8. Date accessed: 15 January 2011.
12. Yoshida Y, Yamaguchi S, Kawamoto Y, Noborio H, Murakami S, Sohmura T. Development of a multi-layered virtual tooth model for the haptic dental training system. Dent Mater J 2011: 30: 1–6.
13. Fugill M. Defining the purpose of phantom head. Eur J Dent Educ 2013: 17: e1–e4.

Part II

Validation of assumptions for the development of a virtual reality environment

Student performance and appreciation using 3D vs. 2D vision in a virtual learning environment

I.R. de Boer
P.R. Wesselink
J.M. Vervoorn

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ABSTRACT

Aim

The aim of this study was to investigate the differences in the performance and appreciation of students working in a virtual learning environment with two (2D)- or three (3D)- dimensional vision.

Materials and methods

One hundred and twenty-four randomly divided first-year dental students performed a manual dexterity exercise on the Simodont dental trainer with an automatic assessment. Group 1 practised in 2D vision and Group 2 in 3D. All of the students practised 5 times for 45 minutes and then took a test using the vision they had practised in. After test 1, all of the students switched the type of vision to control for the learning curve: Group 1 practised in 3D and took a test in 3D, while Group 2 practised in 2D and took the test in 2D. To pass, three out of five exercises had to be successfully completed within a time limit. The students filled out a questionnaire after completing test 2.

Results

The results show that students working with 3D vision achieved significantly better results than students who worked in 2D. Ninety-five percent of the students filled out the questionnaire, and over 90 percent preferred 3D vision.

Conclusion

The use of 3D vision in a virtual learning environment has a significant positive effect on the performance of the students as well as on their appreciation of the environment.

INTRODUCTION

The use of a simulator or a virtual learning environment to train and educate students and professionals in the medical field (e.g., endoscopic surgery[1], laparoscopic surgery[2] and dental simulators[3-6]) has been common for some years now. In addition, patient safety and a focus on quality of care and education are increasingly important[7]. Due to technical limitations, early simulators only had two-dimensional (2D) vision. In neuroendoscopic surgery, it was found that the use of 2D vision impaired depth perception and the ability to estimate size.[8] With further technological developments in three-dimensional (3D) vision, for example in gaming, gradually more simulators have been designed with this technology. It has been suggested that competency within dentistry requires good perceptual and visual skills, both for gathering information and for judging the positions, distances, and sizes of objects.[9] Therefore, the application of 3D vision in dental simulators may be relevant. Studies on the effect of using 3D vision in laparoscopy have published a wide variety of results, supporting both an improved performance with 3D vision as well as equivalency of the results with 2D vision.[10]

The use of 3D vision implies that users always need to wear special 3D glasses to acquire a single image, and some people experience problems with viewing in 3D vision[11] or report symptoms of eye strain while using these glasses. Additionally, the use of 3D vision in a dental trainer has consequences for the design which is more complex and possibly more expensive since special 3D or multiple projectors are required.

The purpose of this study was to investigate the effect of using 3D versus 2D vision on the performance and appreciation of the students in a virtual learning environment.

MATERIALS AND METHODS

To investigate the effects of 3D versus 2D vision, the MOOG Simodont dental trainer ®, a virtual learning environment with haptic feedback, was used (Figure 1). The Simodont dental trainer is a simulator consisting of a force feedback robotic arm connected to software in such a way that every movement of the arm is visualised on a screen. A separate computer containing the courseware with lesson programmes and virtual patients is attached to the simulator.[12, 13]

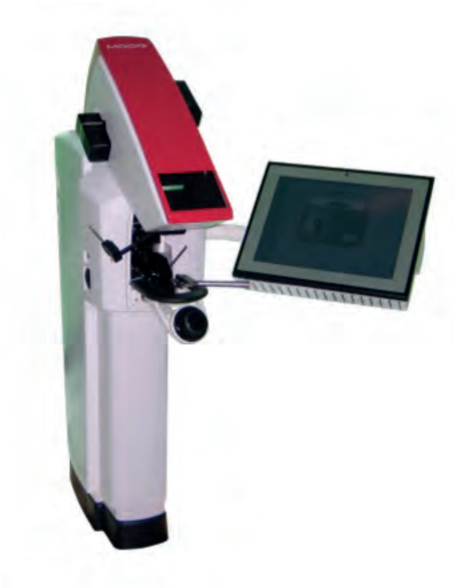

Figure 1. The MOOG Simodont dental trainer.

Stereoscopic (3D) vision in the Simodont dental trainer

The dental trainer is equipped with two digital multimedia projectors from LG®, type HS 101 (resolution 800 × 600) (Figure 2). The acquisition of 3D vision in the dental trainer is based on the projection of two images superimposed onto the same screen through a polarising filter. To obtain a single 3D image, all of the students wear passive circular polarised glasses (3D Optix, Gent, Belgium) (Figure 2).[14] One eye receives the left circular polarised image, and the other eye receives the right polarised image, which results in the reception of one 3D image. Extensive research on the interpupillary distance (IPD) of humans has shown that the vast majority of adults fall within the range of 50 to 70 mm[11]; the IPD between the right and left pupil was set at 60 mm in this study. The eye distance to the object in the dental trainer was set at 30 cm.

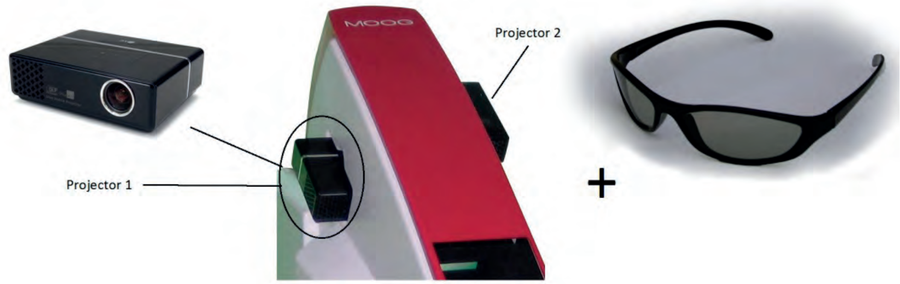

Figure 2. The two projectors in the dental trainer combined with the glasses were used to obtain a 3D vision.

2D vision in the Simodont dental trainer

During the experiment, half of the group practised and tested with 2D vision. This vision was obtained by turning off one of the two projectors in the dental trainer, which resulted in 2D vision because only one image was projected onto the screen (Figure 2).

Experimental protocol

One hundred and twenty-four first-year students were randomly divided into two groups. None of the students had previous experience in cutting a tooth or working in a virtual learning environment. The students received a short introduction to explain that a study would take place during their training on the dental trainer. Arrangements were made with the examination committee of the dental institute to prevent students from experiencing disadvantages in their education and to provide all of the students with the same education and the same conditions for assessment.

During the study, all of the students had to use their personal ID card to log in to the system, which ensured that all of their results were saved in the database and that they practised on the assigned preparation (Figure 3)that was available in their personal 'waiting room'. Both Group 1 and Group 2 consisted of 62 students who practised five times for 45 minutes in scheduled sessions. For the first test, Group 1 practised in 2D vision, and Group 2 practised in 3D vision. All of the students in both the 2D and 3D vision groups had to wear polarised glasses during the practise sessions and when testing to keep all of the circumstances equal. The students were familiar with the type of vision they were working in. Experience gained from earlier education on the dental trainer had shown that 45 minutes is approximately the maximum amount of time a student can focus while working in the Simodont dental trainer before showing symptoms of eye strain. After five practise sessions, the students took the test during session six. Every student tested in the same vision that they had practised with. To pass the test, three out of five exercises had to be completed successfully within 45 minutes. An exercise was completed successfully if 90% of the red target area (2 branches that were 7.0 mm long by 1.5 mm wide by 1.5 mm deep crossing each other in the middle) had been removed and the beige container (a cube that was 10.0 mm long by 10.0 mm wide by 2.0 mm deep and contained the preparation) was completely intact. The green area is called the leeway space (adding 0.2 mm on the bottom and on every side of the target area), and the students were allowed to remove this area completely, but it was not a requirement to pass the test (Figure 3). Students were allowed to enlarge the image from 100% to 125% of the original size of the image. The rotation of the block was limited to 90º to the left and 90º to the right.

After the completion of Test 1, Group 1 switched from 2D to 3D vision, and Group 2 switched from 3D to 2D vision. Again, five practise sessions were conducted, and then the students took the test with the same vision in which they had just practised. The division of the groups was performed to control for the learning curve that was likely to be present between the first and the second test. Table 1 shows an overview of the study design.

Figure 3. Cross preparation manual dexterity exercise.

Table 1. Study design of the experiment.

	Group 1	Group 2
Practise (5*45 min)	2D	3D
Test 1	2D	3D
	SWITCH	
Practise (5*45 min)	**3D**	**2D**
Test 2	3D	2D
	Questionnaire	Questionnaire

Questionnaire

After the completion of both tests, each participant completed a questionnaire (Table 2). The questionnaire consisted of sixteen comparative rating scale questions and one closed question in which students marked their preference for either 2D or 3D vision. A paired t-test was performed on the data collected using the questionnaire (Q1-Q12).

The data collected using the questionnaire and the data collected during both tests were statistically analysed using Statistical Package for Social Science (SPSS) 21.0 (SPSS, Chicago, IL, USA).

Table 2. Questionnaire

Category A	**2D vs. 3D**
Design	Comparative rating scale question
Answer model	5-point Likert scale: 1 (Completely disagree) – 5 (Completely agree)
Number	**Statement**
1	There is sense of depth in 2D
2	There is sense of depth in 3D
3	Passing the test in 2D is possible
4	Passing the test in 3D is possible
5	There was sufficient time for the test in 2D
6	There was sufficient time for the test in 3D
7	During the 2D education, I acquired manual dexterity
8	During the 3D education, I acquired manual dexterity
9	The use of the drill was realistic (2D)
10	The use of the drill was realistic (3D)
11	My eyes got tired whilst working in 2D
12	My eyes got tired whilst working in 3D
13	It was easier to find the model in 3D vision than in 2D vision
14	I work faster in 3D than in 2D
15	Testing in 3D was easier than in 2D
16	In 2D, I depended more on the force feedback than in 3D

Category B	**Preference**
Design	Closed Question
Answer model	2D or 3D

RESULTS

After the completion of Test 1 and Test 2, one student of the 124 participants was removed from the data collection because only one test was completed. Table 3 shows general information on the participants for Test 1, Test 2 and the questionnaire. One hundred and fifteen students filled out the questionnaire after the completion of both tests.

Table 3. General information about the participants for Test 1, Test 2 and the questionnaire.

	Test 1		Test 2		Questionnaire
	2D	3D	2D	3D	
Male	24	21	21	24	40
Female	39	39	39	39	73
Gender unknown	0	0	0	0	2
Total	63	60	60	63	
Total number of participants	123		123		115

The average age of the participants who filled out the questionnaire was 20.3 ± 2.7 years. The ages of the participants for Test 1 and Test 2 were not recorded.

Table 4 shows the results of Test 1 and Test 2. A chi-squared test was performed on the data of both tests. Results for Test 1 showed a chi-squared value of 4.639 (P = 0.031), Test 2 showed a value of 5.043 (P = 0.025).The differences were statistically significant for both tests, showing significantly better results of the students when working in 3D.

Table 4. Results of Test 1 and Test 2.

	Passed (N)	Failed (N)	Total (N)	Total (N) per Test
Test 1 - 2D	13 % (8)	87% (55)	63	123
Test 1 - 3D	28 % (17)	72% (43)	60	
Test 2 - 2D	42% (25)	58% (35)	60	123
Test 2 - 3D	62% (39)	38% (24)	63	

Table 5 shows the mean drilling time to pass the test. The results of the t-test for Test 1 (P=0.636) and Test 2 (P=0.332) showed no statistically significant differences.

Table 5. Results of “Time to pass the test” of Test 1 and Test 2.

	2D (sec.)	3D (sec.)
Test 1	227	214
Test 2	207	190

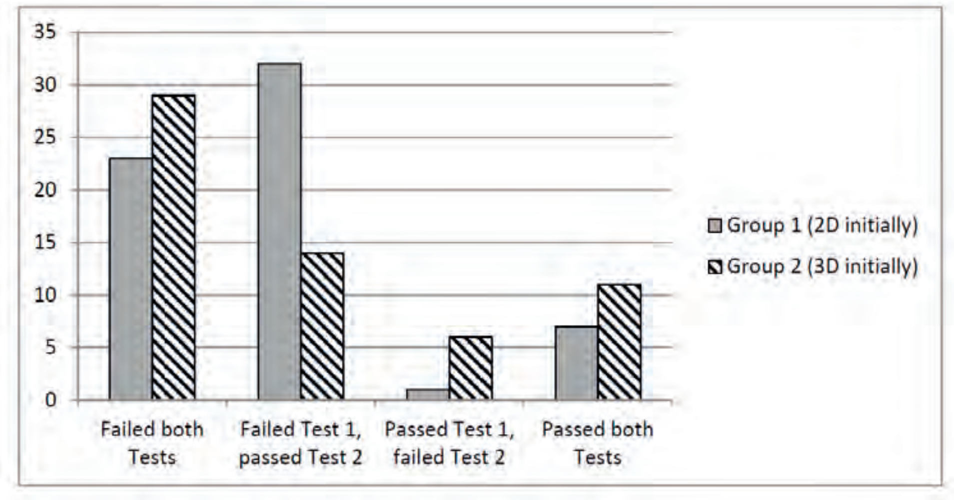

Figure 4. The results on Test 1 and 2 of Group 1 and Group 2, divided and specified.

Figure 4 shows the number of participants of Group 1 and Group 2 who failed both tests, who Failed Test 1 and passed Test 2, who Passed Test 1 and failed Test 2 and who passed both tests. The *post-hoc* tests per sub-category shows there is only a statistically significant difference between the sub-categories 'Passed Test 1, failed Test 2' and 'Failed Test 1, passed Test 2' (P = 0.033).

Questionnaire

Table 6 shows that 93% of the participants preferred to work in 3D.

Table 6. Preferences of the participants who took Test 1 and Test 2 and who filled out the questionnaire.

Preference	N	%
2D	6	5%
3D	107	93%
Unknown	2	2%
Total	115	100%

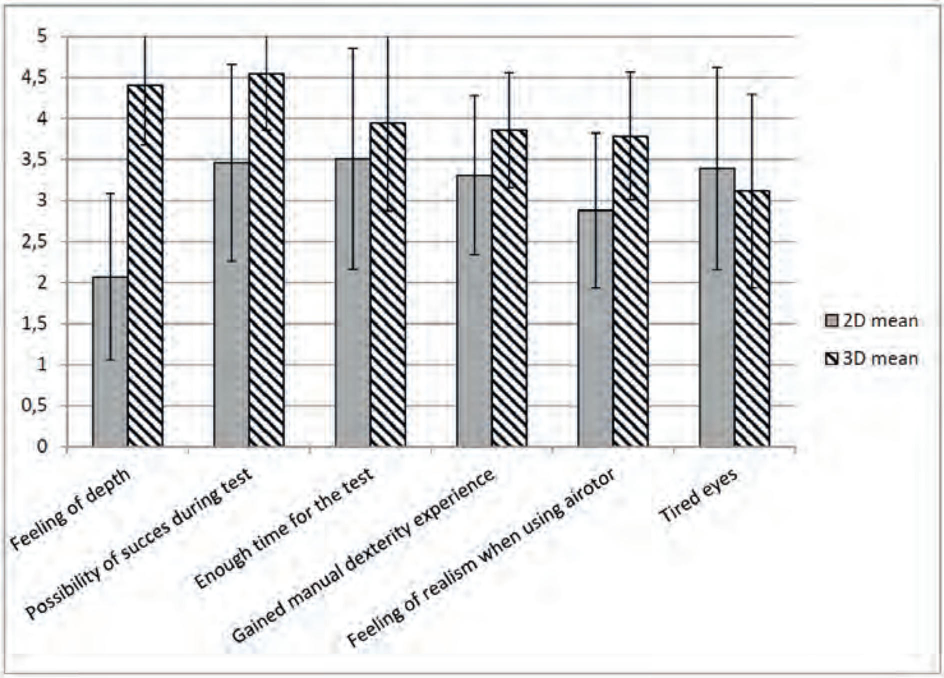

Figure 5. Results of the paired questions on the questionnaire that compared the aspects of working in 2D vs. 3D. This figure is based on the results shown in Table 7.

Table 7. Results of the paired questions on the questionnaire shown in table 1, including the P-values.

	N	2D mean + SD	3D mean + SD	P-value
Q1/Q2 (feeling of depth)	115	2.07 ± 1.015	4.41 ± 0.736	<0.001
Q3/Q4 (possibility of success)	114	3.46 ± 1.198	4.55 ± 0.692	<0.001
Q5/Q6 (sufficient time)	115	3.51 ± 1.347	3.95 ± 1.075	<0.001
Q7/Q8 (gained experience)	114	3.31 ± 0.97	3.86 ± 0.702	<0.001
Q9/Q10 (feeling of realism)	114	2.88 ± 0.942	3.79 ± 0.781	<0.001
Q11/Q12 (eye strain symptoms)	115	3.39 ± 1.233	3.12 ± 1.178	0.009

Table 7 shows the results of the paired samples t-test. The categories “feeling of depth”, “possibility of success during test”, “enough time for test”, “gained manual dexterity experience”, and “feeling of realism” were rated significantly higher in 3D than in 2D when using the air rotor. The category “tired eyes” shows that the participants experienced eye strain symptoms more often in 2D vision than in 3D.

Table 8. Mean values of the unpaired questions in the questionnaire.

	N	Mean + SD
Q13 (finding the model in 3D was easier)	113	4.25 ± 0.851
Q14 (work faster in 3D than in 2D)	115	4.05 ± 0.990
Q15 (testing in 3D was easier)	114	4.26 ± 0.922
Q16 (higher dependence on force feedback in 2D)	115	3.63 ± 1.143

Table 8 shows the mean values for questions 13 – 16. 3D vision was more appreciated than 2D vision and was rated higher when students were asked about finding the subject in space (Q13), time efficiency (Q14), and when taking the tests (Q15). Question 16 shows that participants reported a higher score for their dependence on the force feedback in addition to sight, when working in 2D vision than when working in 3D.

DISCUSSION

In this study, the differences in performance and appreciation of the students working in a virtual learning environment with 2D or 3D vision were investigated. During the experiment, the students were aware of the type of vision that they were working with because it was impossible to keep this information unknown. If a student looked at the screen without glasses, it was very clear to see whether there were two images (3D) or one image (2D). Students pointed out in the questionnaire that working in 2D vision while wearing glasses was unpleasant. This was a requirement during the experiment to keep all circumstances comparable between testing in 3D and 2D vision. The probable reason for the unpleasantness of working with polarized glasses in 2D vision is that only one eye received an image through the polarized glasses, because only one of the two projectors emitted an image. The glasses that were used in this study did not completely block the vision of the 'other' eye. This was tested before the study took place. This means that the students had binocular vision when working in 2D.

Prior to this study, students reported a wide range of positive and negative views regarding working in 3D vision. Studies have shown that 5-10% of the population has stereo blindness.[11] In addition, the use of 3D vision is more expensive and complicated than using 2D vision. These factors led us to test both 3D and 2D vision in a virtual learning environment. The results of this study show that significantly more students passed while working in 3D vision than in 2D vision on both tests. With both tests in 2D and 3D, students performed better during Test 2, results show that there was a statistically significant difference between the group 'Passed Test 1, failed Test 2' and the group 'Failed Test 1, passed Test 2', which is probably the consequence of a learning effect having practiced twice as long before Test 2 than Test 1. The data also showed that working with 3D vision was preferred in every aspect by the students.

This study shows the importance of the use of 3D vision in a virtual learning environment. Previous studies have been published regarding the effectiveness of laparoscopic training using 2D vs. 3D vision. One study showed that the use of 3D imaging offered significant advantages in the teaching of laparoscopic skills to inexperienced individuals.[2] Another study showed that the use of 3D vision compared with 2D vision in laparoscopic suturing and knot tying resulted in a 25% increase in the speed and accuracy of these laparoscopic tasks when working in 3D vision.[1] In addition, several studies in general surgery concluded that task errors, task time and learning time were all decreased when 3D vision was used.[8] However, the use of this technique also has disadvantages. Stereoscopic projection is never perfect because there is some leakage of the left eye image into the right eye and vice-versa. This leakage results in 'ghosting' [15, 16], or showing an (unclear) second image that is visible next to the main object. The previously mentioned incidence of stereo blindness in a (small) part of the population is an additional disadvantage of a 3D learning environment.

In this study, the differences in the results between the male participants and the female participants were also evaluated. The chi-squared test showed no significant differences for Test 1 ($P = 0.184$) or Test 2 ($P = 0.179$). The differences in 'time to pass the test' were also evaluated within the data (Table 6), and students were shown to pass both tests faster using 3D vision. However, these results were not statistically significant. In this study, 'to pass as fast as possible' was not an instruction when assigning the tests, so the students may not have been focusing on the time used during testing. The actual difference in 'time to pass a test' should be investigated in a future study. Given our preliminary results, we would expect students to complete the test in a shorter working time with 3D vision than with 2D vision. Finding the model in space with an instrument was significantly more appreciated in 3D vision, indicating that the orientation in space is more difficult with 2D vision because there is no depth perception. Related to this finding, students reported more eye strain symptoms when working in 2D vision. In this study, only 'novices' were evaluated with no prior working experience with an air rotor. A future study performed with 'experts' in the dental field would show whether 3D vision is also preferred by experienced professionals.

CONCLUSION

Our results show that students perform significantly better at a manual dexterity exercise in a virtual learning environment when working in 3D vision compared with 2D vision. These objective results are supported by the subjective results of the questionnaire. Our results also show that the vast majority of students preferred to work in 3D vision in the virtual learning environment. Based on the results of this study, we concluded that 3D vision is a useful asset to a virtual learning environment.

REFERENCES

1. Durrani AF, Preminger GM. Three-dimensional video imaging for endoscopic surgery. Comput Bio Med 1995: 25: 237–247.
2. Votanopoulos K, Charles Brunicarid F, Thornby J, Bellows CF. Impact of three-dimensional vision in laparoscopic training. World J Surg 2008: 32: 110–118.
3. Ilhan Konukseven E, Ercument €Onder M, Mumcuoglu E, Sukru Kisnisci R. Development of a visio-haptic integrated dental training simulation system. J Dent Educ 2010: 74: 880–891.
4. Ben GG, Weiss EI, Gafni N, Ziv A. Preliminary assessment of faculty and student perception of a haptic virtual reality simulator for training dental manual dexterity. J Dent Educ 2010: 75: 496–504.
5. Rose JT, Buchanan JA, Sarrett DC. The DentSim system. J Dent Educ 1999: 63: 421–423.\
6. Steinberg AD, Bashook PG, Drummond J, Ashrafi S, Zefran M. Assessment of faculty perception of content validity of PerioSim, a haptic-3D virtual reality dental training simulator. J Dent Educ 2007: 71: 1574–1582.
7. Okuda Y, Bryson EO, DeMaria S Jr, et al. The utility of simulation in medical education: what is the evidence? Mt Sinai J Med 2009: 76: 330–343.
8. Fraser JF, Allen B, Anand VK, Schwartz TH. Three-dimensional neurostereoscopy: subjective and objective comparison to 2D. Minin Invas Neursosurg 2009: 52: 25–31.
9. Dimitrijevic T, Kahler B, Evans G, Collins M, Moule A. Depth and distance perception of dentists and dental students. Oper Dent 2011: 36: 467–477.
10. Tanagho YS, Andriole GL, Paradis AG, et al. 2D Versus 3D visualization: impact on laparoscopic proficiency using the fundamentals of laparoscopic surgery skill set. J Laparoendosc Adv Surg Tech A 2012: 22: 865–867.
11. Lambooij M, IJsselsteijn W, Fortuin M, Heynderickx I. Visual discomfort and visual fatigue of stereoscopic displays: a Review. J Imaging Sci Technol 2009: 53: 030201–030214.
12. De Boer IR, Wesselink PR, Vervoorn JM. Creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education. Eur J Dent Educ 2013: 17: 191–197.
13. De Boer IR, Lagerweij MD, Wesselink PR, Vervoorn JM. Evaluation of the appreciation of virtual teeth with and without pathology. Eur J Dent Educ 2015: 19: 87–94.
14. http://www.3doptix.be/Gepolariseerde-3D-brillen/vmchk.html Accessed: 15 March 2014.
15. http://paulbourke.net/stereographics/stereorender/ Accessed: 26 September 2014.
16. Siegel M. Perceptions of crosstalk and the possibility of a zoneless autostereoscopic display. Proc SPIE 2001: 4297: 34–41.

The effect of force feedback in a virtual learning environment on the performance and satisfaction of dental students

I.R. de Boer
M.D. Lagerweij
M.W. de Vries
P.R. Wesselink
J.M. Vervoorn

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ABSTRACT

Introduction

This study investigated the effect of force feedback (FFB) on student performance in a virtual learning environment (VLE) using the Simodont dental trainer (Moog, Nieuw-Vennep, the Netherlands) and evaluated the students' satisfaction with and without FFB.

Methods

The Simodont dental trainer, which was used as a VLE, was randomly assigned to 101 first-year dental students with no previous experience in cutting a tooth or working in a VLE with FFB. This study was designed as a crossover study. One half of the students practiced without FFB, whereas one half practiced with FFB. Both groups practiced four sessions lasting 45 minutes on a cross preparation. In the fifth session, test 1 was scheduled. After test 1, the same practicing and testing protocol was followed, although the environment was switched. After test 2, participants filled out a questionnaire. For the statistical analysis, only the questionnaires of the students who participated in both tests were processed.

Results

The results of test 1 and test 2 revealed that only students who used FFB were able to pass the tests. The questionnaire outcomes supported the results of both tests; 100% of the students preferred working with FFB.

Conclusion

The results suggest that FFB is important for performance in a VLE and essential for satisfaction.

INTRODUCTION

In a dental curriculum, preclinical training offers students the opportunity to develop manual dexterity and master various clinical procedures before treating real patients in a clinic. However, conventional preclinical training methods are associated with several limitations, such as a shortage of learning materials like available extracted teeth with the appropriate pathology for students to acquire the right skills and competence.[1] Alternatives introduced in the late 1990s—primarily virtual reality (VR) and haptics—are nearing their potential to complement these conventional methods.[2]

At its simplest, VR systems provide an artificial environment that users can experience through sensory stimuli provided by a computer or a VR simulator, wherein the occurrences are partly determined by the user's actions.[3] In the fields of medicine and dentistry, simulation and VR are used for training and education in surgery and anesthesiology,[4,5] with the aim of simulating the actual clinical environment as closely as possible.[6]

The realism of VR training is increased by the use of haptics, which provide the user with tactile sensations through a process known as force feedback (FFB).[7] In brief, when a user touches an object in the virtual world, the material can be felt through a haptic hand piece. The FFB allows a learner to obtain the feel of an invasive procedure in a virtual learning environment (VLE).[5,8] The use of haptic technology is particularly advantageous in the field of dentistry because the development of psychomotor and contact-mediated tactile skills is a major part of training.[9] Haptics can distinguish between expert and novice performances in complex haptic procedures.[10] However, no studies have established the performance benefits of haptics (i.e., FFB) in a dental VLE task.

For this study's purposes, the Moog Simodont dental trainer (Nieuw-Vennep, the Netherlands) was used, which is specifically developed as a haptic interface for dental students.[1] It is still under development and regularly updated to improve its technical behavior, to allow it to resemble reality as closely as possible, and to provide new theoretical content for use in the curriculum. The beginning of the development of the Simodont dental trainer in 2007 was based on limited evidence at that time,[11] expectations (e.g., the expectation of students to work with three-dimensional [3D] vision[12]) and assumptions (e.g., FFB is necessary for good performance). The dental trainer was simultaneously implemented in the curriculum during the process of development. During implementation it was assessed whether assumptions made at the beginning of development were accurate and to check if the quality of several aspects of the dental trainer is adequate for students to learn and acquire skills: a previous study[12] assessed the impact of 3D vision on the performance of students in the VLE provided by the Simodont dental trainer and determined their opinions via a questionnaire. The results revealed significantly better student performance and satisfaction with the use of 3D vision.

In the present study, the tested assumption was that FFB affects the performance and satisfaction of students working in a VLE. The null hypothesis was that FFB is not associated with the acquisition of manual dexterity by students.

METHODS

In total, 101 first-year dental students with no previous experience in cutting a tooth or working in a VLE with FFB were included in this study. Each student was informed before the experiment that they would be part of a study during their scheduled training in the VLE. The ethical review committee of the Academic Centre for Dentistry Amsterdam (ACTA, Amsterdam, the Netherlands) approved the study protocol. Arrangements were made with the Board of Exams of the Dental Institute to avoid students from facing disadvantages in their education because of this experiment and to provide all students with the same education and conditions for assessment. All participants provided written consent for anonymous processing of their data and publication of their results.

FFB in the VLE

The FFB in the Simodont dental trainer comprises several components that collectively simulate the actual conditions for cutting in material. The amount of opposing force (i.e., FFB) from the dental trainer, measured at the specific point where the virtual drill touched the virtual material, has three components, as described below.

Hardness of the virtual material [1] × “Cut Speed Gain” [2] + “Push Force” [3] = FFB

1. The hardness of the material is expressed as a gray value. This gray value is a normalized value between 0 and 1 and is originally based on the gray value of the tooth scan, which shows different tooth tissues in the same manner as an X-ray. In addition, the hardness levels of the different tooth tissues were graded from 0 to 1, in which 0 is no FFB [i.e., no material, black in the scan with a gray value of (RGB 0, 0, 0) in the Red Green Blue code] and 1 is the highest [i.e., not possible to remove the material, gray value (RGB 255, 255, 255); Table 1]. The standard FFB level has a hardness comparable with that of dentin from a natural adult tooth. When this was translated to the scale for different tooth tissues, the pulp tissue was set at 0.05 (i.e., softest material), soft caries at 0.20, dentin at 0.6, enamel at 0.9, and amalgam at 0.95 (hardest material, but still possible to remove; Table 1).
2. The “Cut Speed Gain” indicates the ease with which the airotor removes the material. It is a value linked to the hardness of the material and gives a signal for a certain speed of the drill when in contact with a certain hardness. The softer the material, the easier the drill can remove the material.

3. The third component, the "Push Force," indicates the amount of force applied by the operator on the virtual material and its influence on components 1 and 2. If the user applies substantial pressure with the drill, the material is removed faster until a certain limit. If the user touches the material very gently, its removal will be slower.

Table 1. Normalized Hardness Values for Different Tooth Tissues Used in the VLE

Tissue	Hardness Value (Normalized)
Pulp Chamber	0.00
Pulp Tissue	0.05
Plaque	0.15
Caries (Soft)	0.18
Gingiva	0.30
Caries (Hard)	0.35
Calculus (New)	0.40
Spongy Bone	0.40
Cortical Jaw Bone	0.50
Calculus	0.55
Dentin	0.60
Calculus (Matured)	0.60
Enamel (Demineralized)	0.65
Glass Ionomer Cement	0.65
Resin-reinforced Glass Ionomer Cement	0.65
Pulp Stone	0.70
Composite	0.80
Enamel	0.90
Amalgam	0.95

This study was designed as a crossover study to investigate whether FFB is a requirement for working in a VLE for mastering a manual dexterity exercise (Table 2). One half of the students practiced without FFB (group 1), while one half practiced with FFB (group 2). All students were randomly assigned to both groups by a lottery ticket. The level of FFB that each group used during practicing and testing is shown in Tables 2 and 3. During all practicing sessions, a dental teacher was available for questions. Before beginning the experiment, the assignment and the procedures were explained during a lecture to all students. The assessment assignment was similar to the practice assignment, namely, the cross preparation (Fig. 1). The requirements for the test are explained in the "Testing Protocol: Test 1 and Test 2 section," which is written hereunder. The students who had practiced with FFB tested with FFB; students who had practiced without FFB tested without FFB. All students practiced and tested under both circumstances, but in a different order [(a randomly selected) half of the total group started with FFB and half without FFB, Table 2]. After test 2, the participants completed a questionnaire with categories A and B, which are shown in detail in Table 4. The complete experiment had a duration of 4 weeks (Table 2). For the statistical analysis, only the questionnaires of students who participated in both tests were processed (n = 75).

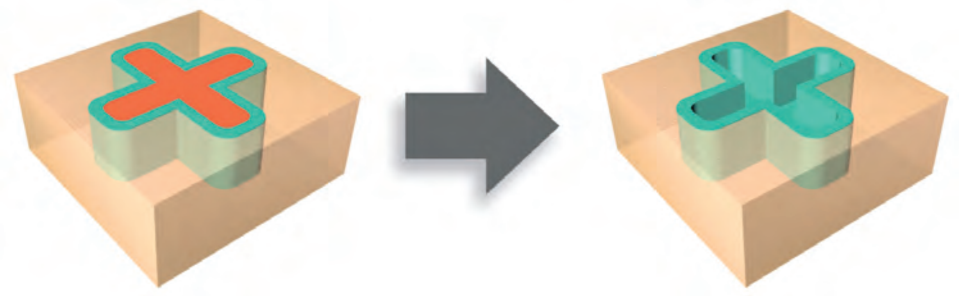

Figure 1. Manual dexterity exercise in the VLE. In the cross preparation, the red target area should be removed for 90%.

Table 2. The Cross-over Study Design for the Experiment, including practicing and testing moments.

Session	Week number	Day	Practicing (P) or Testing (T)	Group 1 Environment	Group 2 Environment
1	Week 1	Wednesday	P (45 minutes)	No FFB	Standard FFB
2	Week 1	Wednesday	P (45 minutes)	No FFB	Standard FFB
3	Week 1	Friday	P (45 minutes)	No FFB	Standard FFB
4	Week 2	Wednesday	P (45 minutes)	No FFB	Standard FFB
5	Week 2	Wednesday	T (45 minutes)	No FFB	Standard FFB
			Switch		
6	Week 2	Friday	P (45 minutes)	Standard FFB	No FFB
7	Week 3	Wednesday	P (45 minutes)	Standard FFB	No FFB
8	Week 3	Wednesday	P (45 minutes)	Standard FFB	No FFB
9	Week 3	Friday	P (45 minutes)	Standard FFB	No FFB
10	Week 4	Wednesday	T (45 minutes) + Questionnaire	Standard FFB	No FFB

Table 3. The Levels of Force Feedback Used in this Study

Level of FFB	0–1 Scale	Explanation
No FFB	0	The user received no FFB
Standard FFB	0.6	Hardness of dentin of an adult tooth

Testing Protocol of Test 1 and Test 2

A preparation for the tests was successfully completed if 90% of the red target area [two branches measuring 7.0 (length) × 1.5 (width) × 1.5 (depth) mm that crossed each other in the middle] was removed while the beige container (a cube measuring 10.0 × 10.0 × 2.0 mm and containing the preparation) remained completely intact. The students were allowed to remove the green area completely, known as the leeway space (adding 0.2 mm on the bottom and on every side of the target area), although it was not a requirement to pass the test (Fig. 1). Students were allowed to enlarge the image from 100% to 125%. Rotation of the block was limited within the system: 90 degrees to the left and 90 degrees to the right. To pass test 1 or test 2, three of five (i.e., cross) preparations had to be successfully completed within 45minutes. The maximum number of permitted manual dexterity preparations during the tests was 5. In addition, it was assured that the colors of the screen, the resolution of the projectors, and the 3D (depth) factor were all set values. The requirements for the test in this study are identical to the test that the students take regularly (not involved in an experiment) in their curriculum and are approved by the board of examinations. After test 2, the students completed a questionnaire. The data of each participant would solely be used if this protocol was followed precisely during the training sessions and test 1 and test 2.

Questionnaire

The questionnaire (Table 4) comprised eighteen comparative rating scale questions (category A) and one closed question (category B) in which the students marked their preference for working with or without FFB. The questionnaire was based on questionnaires used in previously published studies on the Simodont dental trainer.[12]

The questions in category A were set up in nine pairs in which the statements contradicted each other to ensure that the opinions given were consistent and independent of the question. The nine paired questions were bundled into two scales. Scale 1 reported on the students' satisfaction in their performance with FFB and without FFB, and scale 2 reported on the students' experience working with FFB and without FFB with regard to the human senses (i.e., vision, sound, fatigue). The first scale of questions marked a high score if a participant was in favor of working with FFB. The second scale of questions marked a low score if a participant was in favor of working with FFB. The average score of the questions in scale 1 and scale 2 working with FFB (questions 1, 3, 5, 7, 9, 11 and 13, 15, 17, respectively) and without FFB (questions 2, 4, 6, 8, 10, 12 and 14, 16, 18, respectively) were calculated (Figs. 2 A, B).

Table 4. Questionnaire Used in the Experiment: Working with or Without Force Feedback

Category A		FFB vs. No FFB
Design		Comparative rating scale question
Answer model		5-point Likert scale: "1" (completely disagree)–"5" (completely agree)
Number	Pair	Statement
Scale 1		**Questions concerning satisfaction about *performance* in working with FFB and without FFB**
1	1	Drilling with FFB was pleasant
2		Drilling without FFB was pleasant
3	2	Passing the test with FFB was possible
4		Passing the test without FFB was possible
5	3	There was sufficient time to pass the test with FFB
6		There was sufficient time to pass the test without FFB
7	4	Testing with FFB was easier than testing without FFB
8		Testing without FFB was easier than testing with FFB
9	5	The airotor was realistic without FFB
10		The airotor was realistic with FFB
11	6	Determining positions in space was feasible with FFB
12		Determining positions in space was feasible without FFB
Scale 2		**Questions concerning the experience of the human senses (vision, sound, fatigue) working with FFB and without FFB**
13	7	Sound was more important when drilling with FFB
14		Sound was more important when drilling without FFB
15	8	Working with FFB was tiring
16		Working without FFB was tiring
17	9	With FFB, my vision is most important
18		Without FFB, my vision is most important
Category B		**Preference FFB vs. No FFB**
Design		Closed Question
		My preference is working with or without FFB

Statistical Analyses

The data from the questionnaires and data collected during both tests were statistically analyzed using the Statistical Package for the Social Sciences software, Version 21.0 (SPSS, Chicago, Ill). The differences between groups in test 1 and test 2 were analyzed in a cross table using the $\chi 2$ test. The effect size of this difference was calculated using Cramer ϕ. The paired questions and the scales in the questionnaire were considered parametric and statistically analyzed using the paired samples t test. For all statistical analyses, the significance level α was 0.05.

RESULTS

Table 5. General Information of the Participants in the Experiment

Experiment 1	Test 1 (N)	Test 2 (N)	Questionnaire (N)
Male	36	29	27
Female	65	49	48
Total	101	78	75

As seen in Table 5, 101 and 78 students participated in test 1 and test 2, respectively. From these, only the data of 68 students who precisely adhered to the testing protocol were used for statistical analyses.

5

Table 6 shows that three students passed test 1 and fifty nine failed, whereas nine passed test 2 and fifty three failed. All students who passed the test did so during their turn working with FFB, whereas no student passed during their turn working without FFB. The χ2 test produced a value of 4.666 (P = 0.031) for the test 1 results and 7.114 (P = 0.008) for the test 2 results. To interpret the effects of FFB on passing scores, we performed an effect size calculation, which gave a ϕ score of 0.274 (P = 0.031) for test 1 and 0.339 for test 2 (P = 0.008). These values indicated a small effect (df* = 1, value between 0.1 and 0.3) for test 1 and a medium effect (df* = 1, value between 0.3 and 0.5) for test 2.

Table 6 . Results of Test 1 and Test 2

Original 90% Target Removal (0% Container Removal) 3 out of 5								
	No FFB				Standard FFB			
	Passed		Failed		Passed		Failed	
Test 1	N=0	0%	N = 37	60%	N=3	5%	N=22	35%
Test 2	N=0	0%	N = 25	40%	N=9	15%	N=28	45%

Table 7 shows the post hoc calculated test results with more sensitive metric. It shows the number of students who (would have) passed if only one cross preparation at 90% target removal would be sufficient to pass the test, and it shows the number of students that would have passed the test if one cross preparation with a target removal of 60% was sufficient (and ≤10% container removal). To analyze the differences between the groups, we performed a χ2 test for test 1 and test 2 for the 90% target removal group and the 60% target removal group, with the following results:

- Test 1, 90%target removal: the χ2 statistic is 19.7914. The P value is less than 0.001. The ϕ score is 0.0948.
- Test 1, 60% target removal (and ≤10% container removal): the χ2 statistic is 12.518. The P value is less than 0.001. The ϕ score is 0.0809.

- Test 2, 90%: the χ2 statistic is 21.2726. The P value is less than 0.001. The ϕ score is 0.0982.
- Test 2, 60% (and ≤10% container removal): the χ2 statistic is 16.3014. The P value is less than 0.001. The ϕ score is 0.0875.

All ϕ scores are less than 0.1 indicating a small effect for the post hoc analysis results.

Table 7. Results of Test 1 and Test 2 calculated with more sensitive metrics (post hoc), compared to the original test results.

Test 1						
	90% Target Removal (0% Container Removal) 3 of 5		**90% Target Removal**		**60% Target Removal (≤10% Container Removal)**	
	Passed (N=62)		*Passed (N=62)*		*Passed (N=62)*	
No FFB	0	0%	0	0%	18	29%
Standard FFB	3	5%	11	18%	23	37%
Test 2						
	Passed (N=62)		*Passed (N=62)*		*Passed (N=62)*	
No FFB	0	0%	1	2%	14	23%
Standard FFB	9	15%	23	37%	36	58%

Table 8 shows the results of the calculation to analyze the carryover effect between test 1 and test 2. It shows a significant effect in more students passing during test 2. The effect of the presence of FFB during the test and the combination of both mentioned factors (time and presence of FFB) show no significant result.

Table 8. Results of the calculation of the carry over effect between Test 1 and Test 2 General Linear Model.

Multivariate Tests[a]							
Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Passed yes/ no	Pillai's Trace	.806	254.167[b]	1.000	61.000	.000	.806
	Wilks' Lambda	.194	254.167[b]	1.000	61.000	.000	.806
	Hotelling's Trace	4.167	254.167[b]	1.000	61.000	.000	.806
	Roy's Largest Root	4.167	254.167[b]	1.000	61.000	.000	.806
FFB yes/ no	Pillai's Trace	.012	.717[b]	1.000	61.000	.401	.012
	Wilks' Lambda	.988	.717[b]	1.000	61.000	.401	.012
	Hotelling's Trace	.012	.717[b]	1.000	61.000	.401	.012
	Roy's Largest Root	.012	.717[b]	1.000	61.000	.401	.012
factor1 * factor2	Pillai's Trace	.053	3.436[b]	1.000	61.000	.069	.053
	Wilks' Lambda	.947	3.436[b]	1.000	61.000	.069	.053
	Hotelling's Trace	.056	3.436[b]	1.000	61.000	.069	.053
	Roy's Largest Root	.056	3.436[b]	1.000	61.000	.069	.053

Questionnaire

Figures 2A to D show the mean values of the responses to category A of the questionnaire. In total, seventy-five students completed the questionnaire. The error bars show the standard deviation value for each question. The average difference in the comparison of the questions in scale 1 of category A was 1.6, and the average difference in the comparison of the questions in scale 2 of category A was −0.8. Both differences were statistically significant. Each question within both scales contributed to the complete result.

Table 9 shows the results of the paired-samples test for the paired questions in Table 4. Significant differences were observed between the FFB and non-FFB conditions for all paired statements ($P < 0.05$).

The results for category B showed that 100%of the participants who completed the questionnaire preferred working with FFB.

Table 9. The Results for Category A of the Questionnaire

	With FBB	N	Std.	Without FFB	N	Std.	P-value
Scale 1							
Pair 1	4.8	75	0.42	1.3	75	0.68	0.000
Pair 2	4.4	75	1.72	1.9	75	1.01	0.000
Pair 3	3.9	75	0.80	3.1	74	1.24	0.000
Pair 4	4.6	74	0.71	1.2	75	0.55	0.000
Pair 5	4.1	75	0.75	2.1	73	1.05	0.000
Pair 6	4.2	75	0.81	1.6	75	0.97	0.000
Scale 2							
Pair 7	2.7	75	0.94	3.4	74	1.08	0.001
Pair 8	2.8	74	1.03	4.04	66	0.87	0.000
Pair 9	3.4	75	1.06	3.9	75	1.28	0.041

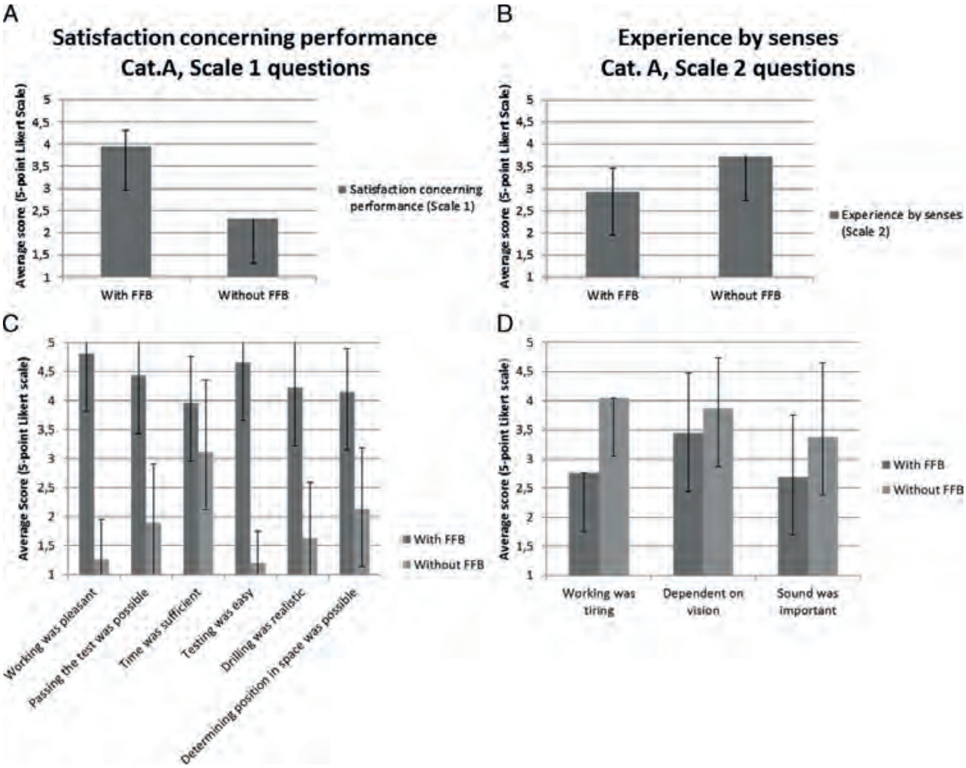

Figure 2. The mean values of the responses to category A of the questionnaire. A, The average scores of scale 1 questions from the questionnaire. The participants reported a high score in favor of working with FFB. B, The average scores of scale 2 questions from the questionnaire. The participants report a high score against working without FFB. C, The average scores of scale 1 questions. D, The average scores of scale 2 questions.

DISCUSSION

In the present study, we investigated the effect of working with or without FFB in a VLE (ie, Simodont dental trainer) on student performance. “Performance” in this experiment was defined as being able to properly work on the dental trainer and to acquire skills. The testing period was designed to investigate whether FFB was required to work on the dental trainer and not as a passing or failing moment for students. Dentists have to work very precisely, on a very small scale in the clinic. Sometimes during patient treatment, it is not possible to see the work area as properly as what the dentist would wish, and in that case, a dentist falls back on acquired experience working on the basis of feeling. Even if a dentist is working without vision or with indirect vision, the dentist knows what to expect and can perform the treatment guided by the “sense of touch” in the first place and vision in the second place.

The results showed that all students failed the test without FFB, thereby confirming the assumption made during the development of the dental trainer that FFB is required to perform in a VLE and should be incorporated in the (further) development. Therefore, the null hypothesis that FFB is not associated with the acquisition of manual dexterity by students may be rejected.

This study showed a low passing rate for working with FFB as well as without FFB. However, the group working with FFB performed significantly better. A possible explanation could be that the requirements of the tests were set too high, especially in consideration of the short period for practicing. The setting of this study took place during "real" educational circumstances. This was a very important aspect of the study, because the VLE is only used during education and thus has to prove itself within these circumstances in which students require a high level of performance of the dental trainer.

This study design was chosen (1) to work with a whole cohort of students to prevent the introduction of a selection bias in the group of participants; (2) to plan the study during the beginning of the curriculum, which assured that there was no "contamination" in the manual skills of the participants from other dental education; (3) to give students the ability to acquire fine motor skills distributed over multiple days during 4 weeks; and (4) to adhere to the testing requirements of tests during regular education, equal to testing conditions of past years, because these were approved by the board of examination.[13–15] The training sessions lasted 45 minutes each, which means that the whole study easily could have fit within 1 day. However, it is proven that distribution of practice is more efficient for psychomotor skills learning compared with massed practice.[13–15] Besides, working in the VLE requires a high level of focus and is therefore very tiring for students to work on; practicing too much in 1 day would probably have a negative effect.

To compensate for the result that only students with the availability of FFB were able to pass the test, a post hoc analysis was made to calculate the results in case the requirements of the test were lower (Table 7). These results showed that students were able to pass the test without FFB. However, the number of participants passing is significantly larger with FFB. In the post hoc test with a target removal of 60%, a container removal with a maximum of 10% was chosen. This value was selected because the original assignment was to keep the container score at 0%. If a score up until 10%was reached, only a very small mistake was made, and therefore, the attempt was judged as serious and useful for analysis.

The results also showed that no student passed any test without FFB, even when they had passed the first test with FFB. Visual information only may be insufficient to perform a manual dexterity task that requires a high level of precision within a short practicing time. Multiple studies in the area of neurophysiology underpin the requirement or necessity of haptics when performing a surgical task.[16–18] The absence of FFB may lead to applying excessive or insufficient forces, which may damage tissue.

A whole cohort of students participated in this study, rather than volunteers, to prevent the introduction of selection bias. At the beginning of the experiment, the participants numbered 101 students. However, the number included in statistical analyses was sixty-two students. This high dropout rate occurred because only those students who precisely adhered to the testing protocol were included in the statistical analyses to ensure clean results. The dropout rate was comparable for number in both groups. Sex and age of the participants that dropped out from both groups were comparable with sex and age of the included students; thus, statistical analysis could be performed. Many students who failed in test 1 continued making preparations during the test sessions while the experiment was ongoing, and thus, they exceeded the maximum number of permitted manual dexterity preparations (n = 5). This factor affected the practice duration, and therefore, the participants deviated from the testing protocol. To maintain similar conditions throughout the study and to maintain the data as uncompromised as possible, the data of these students were excluded from statistical analysis. The participants who were processed in the data adhered to the protocol during test 1 and test 2. If a student adhered to the protocol during the test 1 but did not during the training sessions before test 2, the complete data set from the participant was removed and not used for statistical analysis. All data of the students were saved in our database.

The number of students passing was higher in test 2 than in test 1, which suggests a learning curve and the presence of a carryover effect. Results in Table 8 show that significantly more students pass during Test 2, meaning that the time practiced in this experiment contributed to this result and therefore a learning curve is present. This does not apply to the presence of FFB or the combination of these both factors. There was no washout period because the experiment was scheduled within the running educational program. All students had the same learning period during the experiment.

In addition, during the progress of the curriculum contamination of the study was at risk because the students are starting with practical education in other areas of dental education. To keep all circumstances during the study as controllable as possible, this study took place during 4 weeks at the beginning of their study, in which no other manual dexterity education was planned. To isolate the effect of working with or without FFB, other possible confounding factors were established as much as possible during the practicing and testing session and were identical to all participants (see Testing Protocol: Test 1 and Test 2).

The Simodont dental trainer was developed to allow students to practice independently; the system provides the students with feedback on their achieved scores. A teacher was present during all training sessions, but the students worked primarily independently on manual dexterity exercises.

In addition to the results of performance, 100% of the students reported in the questionnaire that they preferred working with FFB. We decided to record the questionnaire once after the test 2, so that all questions were a comparison between “with FFB” and “without FFB.” The participants stated that it was very difficult to orientate themselves in space without being able to press on the material and receive tactile feedback. The results of the questionnaire showed that the students were significantly more positive about working with FFB than about working without FFB from all aspects and that they had to depend more on their vision when working without FFB. All nine paired questions in the questionnaire showed a significant result in favor of working with FFB. The setup of the paired questions in the questionnaire aimed to discriminate between the opinions/experiences of students working with and without FFB. All pairs were built as contradictory statements to ensure the consistency of the opinion of the students. This design was chosen to warrant for the internal validity.

Seventy-five questionnaires were processed for statistics, whereas sixty-two students adhered to the protocol during test 2. All seventy-five participants filled out a questionnaire after test 2, whereas the first twenty-six students were already excluded after test 1. During the processing of the data after test 2, an extra of 13 students had to be removed before statistical analyses were possible, which resulted in sixty-two participants. All questionnaires were filled out anonymously, and thus, the excluded students could not be removed from the questionnaire data set. To ensure that the results of the questionnaire remained clean, the consistency of the answers of all students was examined. This examination showed that all students answered in line with each other. Therefore, we decided to include the questionnaires in the study because there would be no deviation in results.

Results of scale 1 and scale 2 of the questionnaire category A show that all students reported preference for working with FFB on the Simodont dental trainer, with respect to the “senses” as well as for performance.

It was remarkable that “time was sufficient” had an average score of 3, which indicated that the students neither agreed or disagreed. All students experienced 45 minutes for the test as sufficient, even though no student passed the test. Without FFB, the students failed their test rather quickly—most students failed within 10 minutes; therefore, none of the students used the full 45 minutes. The time limit of 45 minutes was not experienced as a hindrance for passing the test.

In addition, “testing was easy” was rated with a high score (approximately 4.6), although no student passed the test. This finding may be because they filled out the questionnaire after completing both tests. They had to mark the question “with FFB” and “without FFB.” The questionnaire was designed to accomplish a complete comparison between the two situations (i.e., with FFB or without FFB) because these are the two possible options for the dental trainer in development. This comparison between the questions resulted in a score indicating that it was much easier to test with FFB, although the students did not pass.

The force and direction in which hand pieces provide tactile feedback by pressing against a model (i.e., tooth) during preparation can be chosen and adjusted on instinct by the user. It has been shown that the magnitude of the force used depends on the power of the hand piece, not on its free-running speed, and on the operator, albeit to a lesser degree.[19] Therefore, the results of this study can only be applied to the use of an airotor and cannot be directly extrapolated to another hand piece or tool. The role of FFB has also been studied in several medical areas. However, as far as we are aware, there was only one study that compared the effect of FFB versus no FFB in a VLE. It investigated the effect of testing with and without FFB with laparoscopic simulation training.[20] The results of that study showed that FFB improved precision in advanced tasks and the participants had a significantly shorter task completion time. The use of FFB possibly leads to fewer technical errors.[20]

The results of the current study apply primarily to novices. In a future study, this protocol could be repeated with experts in the field of dentistry to test whether FFB is an absolute requirement to perform well in a VLE. In addition, the effect on students' performance of working with different levels of FFB should be investigated to determine whether skills acquired with different levels of FFB are transferable once a manual dexterity exercise is mastered.

CONCLUSION

In conclusion, only students who worked with FFB in the VLE passed the test at the predefined level. The secondary results from the post hoc analysis suggest that it is possible to fulfill tasks on the dental trainer without FFB, but the performance of students working with FFB is significantly better than the performance of students working without FFB, suggesting that FFB is required to perform on the high precision level that manual dexterity tasks in dentistry require. The questionnaire outcomes showed that 100% of the students preferred working with FFB. The results suggest that FFB positively influences the performance and show that students are more satisfied with FFB in the VLE. Thus, FFB is a requirement for further development of the Simodont dental trainer. The relative importance and impact of the level of FFB used, need to be investigated in future studies.

REFERENCES

1. de Boer IR, Wesselink PR, Vervoorn JM. The creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education. Eur J Dent Educ 2013;17:191–197.
2. Kapoor S, Arora P, Kapoor V, Jayachandran M, Tiwari M. Haptics - touchfeedback technology widening the horizon of medicine. J Clin Diagn Res 2014;8:294–299.
3. Suebnukarn S, Haddawy P, Rhienmora P, Jittimanee P. Augmented kinematic feedback from haptic virtual reality for dental skill acquisition. J Dent Educ 2010;74:1357–1366.
4. Fang TY,Wang PC, Liu CH, SuMC, Yeh SC. Evaluation of a haptics-based virtual reality temporal bone simulator for anatomy and surgery training. Comput Methods Programs Biomed 2014;113:674–681.
5. de Boer IR, LagerweijMD,Wesselink PR, Vervoorn JM. Evaluation of the appreciation of virtual teeth with and without pathology. J Dent Educ 2015;19:87–94.
6. Gal GB, Weiss EI, Gafni N, Ziv A. Preliminary assessment of faculty and student perception of a haptic virtual reality simulator for training dental manual dexterity. J Dent Educ 2011;75:496–504.
7. Rhienmora P, Haddawy P, Khanal P, Suebnukarn S, DaileyMN. A virtual reality simulator for teaching and evaluating dental procedures. Methods Inf Med 2010;49:396–405.
8. Suebnukarn S, Phatthanasathiankul N, Sombatweroje S, Rhienmora P. Process and outcome measures of expert/novice performance on a haptic virtual reality system. J Dent 2009;37:658–665.
9. Eve EJ, Koo S, Alshihri AA, et al. Performance of dental students versus prosthodontics residents on a 3D immersive haptic simulator. J Dent Educ 2014;78:630–637.
10. Urbankova A, Eber M, Engebretson SP. A complex haptic exercise to predict preclinical operative dentistry performance: a retrospective study. J Dent Educ 2013;77:1443–1450.
11. de Boer IR, Wesselink PR, Vervoorn JM. Struggle between innovation and evidence in dental education. Abstract and poster presented at: 2015 ADEA Annual Session and Exhibition of American Dental Education Association (ADEA). Boston, MA: March 8, 2015.
12. de Boer IR, Wesselink PR, Vervoorn JM. Student performance and appreciation using 3D vs. 2D vision in a virtual learning environment. Eur J Dent Educ 2015;20:142–147.
13. Andersen SA, Cayé-Thomasen P, Sørensen MS. Mastoidectomy performance assessment of virtual simulation training using final-product analysis. Laryngoscope 2015;125:431–435.
14. Goedert KM, Miller J. Spacing practice sessions across days earlier rather than later in training improves performance of a visuomotor skill. Exp Brain Res 2008;189:189–197.
15. Kwon YH, Kwon JW, Lee MH. Effectiveness of motor sequential learning according to practice schedules in healthy adults; distributed practice versus massed practice. J Phys Ther Sci 2015;27:769–772.
16. Ehrampoosh S, Dave M, Kia MA, Rablau C, Zadeh MH. Providing haptic feedback in robot-assisted minimally invasive surgery: a direct optical force-sensing solution for haptic rendering of deformable bodies. Comput Aided Surg 2013;18:129–141.
17. Schenk T. No dissociation between perception and action in patient DF when haptic feedback is withdrawn. J Neurosci 2012;32:2013–2017.
18. Aggravi M, De Momi E, DiMeco F, et al. Hand-tool-tissue interaction forces in neurosurgery for haptic rendering. Med Biol Eng Comput 2016;54:1229–1241.
19. Elias K, Amis AA, Setchell DJ. The magnitude of cutting forces at high speed. J Prosthet Dent 2003;89:286–291.
20. Panait L, Akkary E, Bell RL, Roberts KE, Dudrick SJ, Duffy AJ. The role of haptic feedback in laparoscopic simulation training. J Surg Res 2009;156:312–316.

The effect of variations in force feedback in a virtual reality environment on the performance and satisfaction of dental students

I.R. de Boer
M.D. Lagerweij
P.R. Wesselink
J.M. Vervoorn

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ABSTRACT

Introduction

The aim of this study was to investigate the effect of practicing a manual dexterity exercise in a virtual reality environment (VRE) at a standard level of force feedback (FFB) to then test the students at various levels of FFB using the Simodont dental trainer (Moog, Nieuw-Vennep, the Netherlands). In addition, the students' satisfaction with the training exercise was evaluated.

Methods

126 first-year dental students were randomly distributed into four groups and underwent a manual dexterity test in the VRE with automatic assessment after a three-month period of practicing with standard FFB. The test consisted of drilling with the standard FFB and an odd level of FFB to evaluate the effect on performance. After the test, the participants completed a questionnaire.

Results

The results showed that 74% of the students who passed the test did so using the standard level of FFB as well as odd levels of FFB (less or more), or solely the odd level of FFB with which they had not previously practiced.

Conclusions

The results of this study imply that if students practice a sufficient amount of time at one level of FFB, a skill is transferable from one level of FFB to another.

INTRODUCTION

Dental education is a specific and demanding area of education because it necessitates the acquisition of knowledge and the development of manual dexterity, clinical skills, and problem-solving abilities.[1] Currently, two main training environments are used to train students for clinical procedures: phantom heads with artificial teeth or extracted human teeth in phantom jaws in simulation labs, and live patients in educational clinics. In addition to the disadvantages inherent in these methods such as high costs, infection control of extracted human teeth,[2] waste of materials, no realistic pathology in plastic teeth, and patient safety in the clinic, the transition from working on a phantom head to treating a patient in the clinic is vast. Over the last decade, virtual reality (VR) simulation has entered the market to overcome the limitations of contemporary dental education and reduce the gap between preclinical and clinical education.[3,4]

An important part of dental students' training is the development of fine motor skills, typically developed in simulation laboratories.[5] The use of a virtual reality environment (VRE) is specifically suitable for this training purpose. Several VR systems and augmented reality systems are available on the market.[3] One challenge faced during the development and implementation of a VRE is the subjectivity of a user's experience while working in the VRE, meaning that users have different opinions on how they experience the hardness of the simulated materials (tooth tissues) in the VRE.[6]

To investigate the necessity of the availability of force feedback (FFB) in a VRE, a study conducted in 2016[7] showed that the existence of FFB was necessary to ensure performance in a VRE and essential for student satisfaction. However, as no previous studies have been conducted to measure the relative effect of FFB, it remains to be determined whether a transfer of skills exists from one level of FFB to another. A dental trainer using a VRE preferably simulates reality as closely as possible.[8] As this is not always entirely possible, there may be slight differences between a VRE and reality. It is interesting to see to what extent these differences from the ideal simulation are important for student performance and acceptance. In other words, should a dental trainer replicate reality exactly with perfect FFB, or is some variety in FFB acceptable to learn and apply the practiced skills in reality?

Thus, the aim of this study was to investigate the ability of students to transfer a skill from one level of FFB to another level of FFB, and to evaluate how students experienced working at different levels of FFB. Specifically, this study aims to determine whether students that prove competent at one level of FFB may perform the same exercise at another level of FFB. Further, this study seeks to reveal what students think about this experience.

MATERIALS AND METHODS

The current study included 126 first-year dental students who were randomly distributed into four groups. None of the students had prior experience in cutting teeth. The students were informed prior to the experiment that a study would take place during their training and assessments. Arrangements were made with the Board of Exams of the Dental Institute to prevent students from having disadvantages in their education and to provide all students with the same education and conditions for assessment. All participants gave consent for anonymous processing of their data and use in publication. The VRE used in this study was the Simodont dental trainer,[9] a haptic dental trainer that transmits FFB to the user, resulting in the experience of removing materials with a drill. The Simodont dental trainer (Nieuw-Vennep, the Netherlands) was developed to provide students with a safe practice environment to develop their clinical competences and improve their fine motor skills.

Levels of FFB in the Simodont dental trainer

FFB in the Simodont dental trainer consists of several components, which combined provide the user the experience of cutting material. The amount of opposing force (FFB) from the dental trainer, measured at the specific point where the virtual drill is in touch with virtual material, consists of three components as presented in the following formula:[7]

*Hardness of the virtual material * "CutSpeedGain" + "PushForce" = FFB*

The CutSpeedGain indicates how easily the airotor removes material. Then, the PushForce indicates how much force the operator applies on the virtual material and influences components one and two. If the user puts a great amount of pressure on the material with the drill, the material is removed faster up to a certain limit.[7] If the user touches the material very gently, the material will be removed more slowly. In this study, FFB levels 0, 1, and 2 were used (Table 1).[7]

Table 1. Description of the levels of FFB used in the current study[7]

Level	LEVEL translation	0 - 1 scale	Explanation
0	Low FFB	0.2	Hardness comparable to soft caries tissue
1	Standard FFB	0.6	Hardness comparable to dentine from an adult tooth
2	High FFB	0.9	Hardness comparable to enamel

Experimental protocol

All participants were given the opportunity to practice ten sessions with a standard amount of FFB (level 1, Table 1) on three different geometric figures (Figure 1) to develop their fine motor skills. At this stage, students were not aware as to what figure would be used for the test. For the study, the participants were divided into four groups (Table 2).

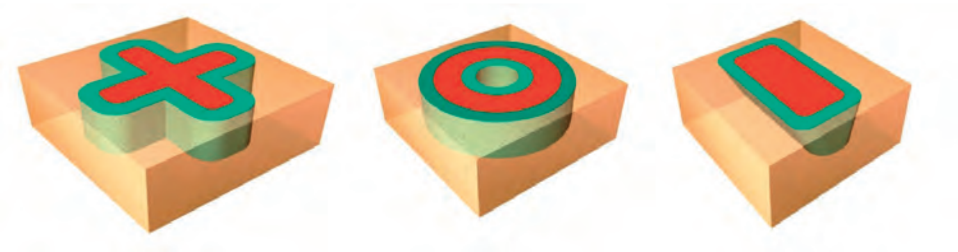

Figure 1. Manual dexterity exercises: (a) Cross-figure preparation, (b) Donut preparation, and (c) Sloped channel preparation.

Table 2. Study design and testing protocol

Cross preparation	Group 1 N=32	Group 2 N=31	Group 3 N=31	Group 4 N=32
Practice (10*45 min)	Standard FFB	Standard FFB	Standard FFB	Standard FFB
Test (time limit: maximum of 90 min)	Low FFB(**0**) & Standard FFB(**1**)	Standard FFB(**1**) & Low FFB(**0**)	High FFB(**2**) & Standard FFB(**1**)	Standard FFB(**1**) & High FFB(**2**)
Attempt 1	0	1	2	1
Attempt 2	1	0	1	2
Attempt 3	0	1	2	1
Attempt 4	1	0	1	2
Attempt 5	0	1	2	1
Attempt 6	1	0	1	2
Attempt 7	0	1	2	1
Attempt 8	1	0	1	2
Attempt 9	0	1	2	1
Attempt 10	1	0	1	2
	Questionnaire	Questionnaire	Questionnaire	Questionnaire

Testing protocol

At the start of the test, it was made known that all participants were required to make a preparation on the "cross figure" (Figure 1a). A test was successfully completed if 90% of the red target area (two branches measuring 7.0 mm [length] × 1.5 mm [width] × 1.5 mm [depth] that crossed each other in the middle) was removed while the beige container (a cube measuring 10.0 mm × 10.0 mm × 2.0 mm and containing the preparation) remained completely intact. The students were allowed to remove the green area completely, known as the leeway space (adding 0.2 mm on the bottom and on every side of the target area), although it was not a requirement to pass the test. Students were allowed to enlarge the image from 100% to 125%. Rotation of the block was limited within the system: 90° to the left and 90° to the right. The colors of the screen, the resolution of the projectors, and the 3D (depth) factor were all fixed values. The requirements for the test used in this study were identical to those of the tests that the students take regularly as part of their curriculum, and were approved by the Board of Examinations.

To pass the test, students had to drill with the standard amount of FFB and another level of FFB, which was either low FBB (softer material) for students in groups 1 and 2 or high FFB (harder material) for students in groups 3 and 4. The standard FFB and the odd FFB were offered alternately during the test, where group 1 started with low FFB and alternated with standard FFB; meanwhile, for group 2, this order was reversed. The same applied for groups 3 and 4 with standard FFB and high FFB (Table 2).

Testing protocol: How to pass the test

The Board of Examinations' requirement for passing the test was to successfully complete three out of five exercises if only the standard FFB was used. However, because an extra level of FFB was added to which the "three out of five" rule applied as well, it was possible for students to pass the test by passing 3 out of the first 5 attempts (option 1a and 1b) or to pass 3 attempts in the odd or standard FFB out of 10 attempts (option 2 and 3). In other words, each student has 5 attempts in passing 3 of them for each level of FFB in which they tested.

Passing options (Table 3):

1. Successfully complete three out of the first five exercises
   a. Pass using two different FFB levels: both the odd level and standard level (e.g., Table 3, option 1a)
   b. Pass using one level of FFB: the odd level or standard level (e.g., Table 3, option 1b)
2. Successfully complete three out of five exercises at the standard level of FFB (e.g., Table 3, option 2)
3. Successfully complete three out of five exercises at the odd level of FFB (e.g., Table 3, option 3)

After completing the experiment, the participants completed a questionnaire (Table 4). In addition to passing or failing the test, the individual use of practice time prior to starting the test was also examined. The aim was to investigate the effect of practicing on the ability to transfer a skill from one level of FFB to another.

Table 3. Possible options to pass the test (green attempts) and examples for each option.

	Option 1a	Option 1b	Option 2	Option 3
Attempt 1	odd	standard	odd	standard
Attempt 2	standard	odd	standard	odd
Attempt 3	odd	standard	odd	standard
Attempt 4	standard	odd	standard	odd
Attempt 5	odd	standard	odd	standard
Attempt 6	standard	odd	standard	odd
Attempt 7	odd	standard	odd	standard
Attempt 8	standard	odd	standard	odd
Attempt 9	odd	standard	odd	standard
Attempt 10	standard	odd	standard	odd

(green = attempt passed, red = attempt failed, non-colored = attempt unused)

Questionnaire

The questionnaire (Table 4) consisted of seven comparative rating scale questions and was developed to measure the opinions of the participants in the current study.

Table 4. Questionnaire – working with different levels of FFB

Design	Comparative rating scale question
Answer model	5-point Likert scale: 1 (completely disagree) – 5 (completely agree)
Number	**Statement**
1	I noticed when I worked with different FFB levels
2	I did not care that the FFB varied
3	The different FFB levels had no influence on my test results
4	There was sufficient time to complete the test
5	The test exhausted me
6	I was well prepared for the test
7	The test was harder than the practice

Statistical analyses

The data collected using the questionnaires and during both tests were statistically analyzed using the Statistical Package for the Social Sciences (SPSS) 21.0 software (SPSS, Chicago, IL, USA). The number of students that passed the test and the ways in which they did so were analyzed. A one-sample binomial test was used to analyze the difference between the groups of students that passed the test with "three of the first five" and those that passed with "three of the same FFB level."

RESULTS

In total, 126 students participated in and completed the study, and 99 of them filled out a questionnaire. Table 5 shows that 83% (n=104) of the students passed the test according to one of the three options mentioned in the testing protocol, while 17% (n=22) failed. The data of the students that passed the test were further analyzed to specify according to which of the options they passed the test, and further whether they passed using two levels of FFB, the odd FFB solely, or the standard level of FFB exclusively.

A one-sample binomial test showed a significant difference ($P < 0.001$) between the groups of students that passed the test with three of the first five and those that passed with three of the same FFB level. Significantly more students passed the test with the option of three of the first five (thus using two levels of FFB) over those who passed with the option of three of the same FFB level.

Table 5. Results of the test

	Group 1 N=32	**Group 2 N=31**	**Group 3 N=31**	**Group 4 N=32**	**TOTAL**
	Low FFB(0) & Standard FFB(1)	Standard FFB(1) & Low FFB(0)	High FFB(2) & Standard FFB(1)	Standard FFB(1) & High FFB(2)	
Passed using **two different** levels of FFB	15	12	23	22	**68% (n=71)**
Passed using the **odd** level solely	1	0	2	3	**6% (n=6)**
Passed using the **standard** level solely	11	9	2	4	**26% (n=27)**
Passed Total	27	21	27	29	**83% (n=104)**
Total number of participants	32	31	31	32	**126**

Effect of practicing time on the transfer of skills to another level of FFB

Table 6 shows the average time in minutes that the students in each of the groups spent practicing from the beginning of the development of their manual dexterity skills until the time of testing in this study, comparing those who passed with three out of the first five to those who passed with three of the same FFB level, as well as to those who failed.

Table 6. Average student practicing time including the test

	Average practice time in minutes
Passed with three of the first five (two different levels of FFB)	300
Passed with three of the same FFB level	271
Failed	224

A one-way ANOVA showed no significant differences with respect to practice time between the three groups, as indicated in Table 6 (P = 0.052). To analyze the effect of each group separately, a post-hoc analysis (LSD Alpha) was performed. A significant difference was observed between the group who passed with three out of the first five and the group who failed, meaning that the latter group practiced significantly less than the former (P = 0.017). There was no statistically significant difference between the groups of three out of the first five and the three of the same FFB level.

Questionnaire

The questionnaire used in this study was based on a shorter version of a questionnaire used in a previous study to investigate the effect of working with and without FFB.[7] It was administered to measure the experience of the students subjectively during the test. Table 7 shows the general information of the respondents of the questionnaire.

Table 7. General information of the questionnaire respondents

	Questionnaire (N)	Average Age of Questionnaire Respondents (Years)
Male	35	20.5
Female	64	20.0
Total	99	

Figure 2 shows the results of the mean values of the questionnaire. Plotted on the error bars are the SD values for each question.

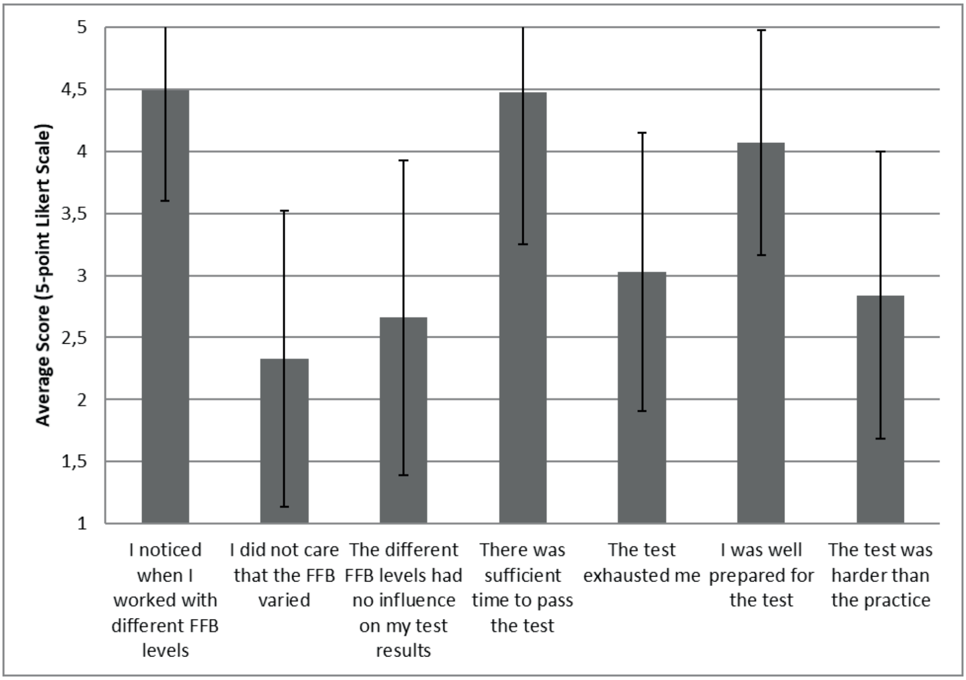

Figure 2. Mean values of the questionnaire.

The questionnaire results show that the students noticed working with the various levels of FFB. Further, the average score suggests that they experienced that it did influence their test results; however, they did not consider the test to be more difficult than the practice sessions.

DISCUSSION

The current study investigated the effect of practicing with a standard amount of FFB followed by testing at an additional new level of FFB through utilizing a VRE (Simodont dental trainer) on student performance. After the experiment, most students completed the questionnaire. Participation in the questionnaire was voluntary, however, so not every student filled out the form.

The testing protocol as shown in Table 2 was used in this study to compensate for the learning effect during the test at the other levels of FFB (not the standard), and to ensure that the order in which participants took the test had no impact on the results. The results showed that it was possible for students to pass the test with other levels of FFB that they had not previously experienced, provided that they had practiced a sufficient amount of time (Table 6). The vast majority of the group passed using two different levels of FFB. This implicates that it is possible to transfer a skill that is acquired at one level of FFB to another level of FFB.

Translated into practice, this result implies that the FFB in this VRE may not need to precisely replicate reality in order to allow the students to acquire a motor skill or learn from conducting the exercise, but further research is needed to investigate if this can be extrapolated to the clinical realm. It also showed that for the students who passed using one level of FFB, more students passed using high FFB than low FFB. This result suggests that working with softer material could be more difficult than learning with harder material. Further, this finding is consistent with the findings of a previous study that indicated that students could not pass the test without FFB.[7]

The particular levels of FFB (0, 1, and 2, Table 1) used in this study were selected because in practice, these are very clearly separated. The values of the tooth tissue levels are based on a normalized scale between 0-1 to describe their relationship to each other through ratios. It was important for the current study to use values that are very common during treatment in daily practice (e.g., when a dentist makes a preparation in a tooth for restoration, several tissues are treated with the airotor: enamel, dentine, and caries) and therefore have high clinical relevance.

The amount of practice time was investigated to underline the effect of testing at different levels of FFB while practicing with the standard level of FFB, and also to visualize the effect of accumulated learning throughout the trial. If students practice a sufficient amount of time, they may be less dependent on the amount of FFB received in the VRE during the test once they master the skill.

The questionnaire showed that the vast majority of students noticed when they worked at a different level of FFB. Additionally, the students cared about the changes in FFB and felt that these changes likely influenced their test results. In contrast, the vast majority of students felt well prepared for the test and did not perceive it to be more difficult than their practice sessions, even though the FFB was not the same as that in their practice session.

The Simodont dental trainer uses virtual teeth for preparations along with manual dexterity exercises. One study showed that haptics can reliably simulate tooth surface and structure.[10] In the Simodont dental trainer, virtual teeth present different levels of FFB based on the various hardness levels of tooth tissue.[9,7,11] When this VRE is used as a trainer to acquire cutting skills at different levels of FFB, the manual dexterity skills acquired using this VRE may be transferred to other environments such as the clinic, where students also experience different levels of FFB while cutting teeth.

As a continuation of studies regarding the use of FFB in a VRE, the force and direction in which hand pieces provide tactile feedback by pressing against a (tooth) model during preparation may be chosen and adjusted instinctually by the user. The results from one study showed that the magnitude of the force used depends on the power of the hand piece that is used rather than on its free running speed, and, to a lesser degree, on the operator.[12] Therefore, the results of this study apply to the use of an airotor and cannot directly be extrapolated to another hand piece. The role of FFB has also been studied in other fields outside of dentistry, such as in laparoscopic simulation training. One study showed that the use of FFB improved precision in advanced tasks, possibly leading to fewer technical errors.[13]

CONCLUSION

This study showed that it is possible for (novice) students to acquire a manual dexterity skill at one level of FFB and transfer this skill to another level of FFB in which they have never previously practiced. Therefore, the amount of FFB received from the VRE might be of less importance once a skill is mastered. Results of the questionnaire showed that students noticed when they received different levels of FFB during their test, but the majority did not experience this as more difficult, meaning that subjectively, they felt confident enough to handle the different levels of FFB. Further research that repeats this study with experienced dentists is necessary to investigate whether the skills of clinically competent people may be reproduced in the virtual world thus showing a transfer of skills from reality to VR, especially because for learning, it may not me necessary to have the exact FFB as in reality, though it might be necessary for acceptation of a VRE during implementation in a dental curriculum.

REFERENCES

1. Dutã M, Amariei C, Bogdan CM, Popovici DM, Ionescu N, Nuca C: An overview of virtual and augmented reality in dental education. Oral Health Dent Manag 2011; 10:42-49.
2. Dominici JT, Eleazer PD, Clark SJ, Staat RH, Scheetz JP: Disinfection/sterilization of extracted teeth for dental student use. J Dent Educ 2001; 65:1278-1280.
3. Wang D, Li T, Zhang Y, Hou J: Survey on multisensory feedback virtual reality dental training systems. Eur J Dent Educ 2016; Epub ahead of print. doi: 10.1111/eje.12173.
4. Hollis W, Darnell LA, Hottel TL: Computer assisted learning: A new paradigm in dental education. J Tenn Dent Assoc 2011; 91:14-18.
5. Al-Saud LM, Mushtaq F, Allsop MJ, Culmer PC, Mirghani I, Yates E, Keeling A, Mon-Williams MA, Manogue M: Feedback and motor skill acquisition using a haptic dental simulator. Eur J Dent Educ Jun 21 2016; Epub ahead of print doi: 10.1111/eje.12214.
6. Springfield E, Fitzgerald M, Johnson LA, Grayden SK, Bayne SC: Haptic simulator tuning protocol: Method and preliminary results. J Dent Educ 2014; 78:300. ADEA Annual Session and Exhibition. San Antonio, TX, USA, American Dental Education Association (ADEA). March 15-18, 2014.
7. De Boer IR, Lagerweij MD, De Vries MW, Wesselink PR, Vervoorn JM: The effect of force feedback in a virtual learning environment on the performance and satisfaction of dental students. Simul Healthc 2017;12:83-90.
8. Gal GB, Weiss EI, Gafni N, Ziv A: Preliminary assessment of faculty and student perception of a haptic virtual reality simulator for training dental manual dexterity. J Dent Educ 2011; 75:496-504.
9. De Boer IR, Wesselink PR, Vervoorn JM: Creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education. Eur J Dent Educ 2013; 17:191-7.
10. Urbankova A, Eber M, Engebretson SP: A complex haptic exercise to predict preclinical operative dentistry performance: A retrospective study. J Dent Educ 2013; 77:1443-50.
11. De Boer IR, Lagerweij MD, Wesselink PR, Vervoorn JM: Evaluation of the appreciation of virtual teeth with and without pathology. Eur J Dent Educ 2015; 19:87-94.
12. Elias K, Amis AA, Setchell DJ: The magnitude of cutting forces at high speed. J Prosthet Dent 2003; 89:286-91.
13. Panait L, Akkary E, Bell RL, Roberts KE, Dudrick SJ, Duffy AJ: The role of haptic feedback in laparoscopic simulation training. J Surg Res 2009; 156:312-6.

Part III

Innovation ‘on-the-fly’

Innovation in dental education: the 'on-the-fly' approach to simultaneous development, implementation, and evidence collection

I.R. de Boer
D.R. Bakker
C.M. Serrano
P. Koopman
P.R. Wesselink
J.M. Vervoorn

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ABSTRACT

Introduction

This paper outlines an approach for education innovation and addresses the ambivalence between evidence-based and non-evidence based conditions. The 'on-the-fly' approach was described as involving implementation during the development of an innovation for dental education.

Materials and Methods

The 'on-the-fly' approach is illustrated by the process of designing and implementing cutting-edge technology of the MOOG Simodont Dental Trainer (DT) while systematically collecting evidence.

Results

Using the 'on-the-fly' approach for developing, implementing and collecting evidence simultaneously in an academic environment appears feasible in serving both the professionals, users as well as developers and system designers. During the implementation of the new technology, growing evidence stepwise strengthened its position; therefore, showing stakeholders that evidence was used to improve the technology seemed to support and increase acceptance of the new technology.

Conclusions

When pioneering an innovative technology in a specialty field, the development stage often precedes evidence for its effectiveness. Consciously choosing the 'on-the-fly' approach clarifies to stakeholders in advance about the lack of evidence in an innovation and the need of their support to collect such evidence for improvement and in order to facilitate implementation.

INTRODUCTION

Improving dental education through technological innovation

Continuous advancement in information technology—particularly in dentistry and medicine—has produced valuable technological innovations related to clinical activities, such as digital scanning, computer-aided design and manufacturing, digital radiography, and digital patient records. These developments affect not only the quality of care but also the design of dental curricula. Ideally, the dynamic nature of a dental curriculum means that it is continuously developing, and this process of continuous development involves addressing critical issues for improvement within an existing curriculum while, at the same time, creating opportunities for the improvement of instructional quality. Recently, new technologies have entered the dental education market, which resultantly have also increased the opportunities to address the challenges in the complexity of dental curriculum design. More specifically, these technological innovations offer a powerful catalyst for further development of a dental curriculum and revision of traditional teaching methods.

These days, dental curricula are often developed in response to an urgent problem. For example current dental training is facing a major issue regarding the growing scarcity of human extracted teeth and suitable patients with the right dental needs for students’ education.[1, 2, 3] Therefore, on such condition that dental training is dependent on the availability of specific extracted teeth and patients with specific procedures, this scarcity may prevent students from acquiring the necessary skills and competencies within the limited time for training to develop into confident qualified practitioners.

A virtual reality environment (VRE), which replicates real-world dental pathologies and the tools used to treat those pathologies, offers tremendous opportunities for dental education as training becomes independent from the availability of specific patients and models. In accordance with the ‘rules of art’, use of such VRE must be substantiated by scientific evidence—without such evidence, an academic environment will disincline to incorporate the new technologies into their program.[4] More specifically, most educators need confirmation that the technology adds more value in comparison to their current method before they would be willing to implement it into their program. From the awareness of the need for evidentiary justification for such technology use as well as the need for systematic evidence generation and compilation, especially when the innovation is disruptive in nature, a specific approach was chosen, namely, the ‘on-the-fly’ approach to gather evidence on the design and implementation of a VRE. Generally, the commercial sector develops from a technology driven perspective a product for the market, arising from consumer need; however, its eventual implementation in education happens only after the product has proven its value. In cases where the innovation arises from an educational need and initiated by academic experts on the content, and is developed in cooperation with a commercial partner, the ‘on-the-fly’ approach may be used.

The 'on-the-fly' approach of a VRE development is characterized by simultaneous development and stepwise implementation, while gathering evidence to find the answers that educators need. However, this does not imply that the starting point for the development of a VRE is a 'wild guess'. Rather, the development is based on prior expectations, assumptions, knowledge, and experiences derived from other learning environments, both virtual and otherwise.[5] The decision to implement an educational method in such a fashion has diverse and fundamental implications applicable not only to a VRE for dental education, but also to applications of new technologies in other (educational) fields. Requiring sufficient scientific evidence before a VRE introduction and implementation can make its effective and timely development complicated, and even impractical. Moreover, the evidence value is limited, as it is not gathered in an authentic environment specific to its design. This makes the 'on-the-fly' approach—wherein evidence is gathered gradually from implementation, evaluation, and further development of the innovation in the actual environment for which it is designed—a meaningful and practical way forward. With this approach, the innovation per se and its lack of evidence are not in conflict; rather, they are interdependent and complementary variables.

This paper illustrates the application of the 'on-the-fly' approach through simultaneous stepwise development and implementation of the Moog Simodont Dental Trainer (DT) (Moog Inc. Nieuw-Vennep, The Netherlands) into a dental education curriculum.

MATERIALS AND METHODS

Figure 1 shows the model of the 'on-the-fly' approach, in which a technological innovation was designed, described, and applied during the process of developing, implementing, and generating evidence.

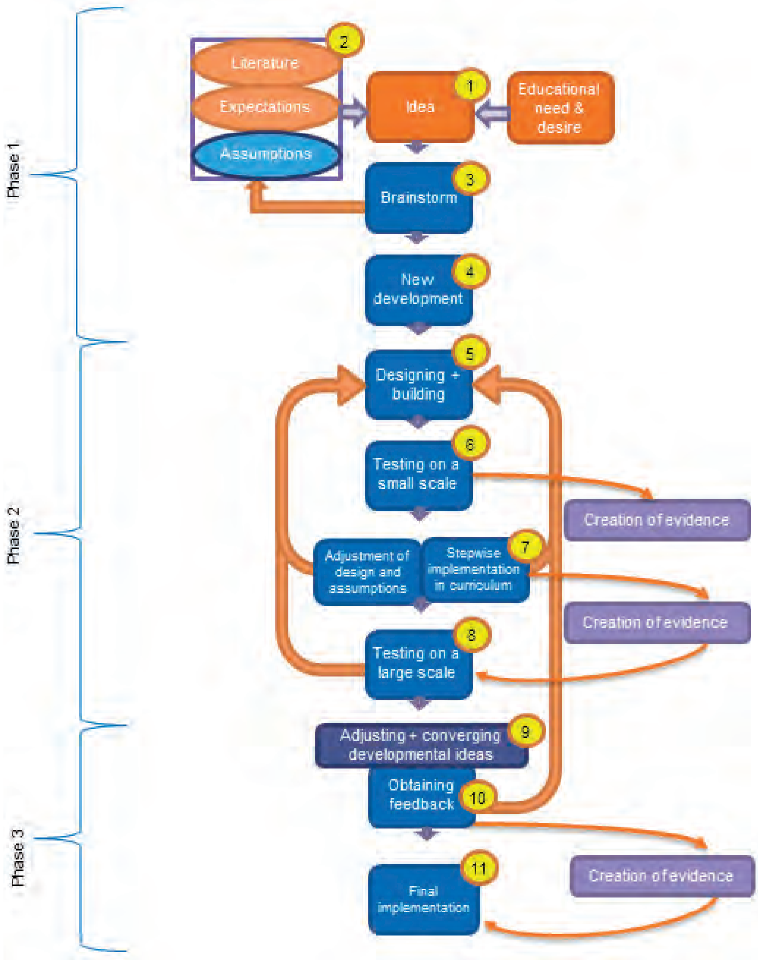

Figure 1. The 'on-the-fly' approach for development, implementation, and creation of evidence for an innovative technology.

Process of developing, implementing, and generating evidence for an educational innovation

The 'on-the-fly' approach consists of 3 phases:

Phase 1: Stepwise development where the innovation was launched prior to its complete (technical) development to introduce stakeholders to a new learning environment;

Phase 2: Stepwise implementation into the curriculum allowed the stakeholders to gradually adapt to the technology and bring them aboard in the process by using the innovation as an addition to the existing curriculum;

Phase 3: Systematic generation of evidence without a selection bias by first collecting evidence from a small group of students and later a whole cohort.[6]

7

In the following section, the three phases will be illustrated by describing the development and implementation of the DT at the authors' dental school.

The DT is a device, which serves as a VRE that allows dental students to drill into virtual teeth and objects, and treat virtual patients using a haptic instrument that generates the feeling of working with real teeth (Figure 2). The DT consists of a training console in which students can work in the VRE and a computer that provides a virtual waiting room with theoretical content.[1, 2, 7]

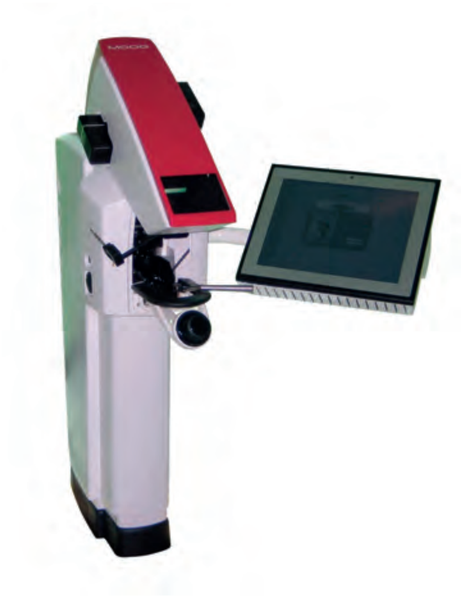

Figure 2. A Moog Simodont Dental Trainer

The 'on-the–fly' approach applied to the DT

Phase 1— Stepwise development

1. The development began with an idea arising from an observed *educational need* or *desire* in the curriculum. The idea for the DT was generated due to the increasing challenges in dental education at the authors' school (see Introduction), and existing virtual or augmented reality systems could not solve the above-mentioned problems.[8]
2. The idea was supported by existing *literature* and *expectations* on the possibility of using contemporary and future technology. Then, *assumptions* were derived based on student learning and skill acquisitions in a VRE. The DT concept was delineated and believed to be a solution in addressing the problems mentioned, while encouraging student autonomous learning.[7]
3. Multiple *brainstorming sessions* were scheduled with all stakeholders to collect input for the development.

4. The brainstorming sessions, then, led to further search in the literature, adjusted expectations and assumptions, and the new development.

Steps 1–4 are cyclical to concretize ideas to address the reasons for innovation.

Phase 2—Stepwise implementation

5. The actual *designing* and *building* of the innovation was performed to meet the standards set in Phase 1.
6. Once the prototype has been developed, *testing on a small scale* was performed in a laboratory to generate feedback and perform preliminary research and therewith *creating evidence.*
7. Based on the received feedback from the small-scale testing, *stepwise implementation* in the curriculum, and the evidence obtained so far, the innovation and its base assumptions were continually *developed, adjusted, expanded, and improved*. The introduction of an educational innovation requires a period for establishing acceptance before a complete rollout.[9] Therefore, stepwise implementation in the curriculum is justified with the development and therewith improvement of the DT as a continuing process.

   The following presents the essential DT implementation steps for support in the school:

- The Board of Examinations nominated the dental trainer as part of the curriculum.
- An educational program was designed by the education management and professors of the departments involved.
- The teachers were tasked to use the dental trainer in the new module.
- Both management and teachers supported the decision to use the dental trainer.

8. Finally, *large-scale testing* with the innovation in the curriculum is performed—this is a major opportunity for the *creation of evidence*. Large scale testing was scheduled for the manual dexterity exercises in the first year of the curriculum, including the whole cohort to prevent selection bias. To ensure that the DT research, conducted throughout its implementation, is ethical and that no students should experience any disadvantages, approval from the ethical commission of the university and written informed consent from students were obtained (each new round of development pre-requires this ethical standards of practice). The dental trainer was initially complementary to traditional education; then, after some years, it was used as a total replacement in the manual dexterity course, wherein students practiced their control over the air rotor and developed fine motor skills.

Phase 3— Generation of evidence

9. Based on the obtained evidence and user feedback, the original and constantly arising new *developmental ideas* were be applied, adjusted, and merged to maintain focus on the development of a feasible instrument.
10. The development continued alongside the use of the innovation in the curriculum. *Feedback* was constantly *collected* and used for further development, improvement, and

adjustment of the innovation. Furthermore, the system's version control was essential to enable concurrent development and use to complement each other. Evidence from the usage data was created and applied directly to the further development and new versions of the DT.

11. Ultimately, the innovation could be completely rolled out to the commercial market and reached its *final implementation* into the curriculum. Over time, newer improved versions of the innovation entered the market with more advanced features. However, feedback is still collected, thus un-limiting the VRE possibilities beyond improving what already is available.

The benefits of the 'on-the-fly' approach are not limited to the development of a complete new technology; in fact, it has been used for every aspect newly added to the DT, for both the software content in the VRE as well as the hardware production. The development of virtual teeth, stepwise implementation, and generation of evidence can be used to demonstrate the applicability of the 'on-the-fly' approach on a small scale.[1,2] Virtual teeth were developed based on an educational need as there has been a prevalent shortage of human extracted teeth with the right dental pathologies. Then, the DT's implementation into the curriculum on a small scale followed, and feedback was collected from the users, namely students, teachers, and dentists. Responses from the users indicated that the use of virtual teeth is appreciated more than the available plastic teeth, thereby providing scientific support and basis to further improve the development of virtual teeth (e.g., higher resolution, more realistic pathology, more realistic colours, and standardisation in hardness) and its implementation in dental education.

Bottlenecks for curriculum innovation

For a curriculum to expand and continuously assure quality, it must be dynamic, and involve continual adjustment to its content and pedagogy to include new research findings and to meet the changing needs of health professionals in training.10 The introduction of the DT in the dental curriculum enhanced this statement as it aimed to improve the quality of education dynamically and produce new evidence continuously. A major focal point for the DT implementation in the curriculum is the teachers, who play an integral role in successfully introducing the DT. Specifically, their exemplary role in instruction affects considerable influence on users' attitudes. Furthermore, it is essential to manage properly the introduction of the new technology because such move can easily bring users out of their comfort zone by putting technology in between them and their existing world. The loss of comfort during the implementation process may result in initial rejection, with the argument of evidential insufficiency. Therefore, specific attention was given to mitigate hurdles in stepwise implementation.

A school, furthermore, has to deal with strict regulatory and legal requirements and any curriculum innovation or change must fit and adhere to the protocols, prioritizing end-users' expectations from the innovation.

To promote its acceptance and thus the success of the introduction, expectations and experiences of teachers and students were followed meticulously. Unfortunately, these data were un-publishable, mainly due to too many confounding factors, but useful information was generated for the management and development. Based on these data, the implementation pace of the dental trainer was adjusted, as was previously done for the development of the Objective Structured Clinical Examination (OSCE).[11]

Gartner's 'hype cycle' (Figure 3) offers some insight into the implementation process of innovations.[12] It represents the five phases that a technological innovation undergoes before acceptance:

1. Technology trigger: a product is introduced
2. Peak of inflated expectation: expectations about the product reach a peak
3. Trough of disillusionment: these expectations are not immediately met and disappointment follows
4. Slope of enlightenment: continuation and maturation of the development
5. Plateau of productivity: the innovation is accepted and its use stabilizes.

Thus, being able to ascertain the dental trainer's position on this curve was crucial in managing stakeholders' expectations. Notably**,** each new addition or change to the dental trainer followed Gartner's cycle on its own. By acknowledging and ultimately mastering the hype cycle as well as the disappointment levels, the depth and width of the stages in the cycle could be managed.[12] It is important to realize that the cycle applies to each change or new concept that is added to the innovation.

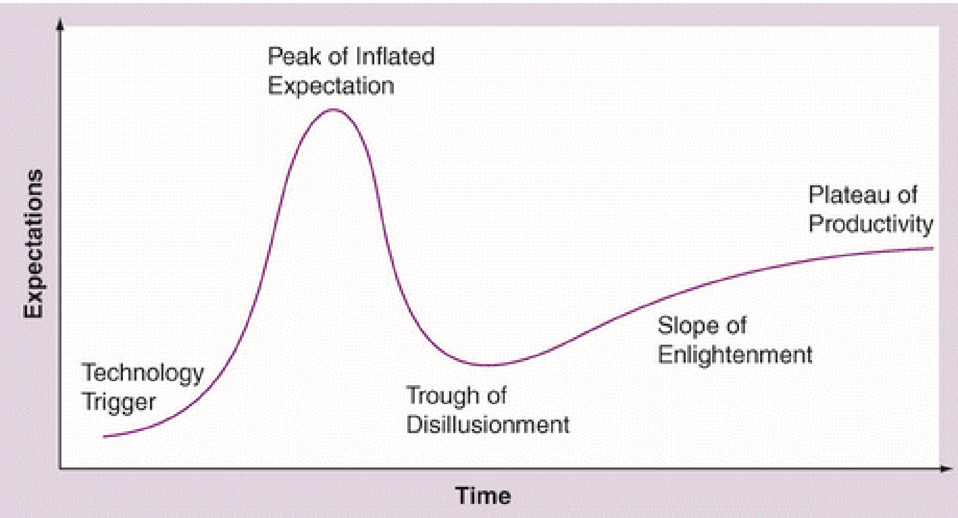

Figure 3. Diagram of Gartner's hype cycle.

Because the data were collected at the school developing the innovation, the curve described in Figure 3 may be more extreme than when a new customer would be introduced with the DT in their curriculum—in the latter case, the deepest trough of disillusionment in the cycle is most likely already smoothened out, as the development is further along than at the beginning. Figure 4 shows some of the factors that should be considered while implementing new technologies in a curriculum. Each change or addition to the innovation can be a hurdle for acceptance; hence, a necessary solution would be using coping strategies, for example *providing information* (Figure 4).

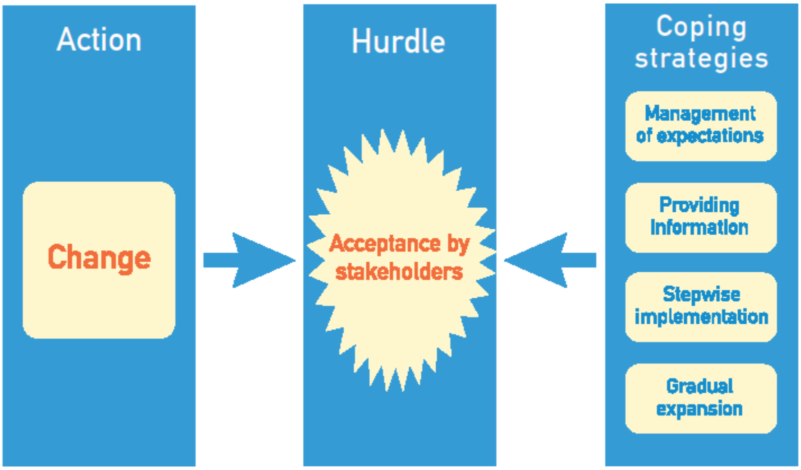

Figure 4. Factors in the implementation of a new innovation into a curriculum.

'On-the-fly' collection of evidence on the DT

In terms of the 'on-the-fly' approach, collection of evidence is paramount. In the authors' school, studies, to-date, have been concerned with the following:

- Development of virtual teeth:[1] Virtual teeth were created from Cone beam CT scans of human extracted teeth. The creation of virtual teeth with and without pathology has numerous benefits for dental education in terms of safety, cost, and usability.
- Evaluation of virtual teeth: The virtual teeth developed in the previous study were evaluated among dentists, teachers (also dentists), and master's and bachelor students. The results indicated that the appearance of the virtual teeth was considered more realistic than the appearance of plastic teeth. Thus, the learning value with virtual teeth was expected to be better.[2]
- Evaluation of students' performance and preferences when working with three-dimensional (3D) or two-dimensional (2D) vision. Using 3D vision in the dental trainer had a significant positive effect on students' performance and their appreciation of the trainer itself.[13]
- Evaluation of the effect of force feedback (FFB) on performance and appreciation. It was found that FFB was necessary for adequate performance in using the dental trainer.[14]

- Evaluation of skill transfers from virtual reality (VR) to reality. Skills, developed using the dental trainer, were transferred to real examinations; thus, the dental trainer appeared useful for developing dental students' manual dexterity.[15]
- A comparison of the performance results between student-determined manual dexterity testing moment and school-assigned testing moment showed that if students determine their own testing moment, their passing rate increased compared to if a school scheduled the testing time.[16]

Selection bias was minimized in the population of all the investigations above because the student-participants in these experiments had equal education and experience level.

RESULTS

After the use of the 'on-the-fly' approach, the following results and experiences pertaining to its implementation were found based on the collection of feedback and other evaluation methods described in the preceding section:

- The school should have the ability and manpower capacity to be in control of the process of development, driven by an education need. Control is achieved by guarding boundaries to ensure the feasibility of each step in the development and clearly defining the result of each intermediate step of the process.
- The approach provides a model for the application of a stepwise implementation into the curriculum and, subsequently, a stepwise introduction of a new technology to the stakeholders.
- The 'on-the-fly' approach seems a feasible method to serve both professional users and program developers to continue improving the system. During the implementation stage, the cumulative evidence stepwise strengthened the position of the new technology. Showing stakeholders that evidence was used to improve the technology supported and increased acceptance of the new technology.
- The approach demonstrated the participating institution's ability to retain the dynamicity of a curriculum and at the same time, to take acceptable risks by pioneering in a specialty field through a series of priority studies to gather scientific evidence to support the educational innovation.
- The approach demonstrated the possibility of innovation with concurrent stages of innovation, development, and evidence collection in a running curriculum within an academic environment in a responsible manner, without disadvantaging the student users.
- The approach showed that the necessity for regular updates to all stakeholders to garner support of the innovation and increase acceptance. The essential part of the 'on-the-fly' approach, namely, stepwise implementation with stepwise development, in applying the

results of collected evidence in further DT development and improvement was a cyclical process that repeated itself during all new technical and content-based additions.

- The pioneers of an innovation, namely the institution and program affiliates, held the advantage of continuous curriculum improvement. Thus, this helped other schools in the subsequent implementations. However, the front line status of a pioneer also includes dealing with setbacks and disappointments; therefore, a strong focus on the essential elements of the program, namely, the end goal of education improvement and consideration of the 'hype cycle', are prerequisites for its growth, maturity, and progress.

DISCUSSION

The 'on-the-fly' approach showed the development of a technological innovation that was developed specifically from an educational need. The educational field required a solution to overcome its challenges; therefore, the 'on-the-fly' educational-driven development to fulfil this need is in stark contrast to the development of a commercial product for the consumer market, which entails production first and implementation later in a curriculum. Developing an innovation within an academic setting allows for the capacity to adapt immediately to any changes in the educational needs. In addition, the technological innovation using the 'on-the-fly' approach was created in an educational setting with continuous feedback from its users who are, in fact, content experts of the new technology; therefore, such valuable feedback provides meaningful insights and suggestions towards a further development of the dental trainer.

When using the 'on-the-fly' approach, it is important to realise that the 'development environment' is always ahead of the 'production environment' in which education is organized. When feedback is received in the cyclical process, a time period to implement this feedback to upgrade the innovation to the next level in the 'production environment' within a running curriculum needs to be taken in consideration.

When a school decides to be involved actively in education innovation, the team leader/ leaders, should form a specific team, based on sound judgment and experience, to guide the innovation and set limits for each step so that the development of the innovation is manageable. The development team should be engaged in both the 'production environment' in which the innovation is being used, as well as in the 'development environment' in which feedback can be incorporated in the innovation. This double engagement of the program team members offers a cyclical process for idea implementation, setting of production limitations, evaluation of use during tests, and result presentation of its use back to the 'development environment' so that the innovation can be upgraded to the next level.

During an innovation within the academic environment, the need for evidence to support that the innovation matches or improves existing educational means should be acknowledged.

The creator of an innovation should maximize the opportunities for education improvement and manage the risks involved to implement the innovation sans evidence. However, evidence is necessary to validate the innovation and generate public support for its use.

Introducing education innovations could be exceedingly difficult, as so nicely phrased by Kalkwarf et al. (2009), 'It's easier to move a cemetery than to change a curriculum'.[17] Numerous authors and speakers over the past twenty years have been convinced that this describes the reality of curriculum reform in a contemporary dental school. Indeed, a number of aspects must be considered when introducing an educational technological innovation in a curriculum. A core aspect was the teacher and student involvement at the start of the brainstorming process, as this could generate support for the innovation in the educational institution. However, involvement in the initial DT testing phase seemed to have resulted in a negative bias, which remained present during further development and further testing moments. Concerning the teachers, it appeared that the better and more accessible the interface of the new DT was, the less they experienced a threshold to use the DT as they could more easily enter the content. Feedback from the use of an education innovation in its nascent stage, namely when the quality is relatively low, could improve and develop further the innovation, supported by the aspiration to improve the quality of education and pioneer a specialty field. However, using an innovation when the quality of the learning environment is already at a higher level makes the implementation and adaptation easier for the stakeholders. Consequently, the advantages derived from the innovation would be missed in the initial stages; however, these benefits could be reaped by later users.

Furthermore, the involvement of a company in the development of an educational product was a challenging factor due to different focuses and interests. Optimally, the world of educational professionals should merge with that of a commercial (technological) company, thereby creating a new world with mutual interests superseding individual gains. However, especially in the trough of disillusionment, this could be a struggle, as both parties would doubtlessly prefer the other to merge into their already existing world.

In addition, constantly monitoring the convergence and coherence of developmental ideas and feedback from stakeholders was important. An educational instrument is likely to generate various opinions and ideas among professionals; to ensure its optimal development, these ideas must be constantly kept in line to maintain focus. Furthermore, we found that management of expectations was an important pillar of stepwise implementation. This was done by information dissemination, surveys, and continuous involvement of professionals in the implementation process, thereby creating a sense of ownership among them. Furthermore, underlining that the DT was still in development, and it was initially a curriculum complement rather than a replacement, may improve user reception. Indubitably, resistance to change must be foreseen; hence, requisite information must be provided to users, particularly highly established teachers and professionals, as they are crucial for the innovation's reputation.

Conducting research for scientific evidence was necessary to support the use of a technological innovation in education. The willingness of students and the faculty in this process, supported by strong leadership of the management are indispensable. Furthermore, during the research, equity is given to students, and they must not be disadvantaged, particularly during the DT development. Its use requires the approval of the Board of Examinations. Such conditions may result in the experimental design of a study being rather complicated. Importantly, with sufficient evidence confirming the soundness of the dental trainer, further research should focus on the educational value derived from the use of the VRE compared to contemporary teaching methods, in terms of quality and cost amongst others. The first data on this showed positive results.[18] A major advantage of VRE in education innovation is being connected to a database that collects all information on performance and student behaviours during their learning process. Using this information to draw conclusions and provide constructive feedback to students is invaluable.[16]

CONCLUSION

The use of the 'on-the-fly' approach for innovation in an academic environment in which scientific evidence is a requirement for support of educational means in a curriculum appeared feasible. Both innovators and users complement each other to progress a new technology into maturity for educational use, dealing with arising issues, justify its use, and increase user acceptance while maintaining focus on the end goal.

Being a pioneer in an education innovation to match pedagogy with contemporary times is possible by using the approach and considering stakeholders' interests and Gartner's repetitive 'hype cycle'. Therefore, to be a pioneer in a certain field of specialty, it is necessary to understand and accept that development precedes evidence.

REFERENCES

1. De Boer IR, Wesselink PR, Vervoorn JM. Creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education. Eur J Dent Educ 2013;17:191–7.
2. De Boer IR, Wesselink PR, Vervoorn JM. Evaluation of the appreciation of virtual teeth with and without pathology. Eur J Dent Educ 2015;19:87–94.
3. Al-Sudani DI, Basudan SO. Students' perceptions of pre-clinical endodontic training with artificial teeth compared to extracted human teeth. Eur J Dent Educ 2016. Epub ahead of print. 2016 Aug 6. doi: 10.1111/eje.1222.
4. Brownstein SA, Murad A, Hunt RJ. Implementation of new technologies in U.S. dental school curricula. J Dent Educ 2015;79:259–64.
5. De Boer IR, Wesselink PR, Vervoorn JM. Struggle between innovation and evidence in dental education. Poster presentation and abstract. Boston, Massachusetts: American Dental Education Association (ADEA), 2015.
6. Pannucci CJ, Wilkins EG. Identifying and Avoiding Bias in Research. Plast Reconstr Surg. 2010 Aug; 126(2): 619–625. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2917255/. Accessed: December 14, 2014.
7. De Boer IR, Bakker DR, Wesselink PR, Vervoorn JM. The Simodont in dental education. Ned Tijdschr Tandheelkd 2012;119:294–300.
8. Wang D, Li1 T, Zhang Y, Hou J. Survey on multisensory feedback virtual reality dental training systems. Eur J Dent Educ 2016;20:248-260. Epub 2015 Nov 7.
9. Koopman P, Vervoorn JM. Innovations in education for the digital student. Ned Tijdschr Tandheelkd 2012;119:286–90.
10. Touger-Decker R. Nutrition education of medical and dental students: innovation through curriculum integration. Am J Clin Nutr 2004;79: 198–203.
11. Schoonheim-Klein M, Walmsley AD, Habets L, van der Velden U, Manoque M. An implementation strategy for introducing an OSCE into a dental school. Eur J Dent Educ 2005;9:143–9.
12. Mason C, Manzotti E. Induced pluripotent stem cells: an emerging technology platform and the Gartner hype cycle. Regen Med 2009;4:329–31.
13. De Boer IR, Wesselink PR, Vervoorn JM. Student performance and appreciation using 3D versus 2D vision in a virtual learning environment. Eur J Dent Educ 2016; 20:142-7
14. De Boer IR, Lagerweij MD, De Vries MW, Wesselink PR, Vervoorn JM. The effect of force feedback in a virtual learning environment on the performance and satisfaction of dental students. Simul Healthc 2017;12:83-90.
15. Bakker DR, Lagerweij ML, Wesselink PR, Vervoorn JM. Transfer of manual dexterity skills acquired on the Simodont, a dental haptic trainer with a virtual environment, to reality, a pilot study. Bio-algorithms Med-Systems 2010;6:21–4.
16. Bakker DR, Wesselink PR, Vervoorn JM. Effect of students' determination of testing time on their test performance. Eur J Dent Educ 2017;21:137-141.
17. Kalkwarf KL, Haden NK, Valachovic RW. Beyond the crossroads: change and innovation in dental education. ADEA Commission of Change and Innovation in Dental Education. ADEA, Washington DC, 2009.
18. Al-Saud LM, Mushtaq F, Allsop MJ, Culmer PC, Mirghani I, Yates E, Keeling A, Mon-Williams MA, Manogue M. Feedback and motor skill acquisition using a haptic dental simulator. Eur J Dent Educ 2016 Epub ahead of print doi: 10.1111/eje.12214 2016 Jun 21.

8

General discussion

REFLECTION

This thesis describes the evaluation and validation of assumptions made prior to the development of a virtual reality learning environment (VRE) for use in dental education: the Moog Simodont dental trainer. This technological development was conducted using the 'on-the-fly' approach for simultaneous development, implementation, and evidence collection. This approach permitted the developed VRE to be immediately employed in the dental curriculum, enabling feedback acquisition for further development, without a participant selection bias. An iterative process was maintained throughout, with user-feedback continuously used to improve and expand the possibilities of the VRE.

Virtual teeth, with and without pathology, were created with a specially designed computer programme, called ColorMapEditor (CME), that allowed the creator to build a virtual patient with virtual teeth with realistic dental characteristics, to simulate a clinical situation as much as possible. Aside from learning from the theoretical aspects of the case (e.g. patient history, x-rays), the VRE with virtual teeth enables users to perform treatments in the virtual world. CME is a feasible programme, but requires continuous updating with further possibilities, to strive for a vast library of virtual teeth resembling realistic dental problems for students to learn from.

The first batch of virtual teeth was evaluated among key VRE users: dentists, teachers, and students. Their opinions on the appearance of several aspects of the virtual teeth, compared to plastic teeth (contemporary preclinical teaching method) and human extracted teeth (gold standard), were evaluated. Results revealed that, compared to plastic teeth, virtual teeth were better in terms of appearance and learning possibilities; however, natural teeth remained the gold standard. Nevertheless, as natural teeth are becoming increasingly rare, alternatives are needed and virtual teeth seem promising as a replacement. Further research on the quality of virtual teeth in the treatment of virtual patients is necessary to improve learning possibilities and increase the potential of the VRE as an alternative to certain clinical procedures.

Very specific choices were made early in the development of the VRE, which affected the technical properties of the dental trainer.

Firstly, a major decision was whether to work with two-dimensional (2D) or three-dimensional (3D) vision. Both options have their advantages (e.g. 3D vision could be more clinically realistic for acquiring manual dexterity, 2D is less expensive) and disadvantages (e.g. 3D vision is complex to produce, and with 2D users can experience problems with depth in their vision). Evaluation of the performance and user preferences revealed that 3D vision has significant positive effects on performance and was identified as highly preferable among students compared to 2D vision. Thus, with the development of this VRE, the use of 3D vision was confirmed and if cost reductions are of importance, there should not be saved on the visualisation in the dental trainer.

Secondly, it was decided to build a Simodont dental trainer with haptic or force feedback (FFB) during virtual treatments or exercises. This decision had major implications, as it increases both the building and implementation complexity. User feedback revealed that users have strong, albeit diverse, opinions on the level of FFB that they experience while working with the dental trainer.[1] Discussions, as to the amount of FFB required, are still ongoing, and will probably continue until a high level of realism is achieved, making the dental trainer a simulator. To nuance the discussion it was investigated whether FFB is required in the VRE, as well as the effect of different levels of FFB on the performance and experience of students. The first study revealed that FFB is a requirement for performance in the VRE; it was almost impossible to complete an exercise without tactile feedback. The second study on FFB revealed that, after a certain amount of practice, the level of FFB seemed less relevant, as students could perform satisfactory independently of the FFB received. This provides information as to whether a certain level of FFB is required to train students within the VRE to enable them to perform the same treatment in the clinic, even though the level of FFB is not (yet) an exact simulation of reality. In contrast, FFB in reality varies considerably between different materials and between and within different individuals' teeth.

All research presented in this thesis was based on the steps of the 'on-the-fly' approach, concerning simultaneous stepwise development, stepwise implementation, and stepwise collection of evidence with the goal of improving technological development and dental education, as well as expanding the VRE applications. Innovation in dental education necessitates many choices to enable continuous development prior to scientific evidence to confirm choices and demonstrate effectiveness. Creating evidence as soon as possible is fundamental to support the acceptance of the innovation within the academic environment. Collecting user-feedback to improve the innovation and conducting scientific research to confirm decisions are helpful for implementation within the curriculum. All factors are inter-connected.

Pioneering in a specialty field usually encounters resistance from many directions; a feeling of 'why change what has worked for many years?' is very likely to result. Innovation could feel 'unsafe' and evoke hesitation. Of interest, the well accepted traditional learning environment is based on very limited evidence. However, the development of the Simodont dental trainer arose from the necessity to innovate, improve the quality of dental education, and thus ensure that the dental curriculum is future-proof.

All research described in this thesis has the advantage of evidence collection with a complete cohort of students and therewith the exclusion of a selection bias in the group. The disadvantage was that performing research in a running curriculum implied that all tests had to adhere to the educational rules and regulations as set by the Board of Exams and had to be performed within the timeframe that all students were available. This resulted in limitations concerning the distribution of students in groups, as each student had to receive the same amount of training time and education.

The research performed so far has confirmed the developmental choices of the Simodont dental trainer. Further research on validation should be performed concerning the use of sound in the dental trainer and the necessity of co-location; meaning that the 3D image in the Simodont should be projected where the hand of the operator is located.

The importance of innovation in dental education

There are several reasons why innovation in dental education is not a luxury or an 'option'.[2] Contemporary society is rapidly changing. In the past, the primary focus in dentistry was on repairing tissue damage and creating durable restorations. A paradigm shift has now turned the focus to prevention of (dental) problems and sharing knowledge with the patient by coaching and providing guidance toward a healthier lifestyle. Society standards, values, and priorities change over time. Thus, innovation for continued progression to meet future needs is of high importance.

Students should be trained and educated to operate in the contemporary knowledge-driven society; patients have the availability of information of varied quality (high and low), to which a dentist must respond. Moreover, the use of patients for learning is now less acceptable; if a student provides care to a patient, the student should have demonstrated competence prior to the treatment. Thus, the question remains, how should we educate students to meet this principle while also ensuring that they are sufficiently competent prior to entering the clinic? A phantom head offers opportunities for developing manual dexterity with precise handling of the instruments on plastic teeth, by copying the environment and tools but without clinical problem solving, a situation far from reality or comparable to the clinical setting. With contemporary possibilities in the 21st century, developments within information computer technology seem an obvious path for the development of dental education. Embedding technological innovations within education increase the guarantees of a future-proof curriculum.

A future-proof curriculum for dental education

The creation and development of a future-proof dental curriculum involves both updating the contemporary curriculum and ensuring that (technological) developments, such as the VRE applications, continuously advance to become less and less dependent upon the availability of patients in the clinic.[2] In this way, a curriculum will always be subject to change. Educating dental students should be possible without dependence on the availability of patients with certain dental pathologies. Being less dependent on patients' availability also creates the opportunity to easily adapt to higher or lower intakes of students. In the near and distant future, the dental profession is subject to change, influenced by both society and commercial technological innovations. Current dental students have developed competences which may or may not be needed one or two decades from now. What are the future societal and patient requirements? To prepare for this, a training environment should be flexible and easily adaptable to changing learning needs, to serve both undergraduate and postgraduate training, as well as lifelong learning. High quality education should prepare to meet the expectations of society.

The contribution of a virtual learning environment to a future-proof curriculum

With the use of technology in education, changes occur not only in teaching, but also in the methods of learning. A VRE can meet the high demands and standards of students in terms of flexibility and communication with teachers and fellow students[3], and thus developments such as the Simodont dental trainer would be instrumental in the creation of a future-proof curriculum. A VRE offers virtual patients, endless treatment opportunities and helps ensure student competency before treating a real patient. Other technological innovations can be aligned to create enhanced resemblance to reality, such as uploading patient data of an intra-oral scanner into the virtual learning environment. New dental treatments can be practised in the VRE before application in a real patient. Additionally, this offers the opportunity for continuous education or reintegration courses. Over time, the VRE should evolve from a 'trainer' into a 'simulator', thereby further closing the gap between learning and training in preparation for the clinic and actual clinical treatment of patients.

Dreams, wishes, and expectations for the future

Based on the current development and application of technology for dental education, what can we expect for the future? Is it possible that a VRE in dental training will no longer be an adjunct, but will completely replace contemporary educational means? Will it be possible to switch between a VRE and reality without noticing? How far can technology take us in optimizing education and striving for a future-proof dental curriculum, future-proof dentists, and lifelong learners? The technology requirements for educational use will become increasingly more complex, aiming for a smooth transition between simulation and reality. When will the use and replacement of reality by a VRE in dental training be accepted in education and considered 100% 'safe'? Learning completely new skills on real patients in clinic has become increasingly less acceptable with the introduction and early use of virtual reality in education many years ago. Moreover, this was one of the many reasons why virtual reality was initially developed and introduced.

How far can we go and what is ethically desirable in a profession that is also based on human interaction? Could virtual reality become a social major as well and replace human interaction? Is the social transition to virtual reality desirable?

The constant drive to keep on innovating, moving forward, accomplish aforementioned dreams, and renew possibilities of the virtual world for transition of the VRE into reality is only possible with continuous educated risk-taking and the introduction of new developments without the availability of scientific evidence. The continuous collection and creation of evidence remains important to support and guide future innovation. The 'on-the-fly' approach, as presented in this thesis, will remain a constant iterative and necessary process to conquer hesitance to change of the academic world.

If the aforementioned could become possible, replacement of contemporary educational tools and transition to a complete educational virtual world might just become reality….

A well-educated guess

Approximately fifteen years ago I made my entrance into the (educational) world of dentistry. Considering the application of computer technology in dental education over time, several aspects in the curriculum have changed. Treating patients early on in the curriculum was common; my first invasive procedure occurred in the second year of my training. Learning and acquiring skills on patients was the standard, which is in line with the fact that no alternative methods were available.

Considering the present time, it is less acceptable to use patients for learning new (invasive) skills, surely since the process of offering an alternative and safer learning environment to students is expanding. This requires a transition by letting go the 'old reality' and accepting the 'new reality', which is specifically applicable to the technical aspects of the training, as interaction with patients remains important for development of social skills.

Moving forward in time; with the wish to create a more sustainable, more efficient, safer and more (cost) effective curriculum for dental training, the use of alternatives such as VR will continue to expand. Assuming that the opportunities with VR continue to expand and improve, a fast take-over of traditional methods can be expected in both preclinical and clinical education. Depending on the speed of further technological development (i.e. advanced computer aided methods, interactive software, artificial intelligence), demands from universities and students and therewith the necessity for this revolution, this may be realized in a timeframe of fifteen to twenty years. This revolution will probably be (at first) most important for the acquisition of technical skills, as it could remain desirable to keep the training of social aspects in the clinic with patients from both a costs point of view as well as the will to remain socially connected through face-to-face meetings. However, in the continuously developing society, human interaction is increasingly more digital and thus even the training in communication may in the future - if costs are no longer a limitation - be designed in VR, enabling students to develop complete clinical competency without clinical exposure.

References

1. Springfield E, Fitzgerald M, Johnson LA, Grayden SK, Bayne SC. Haptic simulator tuning protocol: Method and preliminary results. J Dent Educ. 2014; 78:300. ADEA Annual Session and Exhibition. San Antonio, TX, USA, American Dental Education Association (ADEA). March 15-18, 2014.
2. Palatta AM, Kassebaum DK, Gadbury-Amyot CC, Karimbux NY, Licari FW, Nadershahi NA, Walji MF, Stewart JCB, Valachovic RW. Change Is Here: ADEA CCI 2.0-A Learning Community for the Advancement of Dental Education. J Dent Educ. 2017; 81:640-648.
3. Koopman P, Vervoorn JM. Innovations in education for the digital student. Ned Tijdschr Tandheelkd. 2012; 119:286-290.

SUMMARY

With the development of the Moog Simodont dental trainer, a technological innovation for dental education was introduced. This dental trainer is a virtual reality environment (VRE) in which the user is fully emerged into the virtual world enabling the treatment of virtual patients and performance of manual dexterity exercises. This thesis describes the evaluation and validation of assumptions made prior to the development of the Simodont dental trainer and it describes the development and appreciation of the virtual teeth for use in the Simodont dental trainer. The final Chapter describes the 'on-the-fly' approach which was used to create the above mentioned evidence.

Part one of this thesis consists of a general introduction and the first chapters which describe the development and validation of virtual teeth, necessary to create and treat virtual patients (Chapter 1-3).

Chapter 1 outlines the reasons for innovation in dental education and the dawn of the Simodont dental trainer. The reasons for innovation and the need for use of VR in dental and medical education are widespread. Many advantages are mentioned related to the use of VR in education such as patient safety, reduction in use of disposable materials, resolving issues concerning hygiene as there is no use of human tissue and the introduction of a computer controlled environment provides possibilities for objective assessment and traceability of the treatment process. Disadvantages mentioned concerning the use of VR are issues concerning patient data privacy if scans of patients are uploaded in the VRE, the use of virtual teeth are not yet equal in learning possibilities compared to human extracted teeth and costs for acquisition and maintenance could be high. However, as the advantages outweigh the disadvantages and in order to create a future proof curriculum, the development of the Simodont dental trainer was established. **Chapter 2** describes the creation and use of virtual teeth with and without pathology for use in a VRE in dental education. A virtual tooth is created based on a cone beam CT scan, consisting of multiple two-dimensional greyscale images. The specially designed software program ColorMapEditor (CME) creates therewith a three-dimensional tooth and offers the opportunity to modify any aspect of a virtual tooth thus enabling the creation of a wide range of dental pathology. The created teeth can be implemented in virtual patients within the VRE. Realistic virtual teeth with and without pathology are presented, showing the infinite possibilities of CME to optimize virtual teeth. Further developments in software and hardware technology are necessary to refine the editing options and create a greater degree of realism. The creation and use of virtual teeth in dental education requires continuous development to strive for teeth representing reality as close as possible.

Chapter 3 describes the evaluation of the appearance of the developed virtual teeth for use in dental education and the comparison with contemporary educational models, such as plastic teeth and extracted human teeth. Photographs of virtual, plastic and real human teeth

were presented to dentists, teachers and dental students. Each participant rated the appearance of the virtual teeth (overall and in terms of caries, restoration and colours), whether the virtual or plastic teeth resembled the extracted teeth better and from which teeth they expected to learn the most (extracted, virtual or plastic). Results showed that each group of participants considered the virtual teeth to resemble the extracted teeth more than the plastic teeth and the majority of 71% expected to learn more from the virtual teeth than from the plastic teeth.

Part two of this thesis is about the development and validation of technical aspects of the Simodont dental trainer (Chapter 4-6).

Chapter 4 describes the differences in the performance and appreciation of students working in a virtual learning environment with two (2D) - or three (3D)-dimensional vision in the VRE. First-year dental students performed a manual dexterity exercise on the Simodont dental trainer with automatic assessment. Group 1 practised in 2D vision and Group 2 in 3D. All of the students practised five times for 45 min and then took a test using the vision they had practised in. After test 1, all of the students switched the type of vision to control for the learning curve: Group 1 practised in 3D and took a test in 3D, whilst Group 2 practised in 2D and took the test in 2D. The results showed that the use of 3D vision has a significant positive effect on the performance of the students as well as on the appreciation of the environment.

Chapter 5 describes the effect of force feedback (FFB) on student performance in a virtual learning environment (VLE) using the Simodont dental trainer and evaluated the students' satisfaction with and without FFB. Hundred and one first-year dental students participated in this study and none of them had previous experience in cutting a tooth or working in a VLE with FFB. This study was designed as a crossover study, one half of the students practiced without FFB, whereas one half practiced with FFB. Both groups practiced four sessions lasting 45 minutes on a cross preparation. In the fifth session, test 1 was scheduled. After test 1, the same practicing and testing protocol was followed, although the environment was switched. After test 2, all participants completed a questionnaire. Results revealed that only students who used FFB were able to pass the tests. The questionnaire outcomes supported the results of both tests; 100% of the students preferred working with FFB. The results suggest that FFB is important for performance in a VLE and essential for satisfaction.

Chapter 6 describes the effect of practicing a manual dexterity exercise in a virtual reality environment (VRE) at a standard level of force feedback (FFB) to then test the students at various levels of FFB using the Simodont dental trainer. In addition, the students' satisfaction with the training exercise was evaluated. Hundred and twenty six first-year dental students were randomly distributed into four groups and performed a manual dexterity test in the VRE with automatic assessment after practicing a three-month period with a standard level of FFB. The test consisted of drilling with the standard FFB and an odd level of FFB to evaluate the effect on performance. After the test, the participants completed a questionnaire. Results of the study imply that if students practice a sufficient amount of time, a skill is transferable from one level of FFB to another.

Part three discusses a structured approach on implementation of a new technology in an academic environment- as was applied in all the above mentioned studies.

Chapter 7 describes the ‘on-the-fly’ approach, an approach for simultaneous stepwise development, stepwise implementation and generation of scientific evidence to support the innovation in a running curriculum. To illustrate the ‘on-the-fly’ approach, the process of designing and implementing the Simodont Dental Trainer (DT) was described while systematically collecting evidence. Using the ‘on-the-fly’ approach for developing, implementing and collecting evidence simultaneously in an academic environment appears feasible in serving both the professionals, the users, as well as the developers, the system improvers. When pioneering as a school with an innovative technology in a specialty field, the development stage (often) precedes evidence for its effectiveness. Consciously choosing the ‘on-the-fly’ approach clarifies to stakeholders in advance about the lack of evidence in an innovation and the need to collect such evidence for improvement. The ‘on-the-fly’ approach is a circular process that can be applied to a complete new innovation as well as to any new partial change added to the development.

The future

Patient treatment is an important focus of dental education. Computer technology continues to evolve and expand the possibilities for the VRE. As this method will eventually enable reconstructing the clinical situation in VR, it will become questionable whether learning irreversible treatments on patients is acceptable. However, in addition to technical competencies, dental education involves a major social aspect of treating patients in the clinic and that remains an essential part of the curriculum. Furthermore, it remains to be seen how this social component will evolve with development of robots with emotions and ability to feel pain. The content of the dental curriculum will remain dependent on the ethical standards of the society.

The ‘on-the-fly’ approach can be applied for the support of any innovation in order to justify choices and create support in the academic world. Continuous monitoring of the innovation process and the will to take risks are important principles when aiming to close the gap between VR and reality.

SAMENVATTING

Met de ontwikkeling en het gebruik van de Moog Simodont dental trainer (Simodont) is een technologische innovatie voor de opleiding tandheelkunde geïntroduceerd. De Simodont biedt een volledig virtuele leeromgeving waarin virtuele patiënten kunnen worden behandeld en manuele vaardigheden kunnen worden geoefend. Dit proefschrift beschrijft de evaluatie en validatie van de aannames die zijn gedaan voorafgaand aan de ontwikkeling van de Simodont. Het laatste hoofdstuk beschrijft de 'on-the-fly' methodiek die gebruikt is om de voornoemde validatie uit te voeren.

Deel één van dit proefschrift bestaat uit een algemene inleiding en een beschrijving van de ontwikkeling en validatie van virtuele elementen, die nodig zijn om virtuele patiënten te creëren en te kunnen behandelen (hoofdstuk 1-3).

Hoofdstuk 1 schetst waarom innovatie in het tandheelkundig onderwijs wenselijk is en het daaruit voortvloeiende ontstaan van de Simodont. De aanleiding voor innovatie en voor gebruik van virtual reality (VR) in tandheelkundig en medisch onderwijs kent diverse aspecten. Er zijn vele voordelen denkbaar bij het gebruik van VR in tandheelkundig onderwijs, zoals het beter kunnen waarborgen van de patiëntveiligheid door eerst in de virtuele wereld te oefenen alvorens de echte patiënt invasief te behandelen; het gebruik van wegwerpmateriaal reduceren en de hygiëneperikelen beperken aangezien er geen menselijk weefsel wordt gebruikt. Ook biedt de introductie van een computergecontroleerde leeromgeving mogelijkheden voor een objectieve beoordeling van de kwaliteit en het verloop van het behandelproces en de vastlegging van de prestaties. Beperkingen die bij het gebruik van VR kunnen optreden zijn wet- en regelgeving aangaande de privacy van patiënten als er informatie van patiënten in de virtuele leeromgeving wordt geüpload. Voorts zijn de leermogelijkheden bij het gebruik van virtuele elementen in de onderwijssituatie nog niet gelijk aan die van (humane) geëxtraheerde elementen en is de aanschaf en het onderhoud van een virtuele leeromgeving kostbaar. De voordelen van de Simodont wegen echter op tegen de nadelen wanneer alleen door innoveren een toekomstbestendig curriculum kan worden gecreëerd.

Hoofdstuk 2 beschrijft de ontwikkeling en het gebruik van virtuele elementen met en zonder pathologie in een virtuele tandheelkundige leeromgeving. Een virtueel element is gemaakt op basis van een 'cone beam' CT-scan, bestaande uit meerdere tweedimensionale (2D) laagjes met grijswaarden. Het speciaal ontworpen software programma ColorMapEditor (CME) creeert met deze scan een volumetrisch model van het element en biedt de mogelijkheid om elk aspect van het virtuele element te wijzigen waardoor een breed scala aan tandheelkundige pathologische casus kan worden gecreëerd. De gecreëerde elementen worden gebruikt om virtuele patiënten te ontwikkelen. De tandheelkundige opleiding vereist voortdurende inspan-

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ning en ontwikkeling om de kwaliteit van de virtuele elementen zodanig te optimaliseren dat zij de realiteit zo dicht mogelijk benaderen.

Hoofdstuk 3 beschrijft de evaluatie van de ontwikkelde virtuele elementen en wordt de vergelijking gemaakt met de huidige educatieve modellen zoals plastic elementen en geëxtraheerde menselijke elementen. Foto's van virtuele, plastic en menselijke elementen zijn voorgelegd aan tandartsen, tandheelkundedocenten en -studenten. Elke deelnemer heeft het uiterlijk van de virtuele elementen beoordeeld: het totale beeld van het element, de cariës, restauratie en de kleuren. Zij hebben bepaald of de virtuele dan wel de plastic elementen een betere gelijkenis vertonen met de geëxtraheerde elementen en aangegeven op welke elementen zij verwachten het meest te kunnen leren (geëxtraheerd, virtueel of plastic). Alle drie groepen deelnemers hebben geoordeeld dat de virtuele elementen een betere gelijkenis vertonen met de geëxtraheerde dan de plastic elementen. De meerderheid, te weten 71%, verwacht meer te leren van het behandelen van virtuele elementen dan van plastic elementen.

Deel twee van dit proefschrift beschrijft de ontwikkeling en validatie van technische aspecten van de Simodont (hoofdstuk 4-6).

Hoofdstuk 4 beschrijft de verschillen in prestatie en waardering van studenten die werken in een virtuele leeromgeving met twee- (2D)- of drie- (3D)dimensionaal beeld. Eerstejaars tandheelkunde studenten hebben een handvaardigheidstraining gevolgd op de Simodont met automatische beoordeling door de computer. Groep 1 heeft geoefend in 2D-weergave en Groep 2 in 3D. Alle studenten hebben vijf keer 45 minuten geoefend en hebben vervolgens testen afgelegd met de weergave waarmee ze oefenden. Na test 1 zijn alle studenten overgeschakeld naar de andere weergave: zo heeft Groep 1 geoefend en een test afgelegd in 3D en heeft Groep 2 hetzelfde gedaan in 2D. Uit de resultaten bleek dat het gebruik van 3D-weergave een significant positief effect heeft op zowel de prestaties van de studenten als op hun waardering (zoals vastgesteld aan de hand van een vragenlijst) van de leeromgeving.

Hoofdstuk 5 beschrijft het effect van het gebruik van krachtenterugkoppeling (force feedback (FFB)) in de virtuele leeromgeving van de Simodont op studentenprestaties en evalueert de tevredenheid van de studenten met en zonder gebruik van FFB. Honderdeneen eerstejaars tandheelkunde studenten hebben deelgenomen aan deze studie. Geen van hen had eerdere ervaring met boren in een element of werken in een virtuele leeromgeving met FFB. Deze studie is ontworpen als een cross-over studie: de helft van de studenten heeft geoefend zonder FFB, de andere helft met FFB. Beide groepen hebben in vier sessies van 45 minuten een manuele vaardigheidstraining gevolgd met als oefening een volumetrisch kruisje. In de vijfde sessie was test 1 gepland. Na test 1 is nogmaals hetzelfde oefen- en testprotocol gevolgd, maar is het aanbieden van FFB omgewisseld in de groepen. Na test 2 hebben alle deelnemers een vragenlijst ingevuld. Uit de resultaten bleek dat alleen de studenten die FFB gebruikten aan de resultaatseisen van tests hebben voldaan. De uitkomsten van de vragenlijst laten zien dat 100% van de studenten liever met FFB werkt. De resultaten suggereren dat FFB belangrijk is voor de prestatie in een virtuele leeromgeving en van belang is voor de mate van gebruikerstevredenheid.

Hoofdstuk 6 beschrijft het resultaat en de tevredenheid bij boren met verschillende niveaus van krachtenterugkoppeling (FFB). Honderdvierentwintig eerstejaars tandheelkunde studenten zijn willekeurig verdeeld in vier groepen en hebben na het oefenen gedurende een periode van drie maanden met een standaardniveau van FFB een manuele vaardigheidstest in de Simodont uitgevoerd met automatische beoordeling door de computer. De test bestond uit het afwisselend boren met het standaardniveau FFB en met een afwijkend niveau van FFB (in casu hoger of lager dan het standaardniveau) om het effect van het verschil in FFB-niveau op de prestatie te evalueren. Resultaten van de test suggereren dat als de student voldoende lang oefent, de verworven vaardigheid overdraagbaar is van het ene niveau van FFB naar een ander niveau.

Deel drie bespreekt een gestructureerde aanpak van de gelijktijdige innovatie en implementatie van een technologische ontwikkeling in een academische omgeving. Deze methodiek is in alle bovengenoemde studies toegepast.

Hoofdstuk 7 beschrijft de ‘on-the-fly’ methodiek: een aanpak om te kunnen innoveren in een operationeel curriculum door stapsgewijze gelijktijdige ontwikkeling, implementatie en verzameling van wetenschappelijk bewijs. Om de ‘on-the-fly’ methodiek te illustreren wordt het proces van het ontwerpen en implementeren van de Simodont dental trainer beschreven met het gelijktijdig systematisch verzamelen van wetenschappelijk bewijs. Het gebruik van de ‘on-the-fly’ methodiek is bedoeld als een gestructureerde innovatieaanpak om vooraf duidelijkheid te geven over het verloop van het innovatieproces en tegelijkertijd de professionals, gebruikers, ontwikkelaars en de systeemverbeteraars te voorzien van noodzakelijke informatie. Bij het implementeren van een vernieuwende technologie in een specialistisch vakgebied is het belangrijk om zich te realiseren dat de ontwikkeling van de technologie vaak vooruitloopt op de beschikbaarheid van wetenschappelijk bewijs over de effectiviteit van de desbetreffende technologie. Het bewust kiezen van de ‘on-the-fly’ methodiek maakt vooraf duidelijk aan de belanghebbende partijen dat voor het welslagen van de innovatie de noodzaak bestaat om bewijsmateriaal ‘on-the-fly’ te verzamelen en zo de innovatie verder vorm te geven en te verbeteren op geleide van de terugkoppeling van de gebruiker. De ‘on-the-fly’ methodiek is een iteratief proces dat kan worden toegepast op zowel een volledig nieuwe innovatie als op elke gedeeltelijke wijziging/verbetering in een reeds bestaande innovatie.

Toekomst

Patiëntenbehandeling is een belangrijke pijler van het tandheelkundig onderwijs. Als de ontwikkelingen in de computertechnologie zodanig zijn dat de echte wereld in virtuele realiteit kan worden nagebouwd is het de vraag of het leren van irreversibele handelingen op een patiënt nog acceptabel is. Daar tandheelkunde echter naast technische competenties ook een groot sociaal aspect in zich bergt, blijft het behandelen van de echte patiënten een essentieel onderdeel van de opleiding. Voorts is het de vraag hoe de toekomst er uit zal zien wanneer virtuele leeromgevingen worden doorontwikkeld tot robots uitgerust met emoties en pijn. De keuzes van opleidingen zullen ook uit ethisch perspectief worden beoordeeld waarbij de uitkomst wordt bepaald door de maatschappelijke opvattingen van dat moment.

De ‘on-the-fly’ methodiek kan bij elke vernieuwing worden toegepast om keuzes te onderbouwen en te verantwoorden binnen de academische wereld. Continue bewaking van het innovatieproces en het nemen van risico’s is voorwaarde om grenzen te kunnen verleggen waardoor bovenstaand toekomstbeeld ooit werkelijkheid wordt.

REFERENCES

Aggarwal R, Tully A, Grantcharov T, et al. Virtual reality simulation training can improve technical skills during laparoscopic salpingectomy for ectopic pregnancy. British Journal of Obstetrics and Gynaecology 2006;113:1382–1387.

Aggravi M, De Momi E, DiMeco F, et al. Hand-tool-tissue interaction forces in neurosurgery for haptic rendering. Medical & Biological Engineering & Computing 2016;54:1229–1241.

Al-Saud LM, Mushtaq F, Allsop MJ, Culmer PC, Mirghani I, Yates E, Keeling A, Mon-Williams MA, Manogue M: Feedback and motor skill acquisition using a haptic dental simulator. European Journal of Dental Education Jun 21 2016; Epub ahead of print doi: 10.1111/eje.12214.

Al-Sudani DI, Basudan SO. Students' perceptions of pre-clinical endodontic training with artificial teeth compared to extracted human teeth. European Journal of Dental Education 2016. Epub ahead of print. 2016 Aug 6. doi: 10.1111/eje.1222.

Andersen SA, Cayé-Thomasen P, Sørensen MS. Mastoidectomy performance assessment of virtual simulation training using final-product analysis. Laryngoscope. 2015;125:431-435.

Aycock Jeffrey E, Hill Edward E. Should preclinical typodonts be disinfected prior to grading? Journal of Dental Education 2009;73:133–136.

Bakker DR, Wesselink PR, Vervoorn JM. Effect of students' determination of testing time on their test performance**.** European Journal of Dental Education 2017;21:137-141.

Bakker DR, Lagerweij ML, Wesselink PR, Vervoorn JM. Transfer of manual dexterity skills acquired on the Simodont, a dental haptic trainer with a virtual environment, to reality, a pilot study. Bio-algorithms Med-Systems 2010;6:21–24.

Ben GG, Weiss EI, Gafni N, Ziv A. Preliminary assessment of faculty and student perception of a haptic virtual reality simulator for training dental manual dexterity. Journal of Dental Education 2010;75:496–504.

Brownstein SA, Murad A, Hunt RJ. Implementation of new technologies in U.S. dental school curricula. Journal of Dental Education 2015;79:259–264.

Burden C, Oestergaard J, Larsen CR. Integration of laparoscopic virtual-reality simulation into gynaecology training. British Journal of Obstetrics and Gynaecology 2011;118:5–10.

De Boer IR, Bakker DR, Wesselink PR, Vervoorn JM. The Simodont in dental education. Nederlands Tijdschrift voor Tandheelkunde 2012;119:294–300.

De Boer IR, Lagerweij MD, Wesselink PR, Vervoorn JM. Evaluation of the appreciation of virtual teeth with and without pathology. European Journal of Dental Education 2015;19:87-94.

De Boer IR, Wesselink PR, Vervoorn JM: Struggle between innovation and evidence in dental education. Abstract and Poster presentation. 2015 ADEA Annual Session and Exhibition. Boston, MA, USA, American Dental Education Association (ADEA). March 9, 2015.

De Boer IR, Wesselink PR, Vervoorn JM. Creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education**.** European Journal of Dental Education 2013;17:191–197.

De Boer IR, Wesselink PR, Vervoorn JM: Student performance and appreciation using 3D versus 2D vision in a virtual learning environment. European Journal of Dental Education 2016;20:142-147.

De Boer IR, Lagerweij MD, De Vries MW, Wesselink PR, Vervoorn JM: The effect of force feedback in a virtual learning environment on the performance and satisfaction of dental students. Simulation in Healthcare 2017;12:83-90.

De Boer IR, Wesselink PR, Vervoorn JM. Struggle between innovation and evidence in dental education. Poster presentation and abstract. Boston, Massachusetts: American Dental Education Association (ADEA), 2015.

Dimitrijevic T, Kahler B, Evans G, Collins M, Moule A. Depth and distance perception of dentists and dental students. Operative Dentistry 2011;36:467–477.

Dominici JT, Eleazer PD, Clark SJ, Staat RH, Scheetz JP. Disinfection/sterilization of extracted teeth for dental student use. Journal of Dental Education 2001;65:1278–1280.

Durrani AF, Preminger GM. Three-dimensional video imaging for endoscopic surgery. Computers in Biology and Medicine 1995; 25:237–247.

Dutã M, Amariei C, Bogdan CM, Popovici DM, Ionescu N, Nuca C: An overview of virtual and augmented reality in dental education. Journal of Oral Health and Dental Management 2011;10:42-49.

Ehrampoosh S, Dave M, Kia MA, Rablau C, Zadeh MH: Providing haptic feedback in robot-assisted minimally invasive surgery: a direct optical force-sensing solution for haptic rendering of deformable bodies. Computer Aided Surgery 2013;18:129-141.

Elias K, Amis AA, Setchell DJ: The magnitude of cutting forces at high speed. The Journal Prosthetic Dentistry 2003;89:286-291.

Eve EJ, Koo S, Alshihri AA, Cormier J, Kozhenikov M, Donoff RB, et al: Performance of dental students versus prosthodontics residents on a 3D immersive haptic simulator. Journal of Dental Education 2014; 78:630-637.

Fang TY, Wang PC, Liu CH, Su MC, Yeh SC: Evaluation of a haptics-based virtual reality temporal bone simulator for anatomy and surgery training. Computer Methods and Programs in Biomedicine 2014; 113:674-81.

Francis HW, Malik MU, Diaz Voss Varela DA, et al. Technical skills improve after practice on virtual-reality temporal bone simulator. Laryngoscope 2012;122:1385–1391.

Fraser JF, Allen B, Anand VK, Schwartz TH. Three-dimensional neuro stereoscopy: subjective and objective comparison to 2D. Minimal Invasive Neurosurgery 2009;52:25–31.

Fugill M. Defining the purpose of phantom head**.** European Journal of Dental Education 2013;17: e1–e4.

Gal GB, Weiss EI, Gafni N, Ziv A: Preliminary assessment of faculty and student perception of a haptic virtual reality simulator for training dental manual dexterity. Journal of Dental Education 2011;75:496-504.

Goedetr KM, Miller J. Spacing practice sessions across days earlier rather than later in training improves performance of a visuomotor skill. Experimental Brain Research 2008;189:189–197.

Hollis W, Darnell LA, Hottel TL. Computer assisted learning: A new paradigm in dental education. The Journal of the Tennessee Dental Association 2011; 91:14-18.

Kalkwarf KL, Haden NK, Valachovic RW. Beyond the crossroads: change and innovation in dental education. ADEA Commission of Change and Innovation in Dental Education. ADEA, Washington DC, 2009.

Kapoor S, Arora P, Kapoor V, Jayachandran M, Tiwari M: Haptics—Touchfeedback technology widening the horizon of medicine. Journal of Clinical and Diagnostic Research Res 2014;8:294-299.

Kato A, Ohno N. Construction of three-dimensional tooth model by micro-computed tomography and application for data sharing. Clinical Oral Investigations 2009;13:43–46.

Kim L, Park SH. Haptic interaction and volume modelling techniques for realistic dental simulation. Visual Computer 2006;22:90–98.

Konukseven EI, Onder ME, Mumcuoglu E, Kisnisci RS. Development of a visio-haptic integrated dental training simulation system. Journal of Dental Education 2010;74:880–891.

Koopman P, Vervoorn JM. Innovations in education for the digital student. Nederlands Tijdschrift voor Tandheelkunde 2012;119:286–90.

Kusumoto N, Sohmura T, Yamada S, Wakabayashi K, Nakamura T, Yatani H. Application of virtual reality force feedback haptic device for oral implant surgery. Clinical Oral Implants Research 2006;17:708–713.

Kwon YH, Kwon JW, Lee MH. Effectiveness of motor sequential learning according to practice schedules in healthy adults; distributed practice versus massed practice. Journal of Physical Therapy Science 2015 27:769–772.

Lambooij M, IJsselsteijn W, Fortuin M, Heynderickx I. Visual discomfort and visual fatigue of stereoscopic displays: a Review. Journal of Imaging Science and Technology 2009;53:030201–030214.

Mason C, Manzotti E. Induced pluripotent stem cells: an emerging technology platform and the Gartner hype cycle. Regenerative Medicine 2009;4:329–31.

Nunez DW, Taleghani M, Wathen WF, Abdellatif HM. Typodont versus live patient: predicting dental students' clinical performance. Journal of Dental Education 2012;76:407–413.

Okuda Y, Bryson EO, DeMaria S Jr, et al. The utility of simulation in medical education: what is the evidence? Mount Sinai Journal of Medicine 2009;76:330–343.

Ota D, Loftin B, Saito T, Lea R, Keller J. Virtual reality in surgical Education. Computers in Biology and Medicine 1995;25:127–137.

Panait L, Akkary E, Bell RL, Roberts KE, Dudrick SJ, et al: The role of haptic feedback in laparoscopic simulation training. Journal of Surgical Research 2009;156:312-316.

Pannucci CJ, Wilkins EG. Identifying and Avoiding Bias in Research. Plast Reconstr Surg. 2010 Aug; 126(2): 619–625. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2917255/. Accessed: December 14, 2014.

Pantera EA, Schuster GS. Sterilization of extracted human teeth. Journal of Dental Education 1990; 54:283–285.

Parsell Douglas E, Karns L, Buchanan William T, Johnson Roger B. Mercury release during autoclave sterilization of amalgam. European Journal of Dental Education 1996;60:453–458.

Philips J, Berge ZL. Second life for Dental Education. Journal of Dental Education 2009;73:1260–1264.

Quinn F, Keogh P, McDonald A, Hussey D. A pilot study comparing the effectiveness of conventional training and virtual reality simulation in the skills acquisition of junior dental students. European Journal of Dental Education 2003;7:13–19.

Rhienmora P, Haddawy P, Khanal P, Suebnukarn S, Dailey MN: A virtual reality simulator for teaching and evaluating dental procedures. Methods of Information in Medicine 2010;49:396-405.

Rose JT, Buchanan JA, Sarrett DC. The DentSim system. Journal of Dental Education 1999;63:421–423.

Schenk R. No dissociation between perception and action in patient DF when haptic feedback is withdrawn. Journal of Neuroscience 2012;32:2013–2017.

Schoonheim-Klein M, Walmsley AD, Habets L, van der Velden U, Manogue M. An implementation strategy for introducing an OSCE into a dental school. European Journal of Dental Education 2005;9:143–9.

Siegel M. Perceptions of crosstalk and the possibility of a zoneless autostereoscopic display. Proc SPIE. Digital Library 2001;4297:34–41.

Springfield E, Fitzgerald M, Johnson LA, Grayden SK, Bayne SC: Haptic simulator tuning protocol: Method and preliminary results. J Dent Educ 2014; 78:300. ADEA Annual Session and Exhibition. San Antonio, TX, USA, American Dental Education Association (ADEA). March 15-18, 2014.

Steinberg AD, Bashook PG, Drummond J, Ashrafi S, Zefran M. Assessment of faculty perception of content validity of PerioSim, a haptic-3D virtual reality dental training simulator. Journal of Dental Education 2007;71:1574–1582.

Suebnukarn S, Haddawy P, Rhienmora P, Jittimanee, P, Viraket P: Augmented kinematic feedback from haptic virtual reality for dental skill acquisition. Journal of Dental Education 2010;74:1357-1366.

Suebnukarn S, Phatthanasathiankul N, Sombatweroje S, Rhienmora P, Haddawy P. Process and outcome measures of expert/novice performance on a haptic virtual reality system. Journal of Dentistry 2009;37:658–665.

Suebnukarn S, Rhienmora P, Haddawy P. The use of cone-beam computed tomography and virtual reality simulation for presurgical practice in endodontic microsurgery. International Endodontic Journal 2012;45:627–632.

Tanagho YS, Andriole GL, Paradis AG, et al. 2D Versus 3D visualization: impact on laparoscopic proficiency using the fundamentals of laparoscopic surgery skill set. Journal of Laparoendoscopic & Advanced Surgical Techniques and Videoscopy 2012;22:865–867.

Touger-Decker R. Nutrition education of medical and dental students: innovation through curriculum integration. American Journal of Clinical Nutrition 2004;79: 198–203.

Urbankova A, Eber M, Engebretson SP: A complex haptic exercise to predict preclinical operative dentistry performance: a retrospective study. Journal of Dental Education 2013;77:1443-50.

Votanopoulos K, Charles Brunicarid F, Thornby J, Bellows CF. Impact of three-dimensional vision in laparoscopic training. World Journal of Surgery 2008;32:110–118.

Wang D, Li T, Zhang Y, Hou J: Survey on multisensory feedback virtual reality dental training systems. European Journal of Dental Education 2016; Epub ahead of print. doi: 10.1111/eje.12173.

Yoshida Y, Yamaguchi S, Kawamoto Y, Noborio H, Murakami S, Sohmura T. Development of a multi-layered virtual tooth model for the haptic dental training system. Dental Materials Journal 2011;30:1–6.

World Wide Web

http://www.frasaco.de/fileadmin/epaper-Lieferprogramm_2014_deutsch/#/8 .
Accessed: 15 January 2011.

http://teem.sourceforge.net/nrrd/
Accessed: 10 December 2011.

http://www.buzzle.com/articles/virtual-reality-in-architecture.html
Accessed: 12 February 2012.

http://www.3doptix.be/Gepolariseerde-3D-brillen/vmchk.html
Accessed: 15 March 2014.

http://paulbourke.net/stereographics/stereorender/
Accessed: 26 September 2014.

LIST OF PUBLICATIONS

Peer reviewed publications

- De Boer IR, Wesselink PR, Vervoorn JM. Creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education. European Journal of Dental Education 2013; 17: 191-7

Author contributions

Designed the study: IRdB, PRW, JMV

Performed the study: IRdB

Analysed the data: IRdB

Drafted the manuscript: IRdB

Critically revised the manuscript: PRW, JMV

- De Boer IR, Lagerweij MD, Wesselink PR, Vervoorn JM. Evaluation of the appreciation of virtual teeth with and without pathology. European Journal of Dental Education 2015; 19:87-94

Author contributions

Designed the study: IRdB, PRW, JMV

Performed the study: IRdB

Analysed the data: IRdB, MDL

Drafted the manuscript: IRdB

Critically revised the manuscript: PRW, JMV

- De Boer IR, Wesselink PR, Vervoorn JM. Student performance and appreciation using 3D versus 2D vision in a virtual learning environment. European Journal of Dental Education 2016; 20:142-7

Author contributions

Designed the study: IRdB, PRW, JMV

Performed the study: IRdB

Analysed the data: IRdB

Drafted the manuscript: IRdB

Critically revised the manuscript: PRW, JMV

- De Boer IR, Lagerweij MD, De Vries MW, Wesselink PR, Vervoorn JM. The effect of force feedback in a virtual learning environment on the performance and satisfaction of dental students. Simulation in Healthcare 2017; 12:83-90

Author contributions
Designed the study: IRdB, PRW, JMV
Performed the study: IRdB
Analysed the data: IRdB, MDL, MWdV
Drafted the manuscript: IRdB
Critically revised the manuscript: MDL, PRW, JMV

Submitted manuscripts

- De Boer IR, Bakker DR, Serrano CM, Koopman P, Wesselink PR, Vervoorn JM. Innovation in Dental Education: The 'On-the-Fly' Approach to Simultaneous Development, Implementation, and Evidence Collection. Revised version submitted to the European Journal of dental Education.

Author contributions
Designed the study: IRdB, DRB, CMS, PK, PRW, JMV
Performed the study: IRdB, DRB, CMS, PK, PRW, JMV
Drafted the manuscript: IRdB
Critically revised the manuscript: PRW, JMV

- De Boer IR, Lagerweij MD, Wesselink PR, Vervoorn JM. The effect of variations in force feedback in a virtual reality environment on the performance and satisfaction of dental students. Submitted to Simulation in Healthcare.

Author contributions
Designed the study: IRdB, PW, JMV
Performed the study: IRdB
Analysed the data: IRdB, MDL
Drafted the manuscript: IRdB
Critically revised the manuscript: PRW, JMV

Other publications

- De Boer IR, Bakker DR, Wesselink PR, Vervoorn JM. De Simodont in het onderwijs. Nederlands Tijdschrift voor Tandheelkunde 2012; 119: 294-300

ABSTRACTS, POSTER PRESENTATIONS AND ORAL PRESENTATIONS AT SCIENTIFIC CONFERENCES

- Association for Dental Education in Europe (ADEE) 2010

Oral presentation at the special interest group (SIG) Virtual reality in dental education.
Title: Creation of tooth pathology in a virtual world

- Association for Dental Education in Europe (ADEE) 2011

Oral presentation at the SIG Virtual reality in dental education
Title: Appreciation of virtual teeth; How real should they be? (Preliminary data)

- Association for Dental Education in Europe (ADEE) 2012

Abstract and Poster presentation
Title: Appreciation of virtual teeth with and without pathology: "New learning standard?"

- Association for Dental Education in Europe (ADEE) 2014

Abstract and Oral presentation
Title: Student performance in 3D versus 2D vision in a virtual learning environment

- American Dental Education Association (ADEA) 2015

Abstract and Poster presentation
Title: Struggle between innovation and evidence in dental education

- Association for Dental Education in Europe (ADEE) 2015

Abstract and Oral presentation
Title: The performance and perception of students with a variation of force feedback in a virtual learning environment

- American Dental Education Association (ADEA) 2016

Abstract and Poster presentation
Title: Effect of sound on students' performance and perception in a virtual learning environment

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The financial disclosure has been added to the publications.

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CURRICULUM VITAE (EN)

Ilse Renée de Boer, born 18 July, 1986.

In 2004 I graduated at the Hermann Wesselink College in Amstelveen from high school. I continued my education in dentistry at the Academic Centre for Dentistry Amsterdam (ACTA) and received my Bachelor of Science degree in 2007 and my Master of Science degree in 2009, cum laude. ACTA is a collaborative venture involving the Faculties of Dentistry at the University of Amsterdam and VU University Amsterdam.

After graduating as a dentist I became a (pre)clinical teacher for second-year Bachelor students. In January 2010 I got involved in the project of the development of the Moog Simodont dental trainer and got the specific job to create virtual teeth. I extended my work and started to conduct research to support and improve the development and use of Simodont in dental education.

Besides my involvement at ACTA I am working as a dentist general practitioner at Aemstelgroep Tandartsen, a group practice in Amstelveen.

CURRICULUM VITAE (NL)

Ilse Renée de Boer, geboren op 18 juli 1986.

In 2004 ben ik geslaagd voor mijn VWO diploma aan het Hermann Wesselink College te Amstelveen. Aansluitend heb ik tandheelkunde gestudeerd aan het Academisch Centrum Tandheelkunde Amsterdam (ACTA), een samenwerkingsverband van de Universiteit van Amsterdam en de Vrije Universiteit Amsterdam. In 2007 heb ik mijn Bachelor of Science titel behaald en in 2009 mijn Master of Science titel, cum laude.

Na het afronden van mijn studie ben ik verbonden gebleven aan het ACTA en heb ik twee jaar (pre)klinisch onderwijs verzorgd voor 2^{e} jaars Bachelor studenten. In januari 2010 ben ik betrokken geraakt bij het 'Simodontproject' met als specifieke opdracht het ontwikkelen van virtuele elementen voor de Simodont. Gaandeweg is mijn takenpakket uitgebreid en ben ik onderzoek gaan doen naar de ontwikkeling, implementatie en het gebruik van de Simodont in het tandheelkundig onderwijs.

Naast mijn werkzaamheden op het ACTA ben ik sinds september 2009 als tandarts algemeen practicus werkzaam bij Aemstelgroep Tandartsen, een groepspraktijk te Amstelveen.

From reality

to virtual reality