The Saudi Dental Journal (2017) **29**, 41–47

King Saud University

The Saudi Dental Journal

www.ksu.edu.sa
www.sciencedirect.com

REVIEW ARTICLE

The need for virtual reality simulators in dental education: A review

Elby Roy, Mahmoud M. Bakr, Roy George *

School of Dentistry and Oral Health, Griffith University, Queensland, Australia

Received 4 December 2015; revised 23 January 2017; accepted 1 February 2017
Available online 6 March 2017

KEYWORDS

Virtual reality;
Dental education;
Dental simulators

Abstract Virtual reality simulators are becoming an essential part of modern education. The benefits of Virtual reality in dentistry is constantly being assessed as a method or an adjunct to improve fine motor skills, hand-eye coordination in pre-clinical settings and overcome the monetary and intellectual challenges involved with such training. This article, while providing an overview of the virtual reality dental simulators, also looks at the link between virtual reality simulation and current pedagogical knowledge.
© 2017 The Authors. Production and hosting by Elsevier B.V. on behalf of King Saud University. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Contents

1. Introduction . . . 42
2. HPL (How People Learn) and virtual reality simulation . . . 42
3. Dental virtual simulators . . . 43
   3.1. DentSim™ . . . 43
   3.2. Individual Dental Education Assistant (IDEA) . . . 44
   3.3. Simodont® Dental Trainer . . . 44
   3.4. Periosim® . . . 46
   3.5. Voxel-Man . . . 46

* Corresponding author at: School of Dentistry and Oral Health, Griffith Health Centre (G40), Southport, QLD 4215, Australia.
E-mail address: drroygeorge@gmail.com (R. George).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.sdentj.2017.02.001
1013-9052 © 2017 The Authors. Production and hosting by Elsevier B.V. on behalf of King Saud University.
This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

4. Conclusion . . . 46
Conflict of interest . . . 46
References. . . 46

1. Introduction

Dental education has evolved through the years and various technologies are being incorporated into the curriculum to improve fine motor skills and hand-eye coordination in pre-clinical settings to allow for smooth transition to the clinical setting. The use of simulation training has become an integral part of dental education and has been practised in dental schools throughout the world. Ziv et al. (2003) in their research on simulation reported that the appropriate use of simulation in a professional education programme allows students to refine their clinical skills without the danger of harming the patient during the learning process.

Some of the challenges faced by dental schools are as follows: (1) insufficient numbers of current and future research/scholarly dental faculty; (2) insufficient integration of dental research into the larger world of science; (3) insufficient application of new science to clinical practice settings; and (4) insufficient acceptance/ownership of research findings by the dental community (Iacopino, 2007). With increasing demands in clinical training but the lack of experienced faculty, the cost factor and changing trends of teaching and assessment, there is a need for universities to turn to technology based teaching and learning software to enhance students' learning.

Currently dental schools use simulators that have realistic manikins along with dental models incorporated in a dental simulated operatory. These simulated models allow the instructors to explain and improve on students' hand-eye co-ordination and dexterity but verbal description of tactile sensation is difficult to explain. New technologies are being developed to include 'haptic' (sense of touch) and 'virtual lab environments' into the simulation exercises as these technologies are reported to increase motor skills and student efficiency as well as reducing the faculty time required. Pedagogical use of virtual reality simulations has been used in various professions such as aviation (Helmreich, 1997), nuclear power, military and health care (Kitagawa et al., 2005; Strom et al., 2006; Tanzawa et al., 2013) to maximise training and minimise risk. Recently in Japan, a robot patient capable of performing real life simulations, such as coughing, shaking neck, tongue thrusting and salivary secretion was reported to have shown to enhance dental skills and allow for better development of skills in the management of medical emergencies in a dental setting (Tanzawa et al., 2013).

Despite these technological breakthroughs, there is only limited integration of the haptic and virtual reality (VR) technologies in undergraduate dental training. A study by Bakr et al. (2013) assessed the realism of the Simodont® haptic 3D-VR dental trainer amongst academic staff in the School of Dentistry and Oral Health, Griffith University, Australia, who appreciated the educational benefits that can be offered by the Simodont®. However, they raised concerns about some technical points that needed adjustment. They also agreed that automated feedback provided by Simodont® dental trainer could not totally replace traditional pre-clinical training methods but could be used as a valuable supplementary tool for students' self-evaluation.

For a meaningful educational experience, reflection and discourse are elements that are inseparable (Iacopino, 2007; Garrison and Vaughan, 2008). In dental education, during simulation laboratory procedures, the student requires constant feedback on their work to move onto the next procedure. This face-to-face discussion with the instructor usually occurs after the procedure due to time constrains and student to tutor ratio. Buchanan in her report, stated that when students trained with virtual reality simulators, they learned faster, practised more procedures per hour, accomplished the same levels of competence as traditional preclinical laboratories and requested more evaluations through the computer thus reducing instructor-student evaluation time (Buchanan, 2004). Therefore, blended learning designs in the form of virtual reality units that provide instant feedback and student requested feedback along with instructor feedback need to be incorporated into dental education to make full use of the laboratory training time and improve fine motor skills before the student can confidently move into the clinical setting. We hypothesise that virtual simulation cannot solely replace neither the traditional teaching methods nor a human lecturer or tutor. Therefore, there is a need to review available virtual reality dental simulators and further investigate their added value to the current preclinical dental education framework.

The aim of the current review was to provide a brief comparison and an overview of the available virtual reality simulators in the market. In addition to the above, the current review aims to shed the light on the value of virtual simulation in the current preclinical dental education framework.

2. HPL (How People Learn) and virtual reality simulation

The HPL (How People Learn) framework by Bransford et al. (1999) symbolises the aim of creating a learning environment where all the factors that influence how people (student) learn are present and in balance for learning. Bransford et al. (1999) reckoned that learning should be learner centred, and this should take into account not only students' background Knowledge, interests, social and cultural values but also provides them with the freedom of learning when and where they want to and at the same time makes them responsible for their own learning. The use of virtual reality devices for dental education is visioned to allow the instructor to better engage students and build on their own knowledge. The ability of these simulators to store and replay students' work further allows self-learning and assessment. The advantage of VR laboratories is that it would allow flexible learning with self-teaching not limited to formal training hours, thus increasing students' training time and reducing the overall future costs. Current simulation technology is often limited by the amount of feedback that it could provide the students. To a large extent the technology still may require considerable supervisor feedback at various steps of the procedure.

Table 1 Dental simulator specifications.

	PerioSim®	Voxel Man	Dentsim™	IDEA	Simodont®
Software	Modified version of Ghost™ (SensAble Technologies, MA)	VOXEL-MAN Dental	DentSim software	ManualDexterity™, Caries Detection, Scaling & Root-Planning™, OralMed™ and PreDenTouch™	Moog Simodont® Dental Trainer Courseware software
	Coin3D software Fast Light ToolKit (FLTK)	(University Medical Centre Hamburg-Eppendorf, Hamburg, Germany)	Tracking software Proprietary tracking cards Proprietary interface card to A-Dec hardware (Image Navigation Ltd.'s, NY, USA)	(IDEA Dental, Las Vegas, NV, USA)	(Moog. Inc., Amsterdam, ND)
Hardware specifications	Two computer monitors with haptic device	Workstation computer, 3D LCD monitor, 3D glasses, force feedback device, and a space navigator	The A-dec patient manikin used in conjunction with DentSim	A stylus, with six degrees of freedom, attached to a stand (Phantom Omni, Sensable Technologies, Wilmington, MA, USA)	Two projectors
	Crystal Eyes Stereo Glasses™ and a Crystal Eyes Workstation™ (Stereo Graphics Corp.™, San Rafael, CA) used for 3D viewing	Similar to the Phantom device used in IDEA	Pentium IV PC 2.66 GHz with 512 MB RAM		Panel Pc
	A PHANToM™ haptic device from SensAble Technologies™ (SensAble Technologies, MA) with 3-degrees of freedom				3D glasses
	VR William's periodontal probe (Hu-Friedy™, Chicago, IL) or periodontal explorer (Hu-Friedy)				Handpiece and mirror connected to force feedback sensors
Use external camera	No	No	Yes Dual CCD IR tracking camera	No	No

Bransford et al. (1999) reported that the key to learning was to ensure that key concepts were understood, rather than memorised. Thomas and Hooper (1991) stated that the use of simulation is more effective when the goal of education is to transfer and apply knowledge to real-world problems rather than memorise facts or procedures. In addition to helping improve manual dexterity skills, virtual reality models such as DentSim™, Voxel Man, PerioSim® and Simodont® could help students explore their understanding of the content and concepts of treatment procedures. The ability to self-assess work done on a VR simulator could help students gauge quality of their work and determine a scope to improve. Bransford et al. (1999) reckoned that frequent opportunities for feedback, reflection and revision, are essential to enhance the quality of learning. VR simulators provide students with the opportunity to not only gain instant feedback but also to practise assessment tasks using similar criteria used by examiners. Virtual reality for dental education holds the promise of merging educational ideas and technological capabilities thus allowing for successful use of technology in higher education; reshaping teaching and learning experiences (Garrison and Akyol, 2009).

3. Dental virtual simulators

Dental simulators for training have emerged from technologies that have been available in the field of aviation (Helmreich, 1997) and medicine (Makransky et al., 2016). Currently the major players in this market are DentSim™, Simodont® and IDEA. This review will provide a quick insight into some of the major dental simulators, their advantages and limitations (Tables 1 and 2).

3.1. DentSim™

The DentSim™ units comprise of a phantom head, a set of dental instruments, infrared sensors, overhead infrared camera with a monitor and two computers (Fig. 1). The infrared sensor scans the simulated patient's mouth and this information is processed by one of the two computers. The second computer is used to run the instructional software for evaluating students' work. This software is programmed to evaluate students' work both critical errors or when requested by the

Table 2 Comparison of dental simulators.

	PerioSim®	Voxel Man	Dentsim™	IDEA	Simodont®
Ergonomic postures	No	No	Yes	No	Yes
Instant feedback	No	Yes	Yes	Yes	Yes
Exam simulation	Yes	Yes	Yes	No	Yes
Wi-fi	No	No	No	No	No
Direct transfer of data to programme convenor/tutor	Not available	Not available	Yes Run-time control application enables the instructor to control run-time grades	Yes The software contains a replay mode. Upon completion of a specified task, it can be watched in full by the student or the instructor	Yes The teacher station allows instructor to watch six simulators live at once and record all preparations for evaluation and giving feedback later
Teeth used	Animated	Animated	Plastic teeth	Animated	Animated
Right and left operation	Available	Available	Available	Available	Available
Ability to use off campus	Possible	Possible	Not possible	Possible	Not possible
Reported real life experience	Tactile sensation is realistic for teeth and not so for gingiva (Luciano, 2006)	N/A	Realistic experience using plastic teeth on a real manikin (Jasinevicius et al., 2004)	Tactile sensation still needs to be tuned to simulate a genuine sensation (Gal et al., 2011)	3D images are realistic. However, the texture of healthy decayed and restored tooth structure still needs improvement (Bakr et al., 2013, 2014)

student. The unit allows the students to visualise their preparation on a computer screen, while also providing them the ability to work on plastic teeth. This ability to mimic real life situations allows students to train independently and enhance clinical skills, thus reducing training costs. A study by Jasinevicius et al. (2004) reported that using virtual methods decreased faculty time by fivefold when compared to traditional preclinical teaching methods. It has also been reported that pre-motor and motor neural cortices show significantly increased activity when working and observing tasks rather than acting as passive observer, thus enhancing learning outcomes (Horst et al., 2009).

3.2. Individual Dental Education Assistant (IDEA)

The IDEA offers a stylus, with six degrees of freedom, attached to a stand (Phantom Omni, SensAble Technologies™, Wilmington, MA, USA) that provides the holder with feedback. This unit provides a 3D animated image on the screen that allows the trainee to practice with tools (Stylus and the Phantom Omni), while providing haptic feedback. For each given task, the simulator measures and records task time, percentage of desired material removed, and deviation from the assigned drilling task, reflecting the level of accuracy, and a score is displayed on the screen. Unfortunately there is currently no literature that has reported a validation of this grading system (Gal et al., 2011). The current unit also offers modules for Manual Dexterity™, Caries Detection, Oral Med™, Scaling and Root Planning™ as well as PreDen Touch™. PreDen Touch™ is a novel system that provides prospective dental students with the opportunity to gain an insight into dentistry as a career option. The company also allows the use of third party applications on the unit to further enhance the learning experience. Currently, available applications include modules for root canal obturation, radiography, bridge removal, pain management, etc. A study by Gal et al. (2011) reported that both experienced academics and fifth year dental students perceived that IDEA simulators had potential benefits in enhancing dental education. However, they reported that while the scoring system needed some improvement, the tactile sensation needed to be substantially improved to more closely mimic the real world experience.

Figure. 1 Showing the different components of the DentSim™. (A) Phantom Head, (B) Overhead Infrared Camera, (C) Light Source, (D) Infrared Sensor.

3.3. Simodont® Dental Trainer

The Simodont® Dental Trainer is a haptic 3D Virtual Reality Simulator manufactured by Moog Industrial Group, Amster-

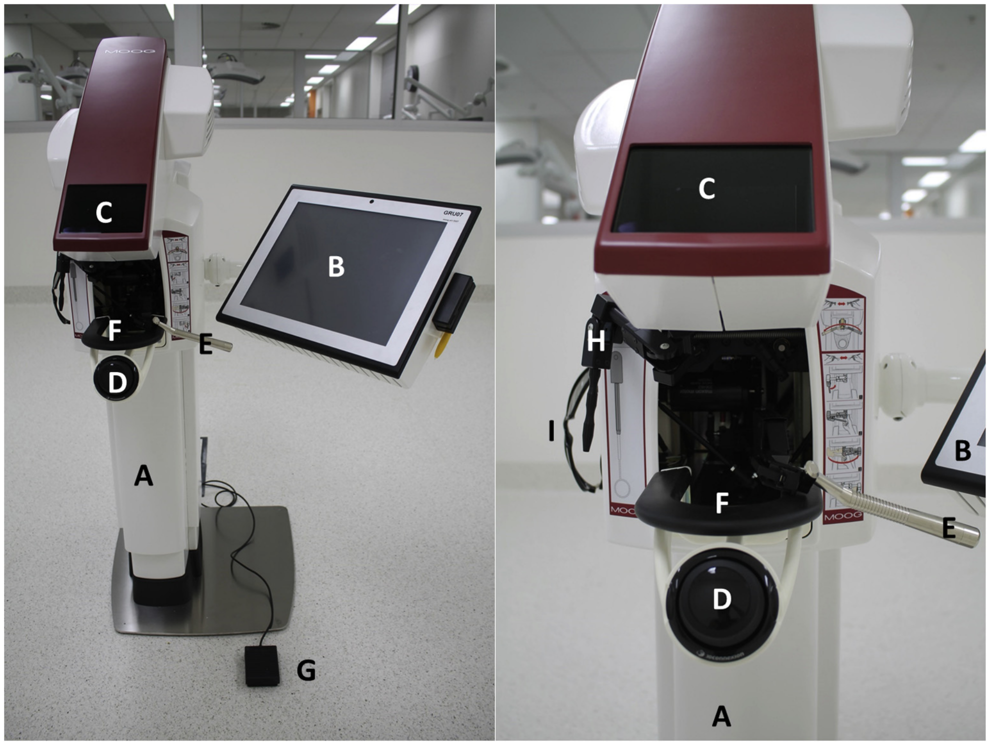

Figure. 2 Simodont® dental trainer showing the different components. (A) Simulator Unit, (B) Panel PC, (C) Stereo Projection, (D) Spacemouse (Joystick), (E) Handpiece, (F) Handrest, (G) Foot Pedal, (H) Mirror Stick, (I) 3D Glasses.

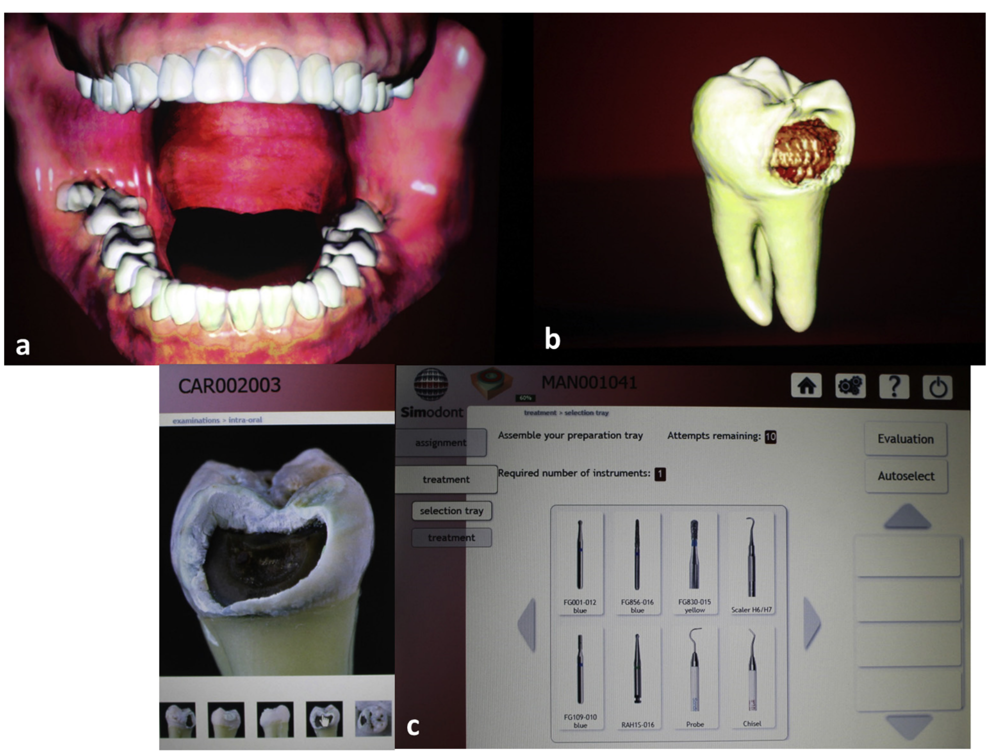

Figure. 3 Showing screen images of the Simodont® dental trainer courseware. (a) The full mouth simulation, (b) an example of a cariology exercises, (c) Instruments tray and clinical photos linked to the cariology exercise shown above.

dam. The Simodont® courseware has been developed by ACTA (Academic Centre for Dentistry in Amsterdam) and is currently being trialled at the School of Dentistry and Oral Health, Griffith University, Queensland, Australia (Fig. 2). The Simodont® software includes modules for manual dexterity, cariology, crown and bridges exercises, clinical cases and a full mouth simulation experience (Fig. 3). Dental Hygiene/ Periodontics as well as Endodontics modules are being developed for future release. These units provide a very unique feature, "The case editor" which allows users to scan their own instruments and clinical cases to create a new exercise.

The Simodont® Dental Trainer provides the user with instant feedback and also allows the students to train in virtual examination settings. Bakr et al. (2014) reported a possible benefit in enhancing manual dexterity following short term exposure to Simodont® dental trainer amongst undergraduate dental students. The authors also reported an overall positive attitude towards the use of haptics to enhance learning experience. In addition to the above, senior dental students appreciated the educational benefits the Simodont® Dental Trainer could provide. However, they agreed that virtual simulation should be used as a supplementary tool in conjunction with traditional teaching methods (Bakr et al., 2015).

3.4. Periosim®

PerioSim® is a virtual reality simulator, developed by Luciano (2006) and offers 3D, VR graphics and tactile sensation allowing the students to use a variety of animated dental instruments in visualising, detecting and evaluating caries or periodontal diseases in a haptic environment, without the need of preparation of teeth surfaces. This device can be accessed by students via internet and also allows instructors to upload different dental procedures which can be saved and replayed by the student at any time (Table 2). A study by Steinberg et al. (2007) stated that the device would help students develop necessary tactile skills and should be incorporated into dental schools. However, it was found that the realism of images of instruments and oral structures as well as the realism of tactile feedback had some limitations that needed further enhancement (Luciano, 2006; Steinberg et al., 2007).

3.5. Voxel-Man

Voxel-Man simulator for surgical training is another 3D, virtual training device for surgical procedures, which was reported to be beneficial for students while transferring knowledge from the virtual world to the real world. This device allows the operator to use animated high and low speed burs of different shapes, which are controlled by a foot pedal. The unit allows the operator to inspect teeth from all aspects using a virtual dental mirror. The unit allows for magnification of teeth as well as showing cross-sectional images. The high-resolution tooth models have been derived from real teeth by microtomography. The software allows students to obtain immediate feedback, problem based study and objective evaluation of their performance. The study by Steinberg et al. (2007) reported that students exposed to the VR software before an apicectomy procedure preserved neighbouring structures such as soft tissue and bone six times better than students who were directly asked to do the procedure on pig cadavers. Moreover, the students were able to self-assess themselves after virtual training.

Advances in hardware and software technology could allow for enhancements in virtual reality experience and better adaptation of this technology into modern education. Addition of features such as virtual water spray, virtual tongue and cheeks for retraction as well as a wider variety of virtual clinical cases covering all disciplines of dentistry is a possible recommendation that could further enhance virtual reality learning experiences.

4. Conclusion

Current literature indicates that virtual reality dental simulators are valuable educational tools that could augment the current traditional teaching methods. Development of a validated single scoring system to the test the improvement in skills achieved across the various available simulators could help assess benefits of each simulator within the pre-clinical dental education framework. Rapid advances in hardware and software technology should further allow for a better virtual reality experience and adaptation of this technology as an essential part of modern education.

Conflict of interest

The authors have no conflict of interest to declare.

References

Bakr, M.M., Massey, W., Alexander, H., 2013. Academic evaluation of the realism and validity of Simodont® haptic 3D virtual reality dental training simulator. Int. J. Dent. Clin. 5, 1–6.

Bakr, M.M., Massey, W., Alexander, H., 2014. Students' evaluation of a 3DVR haptic device (Simodont®). Does early exposure to haptic feedback during preclinical dental education enhance the development of psychomotor skills? Int. J. Dent. Clin. 6, 1–7.

Bakr, M.M., Massey, W.L., Alexander, H., 2015. Can virtual simulators replace traditional preclinical teaching methods: a students' perspective? Int. J. Dent. Oral Health 2 (1). http://dx.doi.org/10.16966/2378-7090.149.

Bransford, J.D., Brown, A.L., Cocking, R.R., 1999. How People Learn: Brain, Mind, Experience, and School. National Academy Press, Washington, DC.

Buchanan, J.A., 2004. Experience with virtual reality-based technology in teaching restorative dental procedures. J. Dent. Educ. 68, 1258–1265.

Gal, G.B., Weiss, E.I., Gafni, N., Ziv, A., 2011. Preliminary assessment of faculty and student perception of a haptic virtual reality simulator for training dental manual dexterity. J. Dent. Educ. 75, 496–504.

Garrison, D., Akyol, Z., 2009. Role of instructional technology in the transformation of higher education. J. Comput. High Educ. 21, 19–30.

Garrison, R., Vaughan, H., 2008. Designing blended learning to create a community of inquiry. In: Blending Learning in Higher Education: Framework, Principles and Guidelines. Jossey-Bass, San Francisco, pp. 31–48.

Helmreich, R.L., 1997. Managing human error in aviation. Sci. Am. 276, 62–67.

Horst, J.A., Clark, M.D., Lee, A.H., 2009. Observation, assisting, apprenticeship: cycles of visual and kinesthetic learning in dental education. J. Dent. Educ. 73, 919–933.

Iacopino, A.M., 2007. The influence of "New Science" on dental education: current concepts, trends, and models for the Future. J. Dent. Educ. 71, 450–462.

Jasinevicius, T.R., Landers, M., Nelson, S., Urbankova, A., 2004. An evaluation of two dental simulation systems: virtual reality versus contemporary non-computer-assisted. J. Dent. Educ. 68, 1151–1162.

Kitagawa, M., Dokko, D., Okamura, A.M., Yuh, D.D., 2005. Effect of sensory substitution on suture-manipulation forces for robotic surgical systems. J. Thorac. Cardiovasc. Surg. 129, 151–158.

Luciano, C.J., 2006. Haptics-Based Virtual Reality Periodontal Training Simulator [Master's thesis]. University of Illinois.

Makransky, G., Bonde, M.T., Wulff, J.S.G., Wandall, J., Hood, M., Creed, P.A., Bache, I., Silahtaroglu, A., Nørremølle, A., 2016. Simulation based virtual learning environment in medical genetics counseling: an example of bridging the gap between theory and practice in medical education. BMC Med. Educ. 16, 98. http://dx.doi.org/10.1186/s12909-016-0620-6.

Steinberg, A.D., Bashook, P.G., Drummond, J., Ashrafi, S., Zefran, M., 2007. Assessment of faculty perception of content validity of PerioSim, a haptic-3D virtual reality dental training simulator. J. Dent. Educ. 71, 1574–1582.

Strom, P., Hedman, L., Särnå, L., Kjellin, A., Wredmark, T., Felländer-Tsai, L., 2006. Early exposure to haptic feedback enhances performance in surgical simulator training: a prospective randomized crossover study in surgical residents. Surg. Endosc. 20, 1383–1388.

Tanzawa, T., Futaki, K., Tani, C., Hasegawa, T., Yamamoto, M., Miyazaki, T., Maki, K., 2013. Medical emergency education using a robot patient in a dental setting. Eur. J. Dent. Educ. 17, e114–119.

Thomas, R., Hooper, E., 1991. Simulations: an opportunity we are missing. J. Res. Comput. Educ. 23, 497–513.

Ziv, A., Wolpe, P.R., Small, S.D., Glick, S., 2003. Simulation-based medical education: an ethical imperative. Acad. Med. 78, 783–788.