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Virtual reality environments for health professional education

Nakul Saxena¹, Bhone M Kyaw², Jitka Vseteckova³, Parvati Dev⁴, Pradeep Paul¹, Kenneth Teck Kiat Lim¹, Andrzej Kononowicz⁵, Italo Masiello⁶, Lorainne Tudor Car⁷, Charoula K Nikolaou⁸, Nabil Zary⁵, Josip Car^{2,9,10}

¹Health Services and Outcomes Research (HSOR), National Healthcare Group, Singapore, Singapore. ²Health Services and Outcomes Research Programme, Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore, Singapore. ³School of Health Sciences, City University London, London, UK. ⁴SimTabs LLC, Los Altos Hills, California, USA. ⁵Department of Learning, Informatics, Management and Ethics (LIME), Karolinska Institutet, Solna, Stockholm, Sweden. ⁶Department of Clinical Science and Education, Karolinska Institutet, Solna, Stockholm, Sweden. ⁷Department of Primary Care and Public Health, School of Public Health, Imperial College London, London, UK. ⁸Centre de philosophie du droit (Cellule Biogov), Universite Catholique de Louvain, Louvain-la-Neuve, Belgium. ⁹Global eHealth Unit, Department of Primary Care and Public Health, School of Public Health, Imperial College London, London, UK. ¹⁰Department of Family Medicine, Faculty of Medicine, University of Ljubljana, Ljubljana, Slovenia

Contact address: Josip Car, Health Services and Outcomes Research Programme, Lee Kong Chian School of Medicine, Nanyang Technological University, Singapore, Singapore. josip.car@imperial.ac.uk. josip.car@ntu.edu.sg.

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ABSTRACT

This is the protocol for a review and there is no abstract. The objectives are as follows:

To assess the effects of virtual reality environment (VRE)-based educational interventions for health professionals on knowledge, skills, and participants' attitude towards and satisfaction with the interventions. Additionally, this review will assess the interventions' economic impact (cost and cost effectiveness), patient-related outcomes and unintended adverse effects of VRE-based educational interventions for post-registration healthcare providers.

BACKGROUND

Description of the condition

Adequately trained healthcare professionals (HCPs) are essential to ensure uniform access to health services and to achieve universal health coverage (WHO 2013). Currently, there is a paucity of HCPs worldwide, especially in developing countries (WHO 2013). In 2013, the World Health Organization (WHO) estimated a shortage of approximately 7.2 million HCPs worldwide

and this shortage is expected to reach 12.9 million by 2035 (WHO 2013). The shortage and disproportionate distribution of health workers worldwide (Chen 2010) can be aggravated by the inadequacy of training programmes (in terms of content, organisation and delivery) and experience needed to provide uniform healthcare services to all (Frenk 2010). It has therefore become essential to focus effort and resources on developing and implementing strategies that can lead to an increase in both the number of healthcare workers and the quality and relevance of their training (WHO 2011).

To address this estimated shortage, another issue that needs to be accounted for is the widening gap between the advancement of new healthcare information and the dissemination of such information to healthcare professionals to update their knowledge and skills. Continued professional development (CPD) and continued medical education (CME) are essential for post-registration HCPs to stay up-to-date with the latest advancements in their respective fields. However, CPD- and CME-based courses or seminars might not always be accessible to post-registration HCPs due to time and travel constraints. Addressing these shortfalls through adequate training requires innovative methods to reach out to a large population in a cost effective and time efficient manner.

eLearning (use of technology and electronic media to disseminate information for the purpose of education) may be one such innovation. This review is one of a series of Cochrane reviews assessing the scope for, and potential impact of, a range of eLearning technologies for different levels of HCP education and training. eLearning may encompass a variety of interventions characterised by their tools, contents, learning objectives, pedagogical approaches and setting of delivery. eLearning can include, but is not limited to, online and offline computer-based eLearning, massive open online courses (MOOCs), virtual reality environments (VREs), virtual patients, mobile learning (mLearning) digital game-based learning (DGBL) and psychomotor skills trainers. This review will focus on the use of VRE-based eLearning interventions for pre- and post-registration health professional education.

VREs are simulated counterparts of a real world that can help users experience situations that would normally be difficult in the real world. VREs help people to gain practical knowledge and experience in a simulated environment. This review aims to assess the change in knowledge and skills, and the participants' attitude toward and satisfaction with VRE-based eLearning interventions.

Description of the intervention

Virtual reality (VR) provides “a combination of human-computer interfaces, graphics, sensor technology, high-end computing and other modern technologies that all work together to enable a user to interact actively with an artificial computer-generated environment” (Akay 1996). VREs provide a computer-generated three-dimensional (3D) experience of places in the real or invented world by using computer multimedia technology, database technology, network technology and other virtual technologies (Akinladejo 2012).

Within a VR simulation, healthcare students are free to explore, and to examine their environment from any viewpoint they desire including hazardous and inaccessible locations. This enables users to experience circumstances in a virtual world in ways that would otherwise be difficult or impossible in reality (Hoffman 1997). With this newfound freedom to explore, students can analyse the clinical problems and evaluate potential alternatives in ways that were not possible before.

For the purpose of this review, we define VR as a technology that allows the user to explore and manipulate computer-generated 2D or 3D, multimedia sensory environments in real time (Strangman 2003), and VRE as the computer-generated representation of a real or artificial environment that can be interacted with by external involvement, allowing for a first-person active learning experience through immersion (Mantovani 2003; Rasmussen 2014). We define ‘immersive VREs’ as “complex technologies that replace real-world sensory information with synthetic stimuli such as 3D visual imagery, spatialized sound, and force or tactile feedback” (Bowman 2007). For this review, as long as there is visual, spatial, sound and/or tactile feedback for the participant, we would consider the VRE to provide an immersive experience. If these feedbacks are not present, VRE will be considered to be ‘non-immersive’.

How the intervention might work

VR provides the opportunity for enhancing and modifying the learning experience of healthcare professionals through immersion in a non-real environment that closely mimics the real world (Dalgarno 2010). A unique feature of VRE-based education is that students can experience different situations in the VRE without physically leaving the classroom setting. This makes the educational experience invaluable.

VR technology is a good learning tool for students with different needs and learning styles (Psootka 1995; Schultheis 2001). It also provides opportunities for group work and peer teaching (Hansen 2008). Students who struggle to be part of a classroom setting can be accepted by their peers thanks to their technology skills (Hansen 2008). This confidence boost may enable students to learn in a more holistic way.

Students actively interact with content and role play skills associated with their profession in a VRE (Mantovani 2003). By allowing students time to interact with other avatars (animated figures the user may navigate to perform various tasks in a VRE) in a safe, simulated environment, a decrease in student anxiety, an increase in competency in learning new skills, and encouragement to cooperate and collaborate, as well as resolve conflicts, is possible (Hansen 2008). Active learning takes place because other participants, being in the same virtual world and performing tasks to represent ideas, help enhance self-reflection and knowledge (Hansen 2008). Internet based 3D VREs provide opportunities for individuals or groups to engage themselves with the environment, accounting for collective intelligence.

A few studies examining the various aspects of VREs and their potential benefits for teaching and learning have collectively yielded a long list of positive capabilities. Mantovani 2003 identified VREs as an attractive educational tool which can provide a rich, interactive learning environment and an opportunity for experiential learning, which may allow students and trainees to develop a better understanding and learn more thoroughly. The advantage of

learning in a VRE is that it provides new experiences that are not too costly to administer, and at the same time provides new experiences in circumstances that might not be feasible to implement in a real world setting.

“VREs tend to provide other instructional benefits, such as allowing for creativity within a rich media environment, providing opportunities for social interaction, facilitating collaboration, increasing a sense of shared presence, dissolving social boundaries, lowering social anxiety, enhancing student motivation and engagement, and accommodating millennial generation learning preferences” (Jarmon 2009). However, the impact of VRE-based interventions specifically on health professional education is yet to be conclusively studied.

Why it is important to do this review

With the increasing use of technology in education it is important to generate a good evidence base to support decision making and formulate policies. VR in education is gaining momentum and therefore needs to be evaluated in order to provide a solid foundation for evidence-based education and learning. This review aims to provide this evidence base.

Past reviews looking at VREs as education media have focused on effectiveness of education and have highlighted the need for further research to better understand the value of VRE-based interventions for knowledge gain and skills acquisition for healthcare professionals (Ziv 2003; Issenberg 2005; Fritz 2008).

Our review will contribute to address the existing gaps by:

- Updating the fast-growing body of evidence on the topic of eLearning through VRE interventions. The last review was conducted more than seven years ago (Fritz 2008).
- Focusing on VRE-based eLearning interventions across various professional fields of health sciences education at the pre- and post-registration level.
 - Evaluating the impact of such intervention on knowledge, skills and attitudes of pre- and post-registration healthcare professionals.
 - Including evidence from developed and developing countries.

It is also important to take into account the potential disadvantages and risks of VRE. Users have to accept a world that has already been designed, and learning and interaction is limited by the scope of this design. Nevertheless, advances in information technology have helped enhance the VRE experience to mimic as closely as possible the real-world scenario. Over the years, the field of education and training has encouraged students to become more creatively involved in the learning process. Nevertheless, immersion in a VRE cannot completely mimic the real world scenarios that healthcare professionals will face (Hansen 2008), and despite the ‘attempted realism’ of a virtual reality experience, at the back of their minds users know it is not real.

OBJECTIVES

To assess the effects of virtual reality environment (VRE)-based educational interventions for health professionals on knowledge, skills, and participants’ attitude towards and satisfaction with the interventions. Additionally, this review will assess the interventions’ economic impact (cost and cost effectiveness), patient-related outcomes and unintended adverse effects of VRE-based educational interventions for post-registration healthcare providers.

METHODS

Criteria for considering studies for this review

Types of studies

Randomised controlled trials (RCTs) and cluster RCTs (cRCTs). We will include RCTs with unclear or high risk of bias for sequence generation. If meta-analysis of included studies is feasible and appropriate, we will include all RCTs regardless of their sequence generation bias rating. However, we will also conduct sensitivity analyses excluding those at unclear or high risk of bias, to examine the robustness of the meta-analysis results to methodological limitations of the included studies. We will exclude cross-over trials due to the high likelihood of carry-over effect.

Types of participants

We will include studies involving students who are enrolled in either of the following:

- A pre-registration, undergraduate, health-related university degree or a basic, health-related vocational training programme. We will define pre-registration, undergraduate education or basic vocational training as any type of study leading to a qualification that: (i) is recognised by the relevant governmental or professional bodies of the country where the studies were conducted, and (ii) entitles the qualification-holder to apply for entry-level positions in the healthcare workforce and/or have direct contact with patients. For this reason, graduate medical education courses from the United States of America (USA) as well as other countries with graduate medical education courses will be included in this category.
- A post-registration healthcare professional educational programme, defined as any type of study after a qualification which is recognised by the relevant governmental or professional bodies that enables the qualification holder entry into or continuation of work in the healthcare workforce in a more independent or senior role. Continued professional development (CPD) and continued medical education (CME) programs that involve the use of VRE-based eLearning interventions will also

be included. We define CME as “all educational activities which serve to maintain, develop, or increase the knowledge, skills, and professional performance and relationships that a physician uses to provide services for patients, the public, or the profession” (ACCME.org) and CPD as “a range of learning activities through which health and care professionals maintain and develop throughout their career to ensure that they retain their capacity to practice safely, effectively and legally within their evolving scope of practice” (hpc-uk.org).

We will include candidates for, and holders of, the qualifications listed in the Health Field of Education and Training (091) of the International Standard Classification of Education (ISCED-F) (UNESCO Institute for Statistics 2013), except students of traditional, alternative and complementary medicine. We will therefore include students from the following categories: dental studies, medicine, nursing and midwifery, medical diagnostic and treatment technology, therapy and rehabilitation, and pharmacy. Participants will not be excluded on the basis of age, sex or any other socio-demographic characteristic.

Types of interventions

We will include studies in which VREs were used to deliver the learning content of the course in health education, either as the sole or partial means (i.e. blended learning) of delivery, for the purpose of teaching, learning and/or training in pre- or post-registration health professional education. Studies which use VREs for other purposes will be excluded from this review.

We will include studies that make the following intervention comparisons:

- VR-based intervention versus traditional learning.
- VR-based intervention versus another form of VR-based intervention.
- VR-based intervention versus other types of eLearning intervention.
- VR-based intervention (where VR technology is used as the sole mode of delivery) versus a blended intervention (where VR technology is used together with another/other forms of intervention).

Only studies that report an immersive VRE as an intervention for healthcare professionals, without the participant using any additional physical objects or devices such as probes or handles for psychomotor/technical skill development, will be included in this review, i.e., this review will focus on the cognitive and affective domains in accordance with the study conducted by [Lim 2007](#). For example, surgical simulators like LapSim ([Feifer 2011](#)), which require the use of probes or other physical devices to manoeuvre through a virtual environment and perform psychomotor tasks will be excluded from this review. Such studies will be part of another systematic review under the eLearning umbrella. However, studies that include the use of a mouse or a joystick to move through a

VRE, without them being used to perform specific psychomotor tasks, will be included.

We will exclude studies that used mannequin-based trainers (eg. cardio-pulmonary resuscitation (CPR) dummies), physical 3D models of anatomy structures and human prototypes. The review will also exclude systems requiring other types of non-standard equipment like haptic devices. Studies including standardised patients will be excluded, as well as those studies where only a video of a 3D educational object is shown without the user being able to manipulate/move the object in the virtual space. Augmented reality-based interventions will also be excluded. Serious games designed for the purpose of education will be excluded as these are covered in another review conducted by our group (publication pending). Virtual patient simulation-based interventions will also be excluded from this review as these will be included in another systematic review on eLearning (publication pending), unless there is a VRE in which the participant is immersed and is interacting with the virtual patient, in which case it will be included in this review.

Types of outcome measures

Primary outcomes

- Learners' knowledge, measured using any validated or non-validated instrument to assess difference in pre- and post-test scores. If several post-test results are available, data as to when those tests were conducted will be recorded and the difference between the pre-test and the first post-test will be used for the analysis. Other tests will be used for the sensitivity analysis (see [Sensitivity analysis](#) below).
- Learners' skills, measured using any validated or non-validated instrument (e.g. pre- and post-test scores, time to perform a procedure, number of errors made whilst performing a procedure).
- Learners' professional attitudes towards patients (e.g. awareness of moral and ethical responsibilities involved in patient contact) and/or towards new clinical knowledge or skills, measured using any validated or non-validated instruments.
- Learners' satisfaction with the learning intervention, measured using any validated or non-validated instruments.

Secondary outcomes

- Patient-related outcomes (only for interventions delivered to post-registration learners).
- Cost and cost-effectiveness of the intervention.
- Adverse and/or unintended effects of VRE-based eLearning interventions for patients (e.g., patient mortality, patient morbidity, medical errors) and learners (e.g. addiction, dizziness).

Search methods for identification of studies

Electronic searches

We will search the following databases:

- MEDLINE(Ovid)
- EMBASE (Elsevier)
- Cochrane Central Register of Controlled Trials (CENTRAL) (Wiley)
- PsycINFO (Ovid)
- Educational Resource Information Centre (ERIC) (Ovid)
- Cumulative Index to Nursing and Allied Health Literature (CINAHL) (Ebsco)
- Web of Science Core Collection (Thomson Reuters)

We will use the MEDLINE strategy and keywords presented in [Appendix 1](#). This will be adapted to search the other databases. Databases will be searched from and including the year 1990 to present. The reason for selecting 1990 as the starting year for our search is because prior to this year, the use of the computer and internet was limited to very basic tasks. We will search for and include papers written in any language.

Searching other resources

For all included studies, we will search reference lists. We will search the lists of references of other relevant systematic reviews that are identified whilst running our electronic searches.

Data collection and analysis

Selection of studies

We will implement the search strategy as described in [Electronic searches](#), and import all references identified into reference manager software. The search results from the different electronic databases will be combined and we will remove duplicate records of the same studies. We will screen references in multiple steps to ensure maximum sensitivity and specificity. Two independent authors will conduct all screening steps. Firstly we (NS & BMK) will screen titles and abstracts for eligibility.

For any references where the review authors are unsure of whether the study meets the inclusion criteria, we will obtain a full-text article to aid decision-making and ultimately use a third author as an arbiter where uncertainty remains. We will retrieve the full texts of all articles that appear eligible for inclusion. Two authors will independently assess the full text of the retrieved articles against the inclusion criteria. Any disagreements will be resolved through discussion between the two authors. If no agreement can be reached, we will consult a third author. Study authors will be contacted

in the case of unclear or missing information. Studies which appeared to be relevant but are excluded at this stage will be listed in the 'Characteristics of excluded studies' table, where the reason for exclusion will be noted. Two review authors will verify the final list of included studies.

Data extraction and management

Two review authors will independently extract and manage the data for each of the included studies using a structured data recording form. We will pilot the data extraction form and amend it according to the received feedback. In addition to the usual information on study design we will extract data regarding participants, study design, interventions, controls, outcomes, and the mode of VRE intervention. We plan to contact study authors in case of any unclear or missing information. Disagreements between review authors will be resolved by discussion. A third review author will act as an arbiter in case disagreements cannot be resolved.

Assessment of risk of bias in included studies

Two review authors will independently assess the risk of bias for RCTs and cRCTs using the Cochrane Collaboration's 'Risk of bias' tool ([Higgins 2011](#)). We will pilot the 'Risk of bias' assessment between the review authors and contact study authors in case of any unclear or missing information. RCTs will be assessed for risk of bias using the following domains: random sequence generation; allocation sequence concealment; blinding (participants, personnel); blinding (outcome assessment); completeness of outcome data, selective outcome reporting; and other sources of bias (e.g., baseline imbalance, inappropriate administration of an intervention and contamination). For cluster RCTs we will also assess the risk of these additional biases: recruitment bias; baseline imbalance; loss of clusters; incorrect analysis; and comparability with individually randomised trials. Judgements concerning risk of bias for each study will be classified using 'yes', 'no' or 'unclear' indicating high, low or unclear risk of bias respectively. We will incorporate the results of the 'Risk of bias' assessment into the review using 'Risk of bias' tables, 'Summary of findings' tables, a graph and a narrative summary.

Measures of treatment effect

For continuous outcomes, we will calculate the mean difference (MD) and 95% confidence intervals (CI) for each study. For dichotomous outcomes, we will calculate the risk ratio (RR) and 95% CI. We will inflate the variances for clustering in cRCTs, when the cluster size, number of clusters and the intra-class correlation coefficient (ICC) (or estimate equivalent) will be obtained for a study. If more than one study measures the same outcome using different tools, the MDs for each study will be recalculated into standardised mean differences by dividing the study MD between groups by the standard deviation of the outcome.

Unit of analysis issues

For cRCTs, we will attempt to obtain data at the student/learner level. In cases where the statistical analysis of cRCTs has already adjusted for clustering of data, we will simply extract the reported effect estimates and use them directly for our analysis. In those cases where the individual data are not available in the study report, we will start by contacting the author(s) to request these data and then meta-analyse them using a generic inverse-variance method in Review Manager 5 (RevMan 2014), which accounts for the clustering of data. When access to individual-level data is not possible, a summary effect measurement will be extracted for each cluster. The number of clusters will be considered as the sample size and the analysis will proceed as if the trial was individually randomised. It must be noted that this technique would reduce the statistical power of the analysis.

Dealing with missing data

We will contact the original investigators for clarification or to request missing information. If we are unable to obtain this, we will use data available from the published studies and assess the risk of bias through the criterion 'incomplete outcome data'. We will not impute any missing data and will discuss all assumptions and subsequent procedures used to deal with missing values in the review. We will, where possible, conduct analyses on an intention-to-treat basis.

Assessment of heterogeneity

We will decide if it is appropriate to pool our measures of effect by assessing if the included studies are similar enough (in terms of their population, intervention characteristics, and reported outcomes) to draw meaningful conclusions. If a meta-analysis of the included studies is indicated, we will assess statistical heterogeneity by visual inspection of the scatter of effect estimates in the forest plot and by calculating the I^2 statistic (Higgins 2011), after using the inverse variance method. In the case of a high degree of heterogeneity (I^2 greater than 50%), we will explore possible reasons for variability by conducting subgroup analysis. Where we detect substantial clinical, methodological or statistical heterogeneity across included studies, we will not report pooled results from meta-analyses but will instead use a narrative approach to data synthesis. In the event of this we will attempt to explore possible clinical or methodological reasons for this variation by grouping studies that are similar in terms of populations, intervention features, methodological features, or other factors to explore differences in intervention effects.

Assessment of reporting biases

We will assess reporting bias qualitatively based on the characteristics of the included studies (eg. if only small studies that indicate

positive findings are identified for inclusion), and if information that we obtain from contacting experts and authors or studies suggests that there are relevant unpublished studies. If we include at least 10 studies, we will assess reporting bias using a funnel plot regression weighed by the inverse of the pooled variance. A regression slope of zero will be interpreted as absence of small study bias.

Data synthesis

Data will be reported using Review Manager software (RevMan 2014). Extracted data will be entered into tables grouped by study design and type of intervention to create a descriptive synthesis. The results of individual RCTs and cRCTs will be reported as mean differences for continuous variables and risk ratios for dichotomous variables with 95% confidence intervals (CI).

Using Miller's classification of clinical competence (Miller 1990) the different types of tests of students' knowledge and skills will be grouped and analysed together. For example, multiple choice questions (MCQs) assessing knowledge (i.e. knows) will be analysed together, and essay questions assessing competence (i.e. knows how) will be analysed together. The focus will therefore be on the testing method rather than the delivery method (i.e. if skills were assessed by a knowledge test they would be categorised as knowledge).

For learners' professional attitudes the different types of assessment will be grouped and analysed as cognitive attitudes, behavioural attitudes or affective attitudes as described by Martin 2002. Learners' satisfaction will include the satisfaction and attitudes towards the learning intervention to which they were exposed. Learners' professional attitudes and satisfaction will only be assessed narratively, as preliminary work conducted by the Global eHealth Unit suggests that there is a high level of heterogeneity in the operational definition of these outcomes across different studies (WHO 2013; George 2014; Rasmussen 2014).

Where studies report more than one measure for each outcome, the primary measure as defined by the primary study authors will be used in the analysis. Where no primary measure has been reported, a mean value of all the measures for the outcome will be calculated and used in the analysis. The choice of model would depend on the level of heterogeneity (assessed as described in Assessment of heterogeneity) of the studies included in the meta-analysis. If meta-analysis is feasible, we will use a random-effects model, which provides a more conservative estimate of effect and can be used where there is moderate heterogeneity. We will separately report interventions for pre- and post-registration healthcare professionals. We will include the intention-to-treat analysis of the results in the meta-analysis.

Subgroup analysis and investigation of heterogeneity

We will conduct the following subgroup analyses (i.e. stratified analyses) in this review:

- Stratified by countries' income status (low- and middle-income countries versus high-income countries).
- Stratified by registration stage (pre- and post-registration interventions).
- Stratified by type of studies (i.e. dental studies, medicine, nursing and midwifery, medical diagnostic and treatment technology, therapy and rehabilitation, and pharmacy).
- Stratified by type of VRE-based intervention.
- Stratified by studies that implemented VRE on a regular basis in the curriculum or not.
- Stratified by number of repeated interventions (one-off versus repeated interventions).

We acknowledge that there are many other subgroup analysis that could be performed, for example comparing interventions according to learning objectives and interactivity of interventions. In future reviews conducted after completion of our series of initial reviews, we will be in a better position to look at these subgroup analyses, because such comparisons would be most meaningful from the perspective of an educator if multiple methods of eLearning were to be compared.

Sensitivity analysis

Sensitivity analyses will be considered to explore the impact of the 'Risk of bias' dimensions on the outcomes of the review. We will remove studies from the analysis deemed to be at high risk of bias after examination of individual study characteristics; to examine the effect on the pooled effects of the intervention. We will exclude studies according to the following filters:

- High risk of bias studies.
- Small studies.
- Source of funding, divided into: industry sponsorship (solely industry funded), mixed sponsorship (public and industry funded, including free provision of study material only), non-industry sponsorship (solely public funded and no free provision of material), not described.
- Time lapse between end of intervention and first post-test (quartiles), as well as last post-test.

- If studies compared more than one VRE or blended learning intervention to traditional learning, we will perform a sensitivity analysis to assess the impact of successively replacing the results of each intervention group on the measure of effect. Additionally, we will average the mean scores for each intervention group and use this average in the meta-analysis. We will then compare the difference between the two approaches.

'Summary of findings' table

We intend to prepare a 'Summary of findings' table to present the meta-analysis results, based on the methods described in chapter 11 of the *Cochrane Handbook for Systematic Reviews of Interventions* (Schünemann 2011). We will present the results of meta-analyses for the major comparisons of the review, for each of the major primary outcomes as well as potential adverse effects, as defined in the [Types of outcome measures](#) section. We will provide a source and rationale for each assumed risk cited in the table(s). Two authors will use the GRADE criteria to rank the quality of the evidence using the GRADE profiler (GRADEpro) software (Schünemann 2011). If meta-analysis is not feasible, we will present results in a narrative 'Summary of findings' table format, such as that used by Chan 2011 (Chan 2011; CCCRG 2014).

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* Indicates the major publication for the study

APPENDICES

Appendix I. MEDLINE (Ovid) search strategy

1. exp education, professional/ not education, veterinary/
2. Education, Predental/
3. Education, Premedical/
4. exp Students, Health Occupations/
5. ((*medic** or *premedic** or *dent** or *laborator** or *predent** or *midwi?e** or *nurs** or *nutrition** or *orthop** or *podiat** or *pharmac** or *psycholog** or *psychiatr** or *health* or *healthcare* or *occupational therap** or *physiotherap** or *physical therap** or *clinical* or *surg** or *radiolog** or *obstetric** or *gyn?ecolog** or *orthodont** or *An?esthesi** or *Dermatolog** or *Oncolog** or *Rheumatolog** or *Neurolog** or *Patholog** or *P?ediatric** or *Cardiolog** or *Urolog**) adj3 (*student** or *graduate** or *undergraduate** or *staff* or *personnel* or *practitioner** or *clerk** or *fellow** or *internship** or *residen** or *educat** or *train** or *novice** or *tutor**)).tw,kf.
6. or/1-5
7. Computer-Assisted Instruction/
8. exp Internet/
9. Computer Simulation/
10. Patient Simulation/
11. software/
12. Mobile Applications/
13. User-Computer Interface/
14. Video Games/
15. Web Browser/
16. Education, Distance/
17. Computers/
18. exp Microcomputers/
19. exp Cell Phones/
20. Games, Experimental/

21. exp Models, Anatomic/
22. Audiovisual Aids/
23. Educational Technology/
24. Electronic Mail/
25. exp Telemedicine/
26. Telenursing/
27. Telecommunications/
28. Webcasts/
29. exp Videoconferencing/
30. ((computer* or digital* or hybrid or blended or mixed mode or distance or remote* or electronic or mobile or online* or interactiv* or multimedia or internet or web* or virtual* or game* or gaming or Videogame* or Videogaming) adj3 (classroom* or course* or educat* or instruct* or learn* or lecture* or simulat* or train* or teach* or tutor* or platform*)).tw,kf.
31. (Simulat* adj3 (course* or educat* or instruct* or learn* or train* or teach* or platform* or high-fidelity)).tw,kf.
32. e-learn*.tw,kf.
33. elearn*.tw,kf.
34. m-learn*.tw,kf.
35. mlearn*.tw,kf.
36. smartphone*.tw,kf.
37. smart-phone*.tw,kf.
38. ((mobile or cell) adj2 phone*).tw,kf.
39. iphone*.tw,kf.
40. android*.tw,kf.
41. ipad*.tw,kf.
42. Personal digital assistant*.tw,kf.
43. handheld computer*.tw,kf.
44. Mobile App?.tw,kf.
45. Mobile Application?.tw,kf.
46. webcast*.tw,kf.
47. webinar*.tw,kf.
48. flipped classroom*.tw,kf.
49. Serious game*.tw,kf.
50. Serious gaming.tw,kf.
51. Patient Simulat*.tw,kf.
52. Virtual patient*.tw,kf.
53. ((educat* or instruct* or learn* or simulat* or train* or teach* or interactiv*) adj2 technolog*).tw,kf.
54. Massive Open Online Course?.tw,kf.
55. Mooc?.tw,kf.
56. (Canvas network or Coursera or Coursesites or edx or Futurelearn or iversity or miriada x or moodle or novoed or openlearning or open2study or plato or spoc or udacity or pingpong).tw,kf.
57. or/7-56
58. 6 and 57
59. Education.fs.
60. Education/
61. Teaching/
62. Learning/
63. exp Inservice Training/
64. Curriculum/
65. educat*.tw,kf.
66. learn*.tw,kf.
67. train*.tw,kf.
68. instruct*.tw,kf.
69. teach*.tw,kf.
70. or/59-69

71. Health Personnel/
72. exp Allied Health Personnel/
73. Anatomists/
74. "Coroners and Medical Examiners"/
75. exp Dental Staff/
76. exp Dentists/
77. Health Educators/
78. Infection Control Practitioners/
79. Medical Laboratory Personnel/
80. exp Medical Staff/
81. exp Nurses/
82. exp Nursing Staff/
83. Personnel, Hospital/
84. Pharmacists/
85. exp Physicians/
86. Physician*.tw,kf.
87. Doctor*.tw,kf.
88. Nurs*.tw,kf.
89. Surg*.tw,kf.
90. Health Personnel.tw,kf.
91. healthcare professional*.tw,kf.
92. radiolog*.tw,kf.
93. dentist*.tw,kf.
94. Pharmacist*.tw,kf.
95. Hospital Administrator*.tw,kf.
96. Podiatr*.tw,kf.
97. Psycholog*.tw,kf.
98. Psychiatr*.tw,kf.
99. An?esthesi*.tw,kf.
100. Clinician*.tw,kf.
101. Dermatolog*.tw,kf.
102. General practioner*.tw,kf.
103. Cardiolog*.tw,kf.
104. Oncolog*.tw,kf.
105. Rheumatolog*.tw,kf.
106. Neurolog*.tw,kf.
107. Patholog*.tw,kf.
108. P?ediatric*.tw,kf.
109. Physiotherap*.tw,kf.
110. Physical therap*.tw,kf.
111. Occupational therap*.tw,kf.
112. dieti?ian*.tw,kf.
113. Dietetic*.tw,kf.
114. midwi?e*.tw,kf.
115. nutrition*.tw,kf.
116. orthopti*.tw,kf.
117. obstetric*.tw,kf.
118. gyn?ecolog*.tw,kf.
119. orthodont*.tw,kf.
120. Urolog*.tw,kf.
121. or/71-120
122. Health Occupations/
123. exp Allied Health Occupations/

124. Biomedical Engineering/
125. Chiropractic/
126. exp Dentistry/
127. exp Evidence-Based Practice/
128. exp Medicine/
129. exp Nursing/
130. Dietetics/
131. Optometry/
132. Orthoptics/
133. exp Pharmacology/
134. exp Pharmacy/
135. Podiatry/
136. Psychology, Medical/
137. Serology/
138. Specialization/
139. exp Surgical Procedures, Operative/
140. exp Radiography/
141. or/122-140
142. 121 or 141
143. 57 and 70 and 142
144. Psychomotor Performance/
145. motor skills/
146. ((psychomotor or procedural or technical) adj3 skill*).tw,kf.
147. (psychomotor adj3 performance).tw,kf.
148. or/144-147
149. 6 and 148
150. 58 or 143 or 149
151. limit 150 to yr="1990 -Current"

CONTRIBUTIONS OF AUTHORS

JC conceived the idea for the review. NS and BMK wrote the protocol. LTC provided methodological guidance, drafted some of the methodology-related sections and critically revised the protocol. JV, PD, PP, KLTK, AK, IM, CKN, NZ and JC provided comments on the protocol.

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PD is co-founder of two companies that create virtual reality environments. The companies are Innovation in Learning, Inc. and SimTabs LLC. However, both companies did not have any direct or indirect involvement in the protocol development. All other authors have no known conflicts of interest.

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- No sources of support supplied