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Effectiveness of virtual and augmented reality for improving knowledge and skills in medical students: protocol for a systematic review

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ABSTRACT

Introduction Virtual reality (VR) and augmented reality (AR) technologies are increasingly being used in undergraduate medical education. We aim to evaluate the effectiveness of VR and AR technologies for improving knowledge and skills in medical students.

Methods and analysis Using Best Evidence in Medical Education (BEME) collaboration guidelines, we will search MEDLINE (via PubMed), Education Resources Information Center, PsycINFO, Web of Knowledge, Embase and the Cochrane Central Register of Controlled Trials for English-language records, from January 1990 to March 2021. Randomised trials that studied the use of VR or AR devices for teaching medical students will be included. Studies that assessed other healthcare professionals, or did not have a comparator group, will be excluded. The primary outcome measures relate to medical students' knowledge and clinical skills. Two reviewers will independently screen studies and assess eligibility based on our prespecified eligibility criteria, and then extract data from each eligible study using a modified BEME coding form. Any disagreements will be resolved by discussion or, if necessary, the involvement of a third reviewer. The BEME Quality Indicators checklist and the Cochrane Risk of Bias Tool will be used to assess the quality of the body of evidence. Where data are of sufficient homogeneity, a meta-analysis using a random-effects model will be conducted. Otherwise, a narrative synthesis approach will be taken and studies will be evaluated based on Kirkpatrick's levels of educational outcomes and the Synthesis Without Meta-analysis guidelines.

Ethics and dissemination Ethical approval is not required for this systematic review as no primary data are being collected. We will disseminate the findings of this review through scientific conferences and through publication in a peer-reviewed journal.

Strengths and limitations of this study

- ► First systematic review assessing the effectiveness of virtual reality and augmented reality technologies for improving knowledge and skills outcomes in medical students.
- ► A rigorous search strategy will be employed, which will involve searching multiple databases, grey literature and for non-indexed trials.
- ► The quality of evidence will be assessed using the Best Evidence in Medical Education Quality Indicators checklist and the Cochrane Risk of Bias Tool.
- ► Limitations include the likely heterogeneity of interventions and outcomes investigated.

INTRODUCTION

The acquisition of clinical and examination skills is a vital component of medical education.[1] Traditionally, the acquisition of such skills has been via mentorship models from senior clinicians in clinical environments. However, due to increased clinical loads and reduced working hours, it is often difficult for trainees to have the same exposure to practical skills as their predecessors.[2] Furthermore, due to increasing infection control risks and costs associated with training practical skills, the need to develop alternative teaching environments is pressing.[3 4] One solution is the use of immersive technologies for education, which place students in a virtual environment whereby they can perform practical procedures as well as interact with a variety of simulated clinical scenarios. This can be useful in the development of physical examination skills (through using sound, tactile and visual examination findings), development of basic life support skills, surgical training and human anatomy.[5–7] Some advantages of such technologies include that they allow for spaced repetition, reduce time burden on senior clinicians and permit students to practice in their own time. The use of simulators also provide real-time feedback, and record data from different attempts, to compare to those of different levels of expertise.[8]

In medical education, the three main types of technology used to construct these simulated environments are: virtual reality

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Table 1 Definitions of terms used in this study

Term (as defined by Moro *et al*[9])	Abbreviation
Undergraduate medical education	Medical students are described as any student undertaking a course of study at a medical school to reach a primary qualification in medicine, enabling them to practice as doctors
Virtual Reality (VR)	Immersion of a user in a synthetic environment, experienced through their senses (sight, hearing and motion), which mimics properties of the real world through head mounted displays, stereo headphones and motion tracking systems.
Augmented Reality (AR)	Superimposition of digital models on to the real world, using a camera and a screen (eg, smartphone or tablet). Users can then interact with the virtual and real-world elements of their environment.
Mixed Reality (MR)	A significant advancement of AR, whereby virtual objects can be mapped onto the real world. MR headset devices present holographic renderings of images in their display, which can be interacted with.

AR, augmented reality; MR, mixed reality; VR, virtual reality.

(VR), augmented reality (AR) and mixed reality (MR) (as defined by Moro *et al*,[9] in table 1). VR is in essence a method that 'provides a three-dimensional (3D) and dynamic view of structures and the ability of the user to interact with them' via a digital interface.[10] AR is a composite view produced by the superimposing of a computer generated image over a user's view on the real world (eg, using your phone to project an image onto a table). MR is an advancement of AR in that it is multisensory and generally involves the use of a computer headset, earphones and tactile gloves to enhance sensory feedback from the clinical scenario and make it as realistic as possible; however, unlike VR it does not take place within a wholly virtual environment, with certain aspects (ie, the background) still remaining 'real'.

E-Learning and current literature

The use of e-learning in medical education has been explored to varying degrees in the literature. A recent review exploring the barriers and solutions to online learning in medical education identified the need for institutional support and a clear strategy on how e-tools and programmes should be applied, as their application was often undirected and unsuccessful.[8] They also identified the necessity of interfaculty collaboration to create a cohesive e-learning system. Further barriers to successful e-learning included poor technical skills, educational skills and training, which could be addressed by improving the training of educators in computational literacy.[11] Immersive technologies, which constitute one modality of e-learning, are being increasingly used to improve knowledge and skills outcomes. Further research into their role and effectiveness would build the required evidence base for industry and medical education bodies to enhance the development and uptake of e-learning.

There have been a number of reviews exploring the use of VR tools for healthcare professionals in different stages of their training, and the vast majority have called for further research in the area. The reviews have primarily focused on healthcare professionals acquiring specific surgical skills (eg, laparoscopy, ear, nose and throat (ENT), ophthalmology) or learning a particular clinical procedure.[12–14] A recent comprehensive review evaluated the effectiveness of VR in educating health professionals, and found it to improve knowledge and skills outcomes. However, it focused on all healthcare professionals, and therefore, may have included clinical skills which are not relevant for medical students.[15] While the review attempted to extract outcome measures relating to postintervention knowledge, skills, attitudes, satisfaction and change in behaviour, almost all of the included studies captured either knowledge or skills outcomes. Although extensive, the review only searched for articles up to 2017, since which there have been several studies published.[5 9 16–21] Furthermore, it did not describe the types of intervention used and only included information on their effectiveness. A Cochrane systematic review in 2015[18] aimed to explore the evidence base for introducing VR into ENT training programmes. The studies assessed the technical skills of both surgical trainees and medical students in controlled environments, for either endoscopic sinus or temporal bone surgery. Nine studies were analysed, of which four included medical students. These studies suggested that VR simulation could be a useful supplementary learning tool for medical students, showing improved anatomical identification scores (MD 4.3, 95% CI 2.31 to 6.29) after use of VR simulators. A systematic review by Tang *et al*[22] investigated the current state and role of AR technologies in medical education. It showed current uses for AR include surgical training, anatomy teaching and as a component of the blended learning approach. Crucially, however, it identified the lack of a review which explores the effectiveness of AR technologies in medical education, and of a standardised assessment tool.

Given the current state of the literature and the burgeoning interest in using immersive technologies to teach medical students, a review is warranted to provide educators as well as researchers with a better understanding of the uses of these tools as documented in the literature, and with information on their effectiveness compared with standard practice. As such, this review aims to evaluate the effectiveness of VR and AR technologies for improving postintervention knowledge and skills outcomes in medical students. It will also describe the characteristics and objectives of the identified devices, as indicated in the literature. Our findings will inform

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medical schools and educational bodies on the current state and effectiveness of immersive technologies in undergraduate medical education and will help shape the design of future curricula.

METHODS AND ANALYSIS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Protocols guidelines were used to facilitate development of this protocol, see online supplemental appendix 1. We will use the Best Evidence in Medical Education (BEME) collaboration guidelines to conduct our systematic review to answer the following research questions:

1. Are VR technologies effective at improving knowledge and skills outcomes in medical students?
2. Are AR technologies effective at improving knowledge and skills outcomes in medical students?

BEME guidelines were chosen as the systematic review framework due to their specificity to medical education methodology. Any significant amendments made to our protocol will be documented and published with the results of our systematic review. Reporting of the review will be informed by the PRISMA guidance and the Synthesis Without Meta-analysis guidelines.[23]

The review has been submitted to and is awaiting registration on the International Prospective Register of Systematic Reviews (ID 250531).

Inclusion criteria

The inclusion and exclusion criteria are summarised in table 2.

Population

Only studies including medical students in undergraduate medical education will be included in this review; those focused only on medical professionals or postgraduate learners will be excluded. Studies with both undergraduate and postgraduate learners will be included if data relating to undergraduate students can be separately analysed.

Intervention

Due to the varied nature of VR simulators and the environment being simulated, it is difficult to define what constitutes immersive (VR, AR and MR) technologies. However, we have provided our definitions of these (table 1), and will include all VR/AR delivery devices and levels of immersion. In order to include all relevant studies, all spatially immersive visualisation technologies which simulate an interactive 3D environment will be included, whether or not they include tactile feedback or other sensory feedback.

Study design and comparators

Randomised trials which provide primary data for our outcomes will be included. We will evaluate and interpret data and results carefully in the context of their design and will assess and report the quality of each study type.

Table 2 Inclusion and exclusion criteria for the proposed study based on a PICO format

	Inclusion criteria	Exclusion criteria
Population	Medical students Undergraduate medical education	Only includes healthcare professionals or postgraduate learners (ie, no medical students)
Intervention	VR, AR and MR technologies	Interventions not explicitly using VR, AR or MR technologies
Comparator	Traditional or alternative teaching methods or techniques (any teaching method not using the same VR/AR), where possible.	
Outcomes	Medical students' knowledge (pre-test and post-test scores). Medical students' skills	
Study type	Randomised trials	Non-randomised trials Qualitative studies Systematic reviews Meta-analyses Letters to the editor Case studies Studies without a comparator group Uncontrolled before-and-after studies

AR, augmented reality; MR, mixed-reality; VR, virtual reality.

We will compare primary outcomes against traditional teaching methods or techniques (which do not use VR/AR).

Outcome measures

As there is significant heterogeneity in the tasks conducted in VR/AR environments as well as the type of VR/AR used, outlining one specific outcome measure to be extracted is not achievable.[24] Instead, primary outcome measures relating to medical students' knowledge and skills will be extracted.

Knowledge will be defined as students' factual or conceptual understanding, and measured using any validated or non-validated instrument to obtain pretest and post-test scores. In the case of multiple post-test results, the difference between the pretest and first post-test will be calculated to include in our analysis.

Skills will be defined as students' ability to demonstrate a technique or procedure, and measured using validated

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or non-validated instruments (eg, to obtain pretest and post-test scores, task performance/errors, observed assessment scores).

Search strategy and sources

We will identify studies by searching the following electronic databases: MEDLINE (via PubMed), Education Resources Information Center, PsycINFO, Web of Knowledge, Embase and the Cochrane Central Register of Controlled Trials.

Databases will be searched for English-language records, from January 1990 to March 2021. Prior to 1990, the use of digital technologies was limited to basic tasks. Additional relevant studies will be identified based on expert knowledge of the reviewers. Grey literature will be identified by emailing primary authors of included studies and searching conference abstracts from relevant meetings.

We will develop our search strategy using a combination of Medical Subject Headings and keywords related to the following concepts: VR, AR and undergraduate medical education (medical school/medical students). A full electronic search strategy for PubMed is included in online supplemental appendix 2.

Patient and public involvement

No patient involved.

Data collection

Two reviewers (NA and NN) will identify studies which fit our inclusion/exclusion criteria independently using titles and abstracts. If there is any disagreement, then a discussion will take place between the two reviewers using the full text of the article in question. If there is still disagreement, then a third reviewer (AK) will be consulted. Cohen's kappa, a measure that identifies the level of agreement between our reviewers, will be calculated as well.[25] A web-based app called Rayyan will be used to track studies that have been identified.[26]

As per PRISMA guidelines, a flow chart will be created once this has been completed to identify the number of studies found using our search terms, the final number of studies and the reason for exclusion of studies not included.[27]

Data extraction and management

All data extraction from relevant studies will be carried out by two independent reviewers (NA and NN), using a modified version of the BEME coding form which will also include data on several measures, as seen in table 3. Both authors will go through a process of orientation to the tool, before full extraction, to ensure inter-rater reliability to a kappa of at least 0.80 agreement. If needed, a third reviewer will be consulted to resolve disagreements (AK).

Quality assessment

Two independent reviewers (NN and NA) will conduct a risk of bias assessment, and similar to our study selection, if there are any points of disagreement which cannot be resolved then a third reviewer (DMN) will be consulted. We will conduct a formal risk of bias assessment for randomised trials using The Cochrane Risk of Bias Tool.[28] The BEME Quality indicators checklist, developed by Buckley *et al*[29] will be used to evaluate internal validity. The checklist consists of 11 criteria, listed in table 4, which are designed specifically for studies in medical education as per the recommendations of the BEME collaboration. Each criterion can be listed as 'met, 'unmet' or 'unclear' and a study is required to meet a minimum of seven indicators in order to be deemed high quality.

Table 3 Types of data that will be extracted

Study	Authors Date of publication Study design Characteristics of control Country Funding
Population	Sample size of both arms Sex proportion Mean age
Intervention	Type of VR, AR or MR device used, including platform. Type of teaching method or technique Characteristics of control method/technique 3-DOF or 6-Degrees of Freedom (DoF) VR simulator Interactive or not interactive Duration of the session No of sessions Task given or skill being developed
Outcome measures	Students' knowledge postintervention Students' skills postintervention

AR, augmented reality; MR, mixed-reality; VR, virtual reality.

Synthesis of extracted evidence

First, we will describe all studies that met the inclusion criteria, based on the information extracted using table 3. Information on the type of VR or AR device used, their characteristics, and on the task given or skill being developed (eg, basic scientific knowledge or clinical skill), will provide insights into the role/use of each of the VR or AR technologies being used.

We will take an iterative and responsive approach as we proceed through data extraction and evaluate studies. Where we find sufficient homogeneity to combine, we will follow standard methods for meta-analysis in the Cochrane Handbook, using the random-effects model.[28] In the case of heterogeneous data, we will conduct a comprehensive narrative synthesis of the evidence, and will group and report studies according to a modification of Kirkpatrick's levels of educational outcomes (hierarchy).[30] Narrative synthesis is often criticised for the lack of transparency in the methods used; to aid transparency,

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Table 4 BEME quality indicators checklist specific to studies in medical education

	Questions
Research question	Is the research question or hypothesis clearly stated?
Study subjects	Is the subject group appropriate for the study being carried out?
Data collection methods	Are the methods used appropriate for the research question and context?
Completeness of data	Attrition rates/acceptable questionnaire response rates
Risk of bias assessment	Is a statement of author positionality and a risk of bias assessment included?
Analysis of results	Are the statistical and other methods of results analysis used appropriate?
Conclusions	Is it clear that the data justify the conclusions drawn?
Reproducibility	Could the study be repeated by other researchers?
Prospective	Is the study prospective?
Ethical issues	Are all ethical issues articulated and managed appropriately?
Triangulation	Were the results supported by data from more than one source?

BEME, Best Evidence in Medical Education.

we will use the recent Synthesis Without Meta-analysis guidelines.[23]

DISCUSSION

The findings of this review will inform educators and institutions around the world on the effectiveness of VR and AR devices for teaching medical students and on how they are being used. This will provide useful information for organising bodies and medical schools when designing future curricula and developing educational interventions.

The outcomes for educational practice include improving the delivery of digital education, and ensuring that investment in digital technologies, including VR and AR, for medical schools, is justified. Institutions will be better informed when exploring such devices, and will be able to ensure they are tailored to and have been tested for, the needs of their students

In future, this review could also be used to develop a set of outcome criteria for testing and deploying immersive technologies.

ETHICS AND DISSEMINATION

Ethical approval is not required for this systematic review as no primary data are being collected. We will disseminate the findings of this review at scientific conferences and through publication in a peer-reviewed journal.

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