

A RAPID REVIEW OF EXTENDED REALITY SOLUTIONS FOR UK UNDERGRADUATE CLINICAL SKILLS

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ABSTRACT

Introduction: Extended Reality (XR) combines the physical world with a computer-generated one, across a reality-virtuality continuum. There is good evidence that XR can promote learning, with reasonable evidence for improving healthcare learner knowledge, moderate evidence for changing healthcare learner attitudes, and less good evidence for improving healthcare learner performance, including performance of clinical skills. The General Medical Council mandates competence in 23 procedural skills and additional wider clinical skills for UK medical undergraduates.

Methods: We undertook a rapid review to identify XR solutions which may improve clinical skills performance.

Results: Four databases were searched for relevant articles, yielding 7167 records, of which 41 studies were included in the review. Data were extracted on study population, intervention, comparator, and outcome. 22 studies were included in the narrative synthesis.

Conclusions: Recommendations were made for pilot implementation of XR solutions in UK undergraduate clinical skills curricula, and the next steps required to assess their impact.

Keywords: augmented reality, clinical skills, extended reality, mixed reality, virtual reality

INTRODUCTION

XR

XR describes any combination of the real world with computer-generated assets: on one end of this reality-virtuality continuum sits physical reality; at the other end exists an entirely artificial world or Virtual Reality (VR) (Milgram and Kishino 1994). Between these extremes lies Mixed Reality

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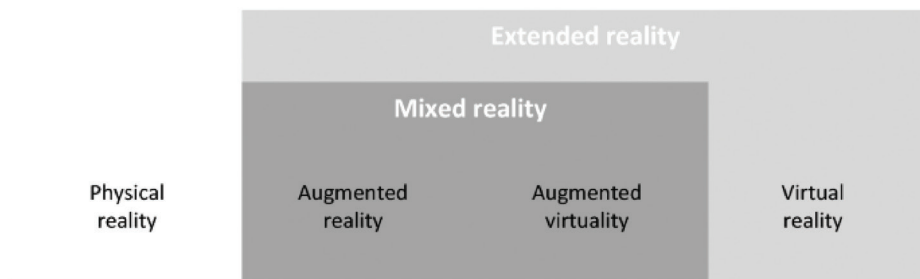


Figure 1. Reality-virtuality continuum (Isabel et al. 2020)

(MR): Augmented Reality (AR) describes the augmentation of physical reality with computer-generated assets, and Augmented Virtuality (AV) describes the augmentation of VR with real-world objects, often allowing for interaction between the two (Rauschnabel *et al.* 2022). MR is an umbrella term for AR and AV; XR is an umbrella term for MR and VR (see Figure 1).

These technologies can be applied across a further spectrum from non-immersive to immersive, including mobile and hybrid approaches: immersive VR was initially developed for entertainment, which is still its predominant use (Stromberga *et al.* 2021). However, head-mounted displays (HMDs) can trigger migraines, vertigo, and travel sickness ('cybersickness') in some users (Y.P. Chao *et al.* 2021); AV induces fewer of these side-effects (Moro *et al.* 2017), and mobile XR fewer still (Moro *et al.* 2021).

XR IN EDUCATION

XR has been applied to education, where it falls under the broader remit of Technology-Enhanced Learning (TEL), which is non-inferior (and possibly superior) to traditional teaching, including for healthcare (Kyaw *et al.* 2019a). With the ubiquity of smartphones and similar mobile devices, mobile TEL is an attractive proposition for scalable and accessible teaching (Navaratnam *et al.* 2022).

XR realises various positive affordances: it can be applied to experiential learning theories, where the egocentric, embodied experience improves learning (Kilteni *et al.* 2012). It can enable simulation (or part-simulation) in a risk-free environment which allows for learning from errors (Akgün and Atici 2022); or it can be used to construct the visuospatial structure for a memory palace (Ranpariya *et al.* 2022). XR has also been applied to game-informed learning techniques (Mansoori *et al.* 2021), where the inclusion of branching and looping scenarios (Berger *et al.* 2018; Bernaitis *et al.* 2018), and access to web-based resources (Burg and Finlay 2016), can promote learning.

Increasing fidelity may benefit confidence (Mather and McCarthy 2021), learning (Mills *et al.* 2016) and cost-effectiveness (Isaranuwachai *et al.* 2014); however, feedback, in one of many forms, remains vital for crystallising learning (Atthill *et al.* 2021).

The educational benefits of XR are dependent on learner demographics, including prior videogame experience, musical instrument playing (Madan *et al.* 2008; Winkler-Schwartz *et al.* 2016), and learner age (Cobb *et al.* 2009); older computers may reduce effectiveness (Kidd *et al.* 2012). Educators must therefore prioritise inclusivity of any implemented XR.

XR IN HEALTHCARE EDUCATION

XR was first developed as a medical education tool by military organisations to train orthopaedic and battlefield medicine, which has led to virtual disaster triage packages (Gout *et al.* 2020) and paramedical training (Mills *et al.* 2020). As consumer HMDs' popularity reduced costs, XR extended into postgraduate surgical education (Lesch *et al.* 2020); with the advent of the COVID-19 pandemic, significant external pressure towards remote and virtual learning further promoted the uptake of XR in medical education (Bala *et al.* 2021).

KNOWLEDGE

There is low-to-moderate grade evidence that VR as an overall modality improves postintervention medical knowledge and skills, compared with traditional or digital educational approaches (Kyaw *et al.* 2019b); XR technology can also prolong learning retention (Gan *et al.* 2023).

XR can provide an innovative method for providing more engaging problem-based learning (Alverson *et al.* 2008; Conradi *et al.* 2009) and interprofessional learning (Williams *et al.* 2020; Bjorklund and Silen 2021). These interventions can improve knowledge in basic sciences, particularly anatomy (Moro *et al.* 2017; Imai *et al.* 2022; Kolecki *et al.* 2022) – which can improve clinical examination skills (Chen *et al.* 2021) and biopsy skills (Farshad-Amacker *et al.* 2023) – and neuroanatomy (Kockro *et al.* 2015); dermatology (Garg 2010), embryology (Ryan *et al.* 2023), pathology (Wilson *et al.* 2020; Pfeil *et al.* 2024), pharmacology (Richardson *et al.* 2013; Bernaitis *et al.* 2018; Hanson *et al.* 2019; Hanson *et al.* 2020; Rakofsky *et al.* 2020; Kim *et al.* 2023), physiology (Nakhoul *et al.* 2022), pathophysiology (Jayasundera *et al.* 2022), parasitology (Sattar *et al.* 2019), and radiology (Drapkin *et al.* 2015). It can also be used for patient education for a variety of conditions (Lau *et al.* 2021; Saab 2021; Vandeweerd *et al.* 2022).

ATTITUDES

XR modalities can increase healthcare student exposure to LGBTQI+ patients (Jones *et al.* 2014; Hannans 2023); vulnerable patient groups (Chuah *et al.* 2013; Drewett *et al.* 2018), including children (Yang *et al.* 2021) who are otherwise difficult to simulate with actors, mental illness sufferers (Lee *et al.* 2020), and patients at the end of their lives (Clabburn *et al.* 2020; Elzie and Shaia 2021); and

racially diverse patients (Hollister *et al.* 2022), which can improve empathy towards racial minorities (Roswell *et al.* 2020). XR interventions can increase the volume of student exposure to intimate examinations, including prostate (Robb *et al.* 2013), vaginal (Cheung *et al.* 2023) and breast (Deladisma *et al.* 2009) examinations; they can also provide risk-free exposure to potentially dangerous health service users (Clay *et al.* 2021).

XR solutions can improve student empathy towards various groups of patients, including children, pregnant women (Chang *et al.* 2022), perioperative patients (Kim *et al.* 2021), older patients (Washington and Shaw 2019), patients with diseases including diabetes (McCalla *et al.* 2023) and dementia (Newman *et al.* 2021; Chan *et al.* 2023; Nakazawa *et al.* 2023), and patients at the end of life (Minukhin 2020). XR can improve empathy and reduce stigma towards mental health (Silva *et al.* 2017; Zare-Bidaki *et al.* 2022; Rodriguez-Rivas *et al.* 2024), and disability (McLaughlin *et al.* 2020). XR education of healthcare workers can reduce parental vaccine refusal for children (Real *et al.* 2017).

XR packages can target student attitudes towards the social determinants of health (Buitron de la Vega *et al.* 2022), climate change and sustainability (Lee *et al.* 2024), antimicrobial guardianship (Kyaw *et al.* 2019c), and resource stewardship (Zhou *et al.* 2019). They can also increase student interest in under-staffed specialities (Hardcastle and Wood 2018; Washington and Shaw 2019; Deuchler *et al.* 2022): this extends to secondary school students, where interventions can increase the diversity applicants to healthcare programs (Metcalf 2016).

PERFORMANCE

Recent studies have found that VR is superior to traditional education for procedural skills – though there is less evidence for undergraduate skills (Zhao *et al.* 2021). For non-technical skills, XR can improve orientation and initial learner confidence in wayfinding (Halfer and Rosenheck 2014), and norms in operating theatres and procedure rooms (Francis *et al.* 2020; Fukuta *et al.* 2021); it can also improve leadership skills (Thomson 2023), and team VR training can reduce error rates through improved teamworking skills (Edwards *et al.* 2023).

Performance in XR simulation can correlate knowledge and performance of clinical skills (Lowe *et al.* 2020), so can be used for assessment of clinical skills (Botezatu *et al.* 2010), including safe patient escalation (Zackoff *et al.* 2021), leading to the development of remote and virtual Objective Structured Clinical Examinations (OSCEs) (Kazemi *et al.* 2010; McGrath *et al.* 2015; Rakofsky *et al.* 2020; García-Seoane *et al.* 2021). These results can help determine selection of surgical trainees (McClusky *et al.* 2005; Winkler-Schwartz *et al.* 2016).

360 degree videos, often viewed on HMDs, and often self-authored by educational institutions, are a particularly successful modality: they can improve learner interest and engagement (Taubert *et al.* 2019; Curran *et al.* 2022); overall exam performance (Petrica *et al.* 2021; Trapero *et al.* 2023), communication

skills performance (Sultan *et al.* 2019), and can encourage the incorporation of medical ethics into clinical decision-making (Torda 2020). They are superior to 2D video for pre-learning of nasogastric tube insertion (Y.C. Chao *et al.* 2021), suturing (Yoganathan *et al.* 2018), and universal precautions (Omori *et al.* 2023); they are equivalent to 2D video for pre-learning of Surgical Scrub (Harrison *et al.* 2017) and respiratory examination (Chen *et al.* 2017). As a standalone self-directed resource, they are superior to traditional simulation alone for trauma skills training (Hainsworth *et al.* 2022), and equivalent to hybrid simulation for clinical reasoning in opioid overdose (Giordano *et al.* 2020). Viewing radiological and surgical images and models on HMDs is superior to viewing the same on computer screens (Imai *et al.* 2022).

Telestration and telementoring of procedures (Schoeb *et al.* 2020; Glick *et al.* 2021), where experts live-stream their perspective to students, or students stream their view to experts (Hale *et al.* 2022), can improve learning, including through teaching students where to look during procedures (Felinska *et al.* 2023); in low-resource, remote, or socially-distanced settings, virtual wards and ward rounds, and bedside and grand round teaching, can compensate for reduced clinical exposure (Bala *et al.* 2021).

MISCONCEPTIONS

Most Virtual Patient (VP) packages involve linear or branching and looping text screens with associated images, and interventions can improve knowledge (Horstmann *et al.* 2009; Menendez *et al.* 2015; Berman and Artino 2018), clinical reasoning (Forsberg *et al.* 2011), cultural competence (Rothlind *et al.* 2021), and metacognition (Yeo and Jang 2023). VPs can foster interprofessional learning (Tran *et al.* 2020), and can be used for assessment (Botezatu *et al.* 2010). However, screen text and multimedia VPs don't create a *reality*, so don't capitalise on the affordances of XR, including greater opportunities for experiential learning, contextualisation of learning, practical skills performance, spatial knowledge representation, and conceptual understanding (Birt *et al.* 2017). Similarly, some 'virtual' solutions, including virtual learning environments and virtual workstations (Strickland *et al.* 2015), are better described as 'online' solutions, and do not constitute XR.

IMPLEMENTING XR FOR CLINICAL SKILLS TEACHING IN OUR INSTITUTION

The General Medical Council (GMC) stipulates the outcomes for UK medical graduates (General Medical Council 2018). Our team works to deliver a GMC-accredited Clinical Skills curriculum for undergraduate UK medical students. We were tasked with identifying and implementing appropriate XR solutions into the taught curriculum, which will be increasingly common among undergraduate medical school teams (Jiang *et al.* 2022). This informs our

research question: ‘Which XR packages should be implemented for UK undergraduate clinical skills teaching, and how should they be implemented?’

In order to identify the most appropriate solutions for our institution, and to overcome potential barriers to implementation, it is vital to consider various context, infrastructure, education, and learner factors (see Figure 2).

Our learners possess a variety of individual characteristics, and different XR solutions will benefit each differently; however, as a cohort their demographic characteristics are comparable to other undergraduate healthcare learners, with no significant differences between successive cohorts.

XR potentially offers interactive solutions to the increasing pressures of student numbers and budget (Pottle 2019). Given this – and the attraction of XR in healthcare course recruitment and advertising materials (Office for Students 2019; Moreira *et al.* 2022; University of Exeter 2025; Brunel University of London 2025) – the programme’s strategic vision demands inclusion of XR education modalities. Each solution will include different content, targeting one or more of the 23 procedural skills the GMC mandates students be competent in by graduation (General Medical Council 2019), or the associated non-GMC-mandated ‘clinical skills’ which encompass the remaining skills required for encounters with patients (Ahmed 2008): these form the potential learning outcomes of interest.

Our team does not include learning technologists, and we have minimal faculty time or in-house technical, programming, or editing expertise available for software or hardware development. We must therefore rely on

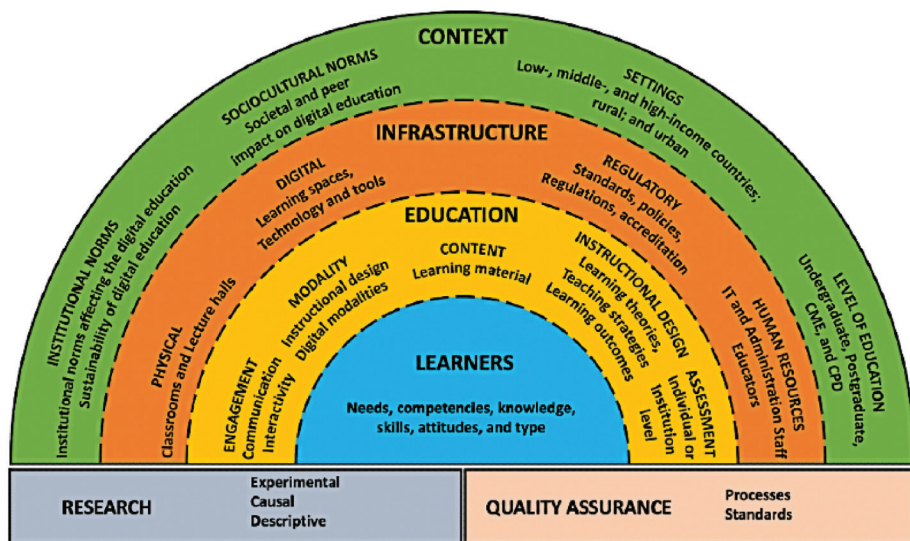


Figure 2. Conceptual map of digital education for health professionals (Car et al. 2022)

‘off-the-shelf’ or ‘black-box’ XR solutions, which are relatively inflexible but which can be reliably implemented with similar results within most infrastructures without such expertise; this approach also benefits from reducing up-front development costs, and reducing curriculum integration time (Meccawy 2022). Using off-the-shelf solutions with minimal customisability ensures standardisation of implementation, compared with proprietary in-house solutions (Curran *et al.* 2023; Lang *et al.* 2024); therefore, the evidence base for black-box solutions may be more reliable for our use case, and more directly applicable to other institutions.

Our institutional norms include teaching clinical skills using mostly traditional methods: facilitated practice with physical models and clinical equipment, with some online videos highlighted for pre-reading. We anticipated one barrier to challenging this norm and implementing XR in healthcare education would be the limited evidence base for its efficacy (Hansen 2008; Sarkar *et al.* 2021), discussed above.

Our task was to identify from the available literature the ‘best’ XR packages for implementation at our institution. This presupposes a positivistic paradigm where one XR package might be truly and consistently superior to other approaches, and where the evidence for its superiority in one context (for example, another institution with different learners and systems) remains valid in another (Brown and Dueñas 2020).

Constraining our solutions of interest to only ‘off-the-shelf’ packages results in numerous relatively discrete and inflexible packages. Of these products, we believe it is reasonable to assume that some will be intrinsically higher-quality, underpinned by more rigorous educational theory, with more relevant regionalised content, complexity level, or other pertinent factors. Given the relative inflexibility of these packages, we further believe it is likely that the evidence for these interventions in one context will still be applicable in another similar context.

As with most novel educational interventions, research from early adoptors focuses on, and often identifies, good learner satisfaction (Kirkpatrick Level 1) (Kirkpatrick 1959) and feasibility (Elston 2021). Pragmatically, it is reasonable to replace traditional teaching with XR or face-to-face teaching with Self-Directed Learning (SDL), if it is preferred by students and noninferior for learning outcomes, and / or cheaper. However, some XR packages have evidence for inferiority compared to traditional methods at various Kirkpatrick Levels (Macnamara *et al.* 2021; Macnamara *et al.* 2023).

In summary, this review of XR solutions seeks to evaluate research into educational content and instructional design, given the fixed context, infrastructure, and learners UK undergraduate clinical skills teams work within, for the XR modality. We aim to identify the most appropriate XR solutions to recommend for implementation into UK undergraduate clinical skills teaching, which are

- 1) ‘off-the-shelf’ with no need for programming expertise,
- 2) evaluated at Kirkpatrick Levels 2–4 to exclude inferiority versus traditional methods, and
- 3) where researchers describe their implementation methods to allow replication in other institutions.

OBJECTIVES

- Identify extant XR solutions with evidence for efficacy in teaching clinical skills relevant to our UK undergraduate students.
- Make recommendations for inclusion of XR into our undergraduate clinical skills curriculum, in-session and for self-directed learning.

METHODS

This study was not registered and did not follow a published protocol. It is reported according to the interim guidance on reporting rapid reviews (RRs) published by PRIMSA-RR working group (Stevens *et al.* 2025). RRs are used to aid evidence-informed decision-making in a high-priority area, by efficiently synthesising the evidence for a narrowly-defined single research question, integrating generalised evidence with local context considerations, where the pace of change is rapid (Wollscheid and Tripney 2021; Cirkony *et al.* 2022). A RR is therefore appropriate for this review.

Studies were judged against the below eligibility criteria (see Table 1).

We developed a targeted search strategy of 4 well-indexed electronic bibliographic databases, according to similar educational rapid review protocols (Wollscheid and Tripney 2021) (see Appendix 1 for database search strategy). Sources of evidence were selected by sequential removal of duplicate articles, screening of titles, screening of abstracts, and screening of full text articles.

All our university’s clinical skills teaching sessions for all five years were extracted from faculty lesson plan resources, divided by OSCE domain. Similar sessions from the spiral curriculum were merged (e.g. ECG rhythm analysis and ECG morphology analysis were merged to form ECG analysis) to identify all potential in-session XR targets. The 23 GMC-mandated procedural skills were extracted to identify any skills XR might target which the curriculum does not currently cover; however, all 23 skills were identified in lesson plans across the clinical skills curriculum. Included studies were charted within this framework, with data items extracted according to study population, intervention (including classification of XR modality), comparison, and outcome. Clinical skills teaching sessions for which no evidence was identified for relevant XR interventions were removed from the resultant table for clarity.

Table 1. Eligibility criteria for rapid review

Framework	Description	Inclusion	Exclusion
Population	Learners who received medical education	Any appropriate learner (e.g. general public for cardiopulmonary resuscitation)	
Intervention	Uses extended reality to teach skills on extracted potential XR target list	Mobile, screen, head-mounted displays, and hybrid solutions; commercially available	Non-immersive virtual patients; teaches skills not appropriate for UK undergraduate medical students (e.g. postgraduate / specialist skills); teaches basic sciences; XR intervention used for assessment only; XR intervention requires programming / modelling / video-editing, or other expertise; not enough details to allow replication; proprietary hardware or software not commercially available; package discontinued
Comparison	Evaluates effectiveness of XR intervention against traditional methods	Books, pen and paper, chalkboard, face-to-face teaching, traditional lectures, small group teaching, problem- / case-based learning, physical models	No evaluation of the effectiveness of XR intervention (e.g. only feasibility assessed)
Outcome	Improved or not improved learning outcome	Assesses intervention at Kirkpatrick Levels 2-4	Only assesses intervention at Kirkpatrick Level 1
Study	Full article in English	Complete research article as identified via the search strategy	Non-English literature; unable to access complete article via University library or NHS England library; article retracted

Extracted articles were assessed against a critical appraisal tool for articles on educational interventions (Morrison *et al.* 1999). Studies with a high or medium weight of evidence were included in a narrative synthesis.

RESULTS

MEDLINE, EMBASE, ERIC, and the British Education Index were searched according to the search strategy, yielding 7167 records. 303 duplicates were removed, and a further 6179 records were excluded on title screening. 685 articles were reviewed, of which 645 were excluded according to the inclusion and exclusion criteria, leaving 40 studies (see Figure 3), whose data were extracted in Table 2. Of these, 17 were excluded after critical appraisal, leaving 24 studies in the narrative synthesis.

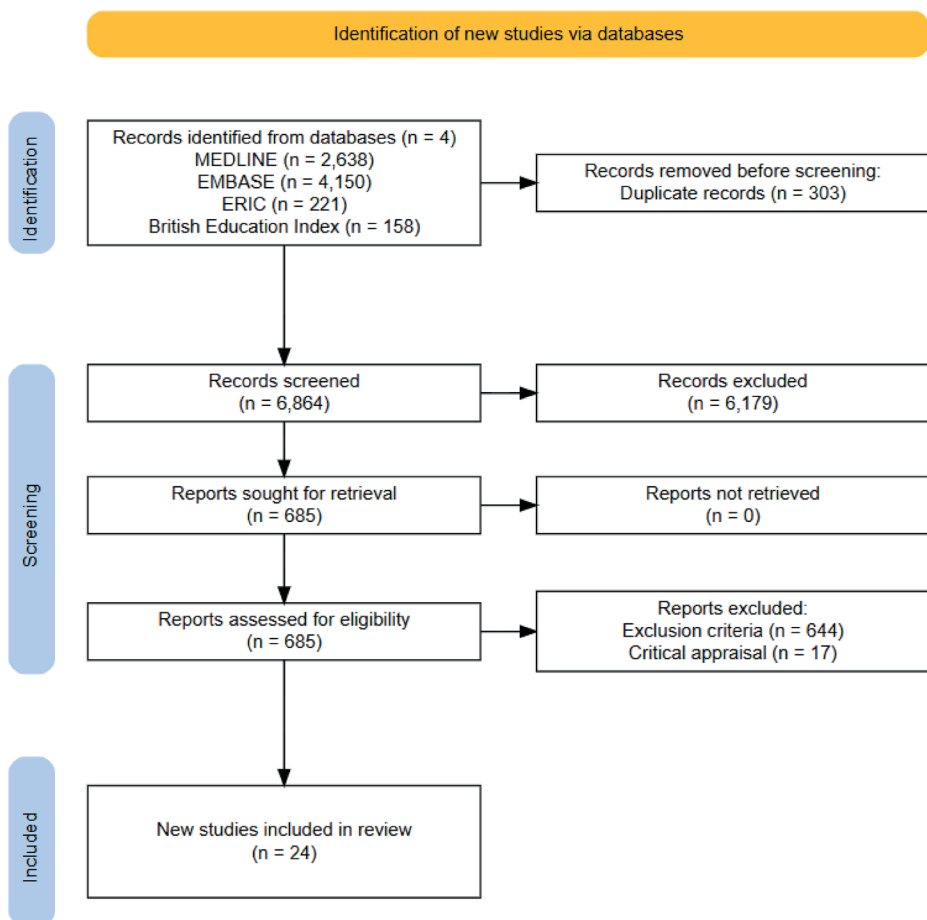


Figure 3. Selection of evidence for inclusion in the review (Haddaway et al. 2022)

NARRATIVE SYNTHESIS

We assessed extracted articles against Morrison *et al.*'s (1999) critical appraisal tool for educational interventions (see Table 3), which is summarised in Figure 4.

The search strategy described above ensured extracted studies scored highly for a clearly focused research question (investigating XR for clinical skills), in a sufficiently similar setting to our institution, and that there were minimal additional resources required to adopt the intervention (beside the software/hardware solution under investigation).

Studies consistently argued a case for the learning intervention based on learner needs; our review seeks to identify interventions for teaching mandated skills, making the learning need self-evident where this case was not made.

Table 2. Extraction of data from included articles

Skill session	Population	Intervention	Comparison	Outcome	Study
Communication					
Initiating the session & building a relationship	Nursing students	Sentinel City (Sentinel U)	Real patient consultations	VR = real consultations for population health evaluation	(Chircop and Cobbett 2020)
	Medical students	MPathic-VR (Medical Cyberworlds, Inc.)	sVP	VR > sVP for verbal & non-verbal OSCE performance	(Kron et al. 2017)
Breaking bad news	Medical students	MPathic-VR (Medical Cyberworlds, Inc.)	sVP	VR > sVP for communication skills OSCE performance	(Kron et al. 2017)
Examination					
Otolaryngology assessment including otoscopy and taking a swab	Medical students and ENT residents	Earsi Otoscope (Haag-Streit Group)	Traditional internship	AV > traditional	(Flockerzi et al. 2024)
	Medical students	OtoTrain (OtoSim Inc)	Lecture	sAV + lecture > lecture alone for diagnostic accuracy on otoscopy videos	(Stepniak et al. 2017)
Heart sounds & murmurs	Medical students	Virtual Patient Examination (recordings of auscultation while examining)	Ward rotations	AR + ward rotation > ward rotation alone, retained at 1 yr post intervention	(Vukanovic-Criley et al. 2008)
Vision & visual assessment including ophthalmoscopy	Medical students	EyeSi Direct Ophthalmoscope Simulator (Haag-Streit Group)	Traditional teaching	AV > traditional for perceived learning	(Tso et al. 2021)
	Medical students	EyeSi Slit Lamp Simulator (Haag-Streit Group)	Traditional teaching	AV > traditional for OSCE performance	(Deuchler et al. 2023)
	Medical graduates	EyeSi AR Binocular Indirect Ophthalmoscopy Simulator (Haag-Streit Group)	Traditional teaching	AV > traditional for EyeSi assessment	(Rai et al. 2017)

(Continued)

Table 2. (Continued)

Skill session	Population	Intervention	Comparison	Outcome	Study
Practical Skills Basic life support	Paramedic students	3DMedSim BLS VR (3DMedSim)	mVR	iVR > mVR	(Aksoy 2019)
	Medical / nursing / psychology students	Ludus CPR (Ludus Tech, S.L.)	Traditional teaching	VR = traditional for knowledge & CPR performance. Traditional > VR for AED	(Castillo et al. 2023)
	Healthcare professionals	Ludus CPR (Ludus Tech, S.L.)	Traditional teaching	VR ≥ traditional for knowledge. VR > traditional for satisfaction & cost	(Figols Pedrosa et al. 2023)
	University students	HTC Basic Life Support VR (4 Help VR)	Hybrid video + F2F, F2F alone	iVR = Hybrid video + F2F = F2F alone	(Chang et al. 2023)
	Medical students	VIREED MED (VIREED GmbH)	Traditional teaching	AV SDL > traditional for overall learning gain but AV SDL < traditional for procedure performance	(Issleib et al. 2021)
	General public	LifeSaver VR (Resuscitation Council UK)	Traditional models	VR alone = traditional for compression rate. VR alone < traditional for compression depth	(Nas et al. 2020)
	General public	LifeSaver VR (Resuscitation Council UK)	Traditional models	VR + pillow < traditional for willingness to perform CPR on stranger. VR + pillow = traditional for theoretical knowledge and awareness-raising	(Nas et al. 2022)
	School children	LifeSaver VR (Resuscitation council UK)	VR alone, F2F alone	VR + F2F > VR alone = F2F alone	(Yeung et al. 2017)

(Continued)

Table 2. (Continued)

Skill session	Population	Intervention	Comparison	Outcome	Study
Standard precautions	Nursing students	Self-authored on Adobe Flash Professional CC and Adobe Flash CS6	Traditional teaching	VR + online video > traditional	(Al-Mugheed <i>et al.</i> 2022)
	Medical students + graduates	Axon Park VR (Axon Park)	Traditional teaching	VR ≥ traditional for asynchronous SDL. VR > traditional for preparedness & confidence	(Kravitz <i>et al.</i> 2022)
Venepuncture	Medical students	CathSim (Immersion Medical) (discontinued)	Traditional models	AV < traditional	(Scerbo <i>et al.</i> 2006)
	Nursing students	CathSim (Immersion Medical) (discontinued)	Traditional models	AV = traditional	(William <i>et al.</i> 2016)
	Nursing students	Virtual IV (Laerdal) (discontinued)	Traditional models	AV ≤ traditional for SDL	(Wandell 2010)
Catheterisation, urinalysis & pregnancy testing	Medical students	Touch Surgery (Medtronic)	Traditional SDL including videos + sample OSCE checklist	mVR = traditional = no resources for 1-hour revision	(Bartlett <i>et al.</i> 2017)
Intravenous cannulation	Nursing students	3DMedSim 3D IV Catheterisation (3DMedSim)	Traditional models	VR > traditional for SDL	(Yildiz and Demiray 2022)
Arterial blood gas	Medical students	Vantari VR (Vantari Pty Ltd)	Traditional models alone	VR + traditional > traditional alone for error reduction	(Kennedy <i>et al.</i> 2023)
Wound care	Medical students	mARble Forensics (Peter L. Reichertz Institute for Medical Informatics)	Textbook	AR > textbook for knowledge improvement	(Albrecht <i>et al.</i> 2013)
	Medical students	mARble-Derma (Peter L. Reichertz Institute for Medical Informatics)	Mobile non-AR	mAR = mobile non-AR for immediate learning. mAR > mobile non-AR for knowledge retention	(Noll <i>et al.</i> 2017)

(Continued)

Table 2. (Continued)

Skill session	Population	Intervention	Comparison	Outcome	Study
	Nursing students	Self-authored with HP Reveal (HP Autonomy) and Aumentaty Creator (Aumentaty S.L.)	Traditional teaching	AR > traditional	(Rodríguez-Abad et al. 2022)
Ultrasound intravenous cannulation	Medical students	VitaSim (VitaSim Aps)	e-learning video	iVR + e-learning video > e-learning video alone	(Andersen et al. 2021)
Resuscitation skills	Anaesthesiology students	3DMedsim ALS VR (3DMedSim)	Lecture	VR < sim for knowledge improvement and skill performance, VR = sim for NTS and overall	(Aksoy et al. 2023)
	ALS instructors	NEUTRANS (Synamon Inc)	F2F	VR = F2F	(Kiyozumi et al. 2022)
Clinical Reasoning					
X-Ray interpretation	Medical students	DIVA (Pasteur Institute and Institute Curie)	Traditional DICOM 3D or 2D renders	VR > traditional for identifying fractures	(Bouaoud et al. 2021)
	Medical students	Second Life (Linden Research, Inc.)	F2F	VR = F2F for AXR interpretation training	(Lorenzo-Alvarez et al. 2019)
	Medical students	SieVRt (Luxsonic Technologies Inc)	Screen teaching	VR ≥ screen teaching, in-session & SDL	(Wu et al. 2023)
	Medical students	Second Life (Linden Research, Inc.)	Non-participants	VR participation > non-participation	(Rudolphi-Solero et al. 2021)
	Medical students	Second Life (Linden Research, Inc.)	Mandatory iVR team game	Voluntary > mandatory VR participation	(Rudolphi-Solero et al. 2022)

(Continued)

Table 2. (Continued)

Skill session	Population	Intervention		Comparison	Outcome	Study
		Self-authored with HP Reveal (HP Autonomy)	mAR			
ECG morphology & rhythm	Paramedicine students	Self-authored with HP Reveal (HP Autonomy)	mAR	Textbook	mAR > textbook for post-learning SDL	(Turan <i>et al.</i> 2021)
Management of acutely ill patients (ABCDE approach)	Medical and nursing students	VirSam	iVR + Haptics	Physical models + equipment	VR ≥ physical models + equipment for SDL	(Berg and Steinsbekk 2020)
	Medical students	Body Interact	sVR long course	sVR short course	Longer VR course > shorter VR course for Body Interact case scores but not OSCEs	(Law <i>et al.</i> 2023)
	Medical students	EMERGE app	mVR	Traditional PBL	VR > PBL for knowledge exam & EMERGE assessment	(Middeke <i>et al.</i> 2018)
Breathlessness (medicine)	Nursing students	Body Interact	sVR	Traditional PBL	VR > PBL for knowledge & clinical reasoning	(Padilha <i>et al.</i> 2019)
	Nursing students	vSim for Nursing (Laerdal)	sVR + hi-fi simulation	sVR alone, hi-fi simulation alone	VR + hi-fi simulation > VR alone = hi-fi simulation alone	(Kang <i>et al.</i> 2020)
	AED, Automated External Defibrillator; AR, Augmented Reality; AXR, Abdominal X-Ray; AV, Augmented Virtuality; DICOM, Digital Imaging and Communications in Medicine; ECG, ElectroCardioGram; F2F, Face to Face; hi-fi, High Fidelity; NTS, Non-Technical Skills; PBL, Problem-Based Learning; SDL, Self-Directed Learning; SG, Serious Game; SP, Simulated Patient; XR, eXtended Reality; VP, Virtual Patient; VR, Virtual Reality.					

i, immersive; m, mobile; s, computer screen.

Table 3. Critical appraisal of extracted studies

	1. Is there a focussed question?	2. Was there a clear learning need the intervention addressed?	3. Was there a clear description of the educational context?	4. Was the precise nature of the intervention clear?	5. Was the study design chosen able to address the aims?	6. Were the outcomes chosen to evaluate the intervention appropriate?	7. Did the authors explore any other results?	8. Were any unanticipated outcomes explained?	9. Were any reported behavioural changes after the intervention linked to measurement of other, more objective measures e.g. changes in referral rates	10. What were the results?	11. How precise were the results?	12. Was the setting sufficiently similar to you own and/or representative of real life?	13. Does it require additional resources to adopt?	Weight of Evidence
Chircop and Cobbett 2020	+	+	+	+	+	+	+	+	-	?	?	?	-	-
Kron et al. 2017	+	+	+	+	+	+	+	?	+	+	+	+	-	+
Flockerzi et al. 2024	-	?	-	?	?	?	-	-	+	+	-	?	-	-
Stepniak et al. 2017	+	+	+	+	+	+	+	?	+	+	+	+	-	-
Vukanovic-Criley et al. 2008	+	+	+	?	+	?	-	+	-	+	?	?	?	+
Tso et al. 2021	+	+	+	+	?	?	+	-	-	+	?	?	-	+
Deuchler et al. 2023	+	+	+	+	+	+	+	-	+	+	?	-	-	-
Rai et al. 2017	+	+	?	+	+	?	+	-	-	+	?	-	-	-
Aksoy 2019	+	?	-	-	+	?	+	-	-	-	?	?	+	-
Castillo et al. 2023	+	+	?	+	+	+	-	-	+	?	-	+	-	+
Figols Pedrosa et al. 2023	+	?	+	+	+	+	+	-	-	?	?	+	-	+
Chang et al. 2023	+	+	+	+	+	?	-	-	+	?	-	+	-	?
Issleib et al. 2021	+	+	+	+	+	+	-	-	+	+	+	+	-	-
Nas et al. 2020	+	+	+	+	?	+	+	+	+	+	+	?	-	+
Nas et al. 2022	+	+	+	+	?	?	+	+	+	+	?	?	-	+
Yeung et al. 2017	+	+	+	+	?	?	+	?	+	?	-	+	-	+
Al-Mugheed et al. 2022	+	+	+	?	+	+	+	-	+	+	+	+	+	-
Kravitz et al. 2022	+	+	+	+	+	?	+	+	?	+	-	+	-	+
Scerbo et al. 2006	+	+	+	+	+	?	+	+	?	-	+	+	-	-
William et al. 2016	+	+	+	+	+	?	?	?	+	?	-	+	-	-
Wandell 2010	+	+	+	+	?	?	?	-	?	-	-	+	-	-
Bartlett et al. 2017	+	?	+	+	+	?	+	+	+	+	-	+	-	+
Kennedy et al. 2023	+	+	+	?	?	?	+	+	+	+	+	+	-	+
Yildiz and Demiray 2022	?	?	+	+	?	?	+	-	-	+	+	+	-	+
Albrecht et al. 2013a	+	+	+	+	+	?	+	-	-	+	-	+	-	+
Noll et al. 2017	+	+	+	+	+	?	+	+	-	+	-	+	-	+
Rodriguez-Abad et al. 2022	+	+	+	+	?	+	+	?	-	+	+	+	-	-
Andersen et al. 2021	+	+	+	+	+	+	+	-	+	+	+	+	-	+
Aksoy et al. 2023	+	+	+	+	+	?	-	-	+	-	?	+	-	-
Kiyozumi et al. 2022	+	+	+	?	?	?	+	-	-	?	-	-	-	-
Bouaoud et al. 2021	+	?	-	?	?	?	+	?	-	+	-	+	-	?
Lorenzo-Alvarez et al. 2019	+	-	+	+	+	?	?	+	-	?	?	+	-	+
Wu et al. 2023	+	+	+	+	-	-	+	+	-	?	?	+	-	?
Rudolphi-Solero et al. 2021a	+	+	+	+	?	+	+	-	-	+	+	+	-	+
Rudolphi-Solero et al. 2021b	+	?	+	+	+	+	+	-	-	+	+	+	-	+
Turan et al. 2021	+	+	+	+	+	+	+	+	-	?	+	+	-	-
Berg and Steinsbekk 2020	+	+	+	+	+	?	+	+	+	?	-	+	-	-
Law et al. 2023	+	?	+	+	+	?	+	+	+	+	?	+	-	?
Middeke et al. 2018	+	+	+	+	+	?	+	?	+	+	+	+	-	?
Padilha et al. 2019	+	-	+	+	?	?	-	-	+	+	+	+	-	?

RAPID REVIEW OF XR FOR CLINICAL SKILLS

RAPID REVIEW OF XR FOR CLINICAL SKILLS



Figure 4. Summary of strength of evidence of extracted studies

Descriptions of the educational context for the interventions (including learner level, logistics and structure of intervention, context within the wider curriculum and previous teaching on the subject), and the precise nature of the intervention (including length, intensity, and content) were consistently well-reported among studies appraised, ensuring the applicability of those studies' findings in practice ourselves.

Study designs were of variable quality. Several studies intended to determine effects on skill performance which collected satisfaction, knowledge,

or self-assessed survey data. Some control arms included ‘traditional’ teaching methods with significantly lower interactivity, or for less time than the intervention arm; or no teaching (in the case of voluntary additional XR teaching courses), introducing confounding factors. Few studies assessed learning retention over time.

Similarly, some studies assessed intervention and control arms on XR performance, which introduces familiarity bias – students in the intervention arm may have scored higher simply through familiarity with devices and software. Some studies used assessment metrics provided by XR software (e.g. identification of retinal pathology on XR screens) to judge students’ performance, which may not correlate with real-life clinical practice. Some studies’ assessments may have been appropriate (e.g. pre- and post- learning quizzes, practical assessments marked by clinicians, etc.), but were not validated.

These concerns were inconsistently explored in studies, some of which did not explicitly recognise the weaknesses inherent to study design and methodology, or discuss the biases introduced and the alternative explanations which could therefore (at least partially) explain their findings.

Unanticipated outcomes were poorly explained in a high proportion of studies. Unanticipated outcomes of interest included subgroup analyses showing variable intervention impact for different learner groups, or variable impact across different domains assessed; or differential learner engagement, or behavioural change (including satisfaction and knowledge) across subgroups, modalities, or timeframes. For example, some studies identified inferior immediate performance improvement with XR compared to control, but reported a primary outcome of noninferior long-term learning with XR.

Many studies intended to identify skill performance improvement instead assessed satisfaction and knowledge (e.g. identification of correct sequencing of skill elements), making their applicability to skill performance interventions uncertain.

The minority of studies included power calculations and sufficient participants; many were pilot studies, or noninferiority studies which were not powered to identify superiority of XR interventions. This is likely influenced by ethical, logistical, institutional, and wider regulatory factors (e.g. the ability to randomise students to inferior learning methods, low student numbers in a given year’s cohort at an institution, and the need for compliance with curriculum accreditation requirements). Study results were consequently often imprecise. However, given the positive affordances of XR described above, noninferiority of performance improvement may be sufficient to recommend replacement of traditional methods in curricula.

In total, 17 studies did not meet the threshold for inclusion in our recommendations. The remaining 24 studies included in this review demonstrate that XR may be selectively implemented in clinical skills sessions,

or used for SDL. Currently available products with reasonable evidence for efficacy are as follows:

- For communication skills session, MPathic-VR.
- For examination skills, EyeSi for ophthalmoscopy, virtual patient examination approaches to ‘heart sounds and murmurs’ and ‘cardiorespiratory assessment’, for example using Student Auscultation Manikins, wearable simulators, or technology-enhanced stethoscopes.
- For practical skills, LifeSaver VR pre-training and Ludus CPR in-session (and keeping traditional teaching on defibrillation, given evidence for superiority of traditional approaches), Axon Park VR for standard precautions and PPE donning and doffing, the Touch Surgery app for catheterisation, 3D MedSim 3D IV Catheterisation app for cannulation, Vantari VR for Arterial Blood Gas, the mARble-derma and mARble-forensics apps for wound care, and VitaSim for ultrasound cannulation.
- For clinical reasoning, Second Life for X-ray interpretation, and interprofessional learning; Body Interact for assessment of acutely unwell patients.

If the pressures of increasing student numbers with a fixed availability of clinical placements, and in-session contact time require, UK medical schools could consider replacing current in-person sessions with SDL XR packages with evidence for equivalent outcomes with SDL use versus traditional teaching, specifically:

- HTC Basic Life Support VR (4 Help VR) for BLS;
- Axon Park VR for standard precautions;
- Touch Surgery app for catheterisation;
- mARble-Forensics and mARble-Derma for wound assessment;
- VitaSim for ultrasound cannulation;
- DIVA or SieVRt for X-ray interpretation;
- Body Interact, or EMERGE app for ABCDE assessment.

DISCUSSION

The NHS Long Term Workforce Plan necessitates increasing medical student numbers in shorter training programmes, alongside an expansion of medical associate profession roles (NHS England 2023). Maintaining graduate quality and competence will require high-quality, scalable training resources.

A key untapped strategy for improving clinical skills session resources is blended learning, with TEL materials for use before, during, and after sessions (Vallée *et al.* 2020). As discussed above, HMD 360-degree video and telestration are successful approaches to TEL. Although excluded from the review, various studies extracted demonstrated HMD video to be equivalent to

tutor-supported or traditional teaching (Peden *et al.* 2016; Peters *et al.* 2023), online mAR SDL to be superior to F2F mAR for some aspects of wound care (Rodriguez-Abad *et al.* 2023), and video plus mannequin self-training to be equivalent to traditional training for PBLs (Vestergaard *et al.* 2011).

Within a blended curriculum, VPs can be made more immersive to improve learning (Stevens *et al.* 2006). Immersive VPs and 360-degree videos could be published for online student interaction as an SDL resource, accessed via university-issued HMDs or tablet devices. These pre- and post-session resources could target any combination of knowledge, attitudes, and performance, be informed by game theory, and include on-screen assessments.

There is already evidence that high-quality simulation could replace up to 50% of undergraduate nursing clinical training (Alexander *et al.* 2015); with clinical placements already saturated with medical students, simulated experiences will have to become a far larger factor in students' learning. In-session, one of the unique affordances of the clinical skills lab is technology-enhanced simulation, and increased fidelity where performance improvement is desired over knowledge improvement (Mitchell and Ivimey-Cook 2023).

Each of these should be evaluated for cost per student per session, and those meeting an acceptable cost threshold should be implemented in undergraduate clinical skills curricula. They should then be evaluated for efficacy in improving student performance in the associated skill, at various Kirkpatrick assessment levels (Smidt *et al.* 2009), including performance in summative OSCE stations.

Finally, emerging technologies including 3D printing (Ramesh *et al.* 2022), and generative AI (Liaw *et al.* 2023a; Liaw *et al.* 2023b), which can be combined with VR (Mergen *et al.* 2023), deserve investigation for their potential to increase cost-efficiency of educational resources, and efficiency of contact time and tutor oversight of interactive SDL resources.

LIMITATIONS

The gold standard evidence would be to prospectively compare learners' patient outcomes in a double-blind randomised controlled trial versus traditional methods and alternative XR solutions; for the reasons noted in the critical appraisal above, ethical and logistical challenges rarely allows for this in the studies assessed. Furthermore, these studies – and medical education literature broadly – rarely identifies improvements in patient outcomes from teaching interventions, which is the end goal of such interventions (Simons *et al.* 2019).

This review makes no assessment of the cost-benefit relationship of the XR packages, other than to determine if there is educational benefit versus the relevant study comparator. This should be considered when commissioning teaching packages, and may involve evaluation of the relative learning needs of

current students: for example, by using successive year groups' OSCE station scores to identify cohorts struggling with a particular skill. Where a deficit is identified, interventions to improve student performance are likely to be greater, increasing the benefit per cost.

This review approached the literature for XR solutions from a positivistic paradigm, in order to identify the 'best' packages for implementation at our institution, as we believed this was the most relevant approach for our current situation and other institutions, to make concrete recommendations for packages to implement. Although these packages are discrete and inflexible, it is likely that the methods of implementation have a significant effect on efficacy. We also restricted the evidence assessed to Kirkpatrick Levels 2–4 in order to control for the known effects of learner enthusiasm for novel-intervention. Given the complexity of these interventions, a future research project which tackles *how* to implement XR solutions could review these studies, applying an interpretivist paradigm, and be no less valid (Bunniss and Kelly 2010).

'Off-the-shelf' or 'black-box' solutions have many limitations, including recurring subscription costs, planned and unplanned obsolescence, and inflexibility of content including regionality of languages, dialects, and medical management guidelines. If undergraduate medical schools intend for XR to become a major part of their curricula, they may benefit from employing learning technologists (including game-based learning experts), computer programmers and 3D modellers – and researchers in order to validate in-house solutions. A small ecosystem of compatible 3D model resources, programs to display these in XR, and hardware to run this software, may be all that is needed for initial development of teaching resources.

A challenge for the recommendations above is the pace of change and innovation in this sector: commercially available packages, particularly those where the evidence identified shows no benefit of their use – and especially open-source repositories – are regularly being bought, sold, discontinued, updated, and abandoned. The wide range of current offerings are unlikely to survive the next 10 years of development, which curtails institutional enthusiasm to adoption; inversely, by evolutionary pressure, the longer a package remains commercially viable, the more likely it is to be useful.

CONCLUSIONS

This review recommends multiple parallel approaches for applying blended learning and TEL principles to UK undergraduate clinical skills curricula. Various XR solutions have been identified with potential educational benefit. Further research should evaluate currently implemented XR packages across UK medical schools, assess the recommended products for cost-effectiveness, and validate additional packages once implemented.

AUTHOR CONTRIBUTIONS

TJ contributed to conceptualisation, data curation, investigation, project administration, and writing.

DECLARATIONS

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

COMPETING INTEREST

The author declares that they have no competing interests.

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REFERENCES

- Ahmed, A. M. (2008). Role of clinical skills centres in maintaining and promoting clinical teaching. *Sudanese Journal of Public Health*, 3(2), 97–103.
- Akgün, M., & Atıcı, B. (2022). The Effects of Immersive Virtual Reality Environments on Students' Academic Achievement: A Meta-analytical and Meta-thematic Study. *Participatory Educational Research*, 9(3), 111–131.
- Aksoy, E. (2019). Comparing the effects on learning outcomes of tablet-based and virtual reality-based serious gaming modules for basic life support training: randomized trial. *JMIR serious games*, 7(2), e13442.
- Aksoy, M. E., Özkan, A. E., Kitapcioglu, D., & Usseli, T. (2023). Comparing the outcomes of virtual reality-based serious gaming and lecture-based training for advanced life support training: randomized controlled trial. *JMIR Serious Games*, 11, e46964.
- Al-Mugheed, K., Bayraktar, N., Al-Bsheish, M., AlSyouf, A., Aldhmadi, B. K., Jarrar, M. T., & Alkhazali, M. (2022). Effectiveness of game-based virtual reality phone application and online education on knowledge,

- attitude and compliance of standard precautions among nursing students. *Plos one*, 17(11), e0275130.
- Albrecht, U. V., Folta-Schoofs, K., Behrends, M., & Von Jan, U. (2013). Effects of mobile augmented reality learning compared to textbook learning on medical students: randomized controlled pilot study. *Journal of medical Internet research*, 15(8), e182.
- Alexander, M., Durham, C. F., Hooper, J. I., Jeffries, P. R., Goldman, N., Kesten, K. S., Spector, N., Tagliareni, E., Radtke, B. and Tillman, C. (2015). NCSBN simulation guidelines for prelicensure nursing programs. *Journal of Nursing Regulation*, 6(3), 39–42.
- Alverson, D.C., Saiki Jr, S.M., Kalishman, S., Lindberg, M., Mennin, S., Mines, J., Serna, L., Summers, K., Jacobs, J., Lozanoff, S. and Lozanoff, B. (2008). Medical students learn over distance using virtual reality simulation. *Simulation in Healthcare*, 3(1), 10–15.
- Andersen, N. L., Jensen, R. O., Posth, S., Laursen, C. B., Jørgensen, R., & Graumann, O. (2021). Teaching ultrasound-guided peripheral venous catheter placement through immersive virtual reality: An explorative pilot study. *Medicine*, 100(27), e26394.
- Atthill, S., Witmer, D., Luctkar-Flude, M., & Tyerman, J. (2021). Exploring the impact of a virtual asynchronous debriefing method after a virtual simulation game to support clinical decision-making. *Clinical Simulation in Nursing*, 50, 10–18.
- Bala, L., Kinross, J., Martin, G., Koizia, L.J., Kooner, A.S., Shimshon, G. J., Hurkxkens, T. J., Pratt, P. J. and Sam, A. H. (2021). A remote access mixed reality teaching ward round. *The clinical teacher*, 18(4), 386–390.
- Bartlett, R.D., Radenkovic, D., Mitrasinovic, S., Cole, A., Pavkovic, I., Denn, P.C.P., Hussain, M., Kogler, M., Koutsopodioti, N., Uddin, W. and Beckley, I. (2017). A pilot study to assess the utility of a freely downloadable mobile application simulator for undergraduate clinical skills training: a single-blinded, randomised controlled trial. *BMC Medical Education*, 17(1), 247.
- Berg, H., & Steinsbekk, A. (2020). Is individual practice in an immersive and interactive virtual reality application non-inferior to practicing with traditional equipment in learning systematic clinical observation? A randomized controlled trial. *BMC medical education*, 20(1), 123.
- Berger, J., Bawab, N., De Mooij, J., Widmer, D. S., Szilas, N., De Vriese, C., & Bugnon, O. (2018). An open randomized controlled study comparing an online text-based scenario and a serious game by Belgian and Swiss pharmacy students. *Currents in Pharmacy Teaching and Learning*, 10(3), 267–276.
- Berman, N. B., & Artino Jr, A. R. (2018). Development and initial validation of an online engagement metric using virtual patients. *BMC Medical Education*, 18(1), 213.
- Bernaitis, N., Baumann-Birkbeck, L., Alcorn, S., Powell, M., Arora, D., & Anoopkumar-Dukie, S. (2018). Simulated patient cases using

- DecisionSim™ improves student performance and satisfaction in pharmacotherapeutics education. *Currents in pharmacy teaching and learning*, 10(6), 730–735.
- Birt, J., Moore, E., & Cowling, M. (2017). Improving paramedic distance education through mobile mixed reality simulation. *Australasian Journal of Educational Technology*, 33(6).
- Björklund, K., & Silén, C. (2021). Occupational therapy and physiotherapy students' communicative and collaborative learning in an interprofessional virtual setting. *Scandinavian Journal of Occupational Therapy*, 28(4), 264–273.
- Botezatu, M., Hult, H., Tessma, M. K., & Fors, U. G. (2010). Virtual patient simulation for learning and assessment: Superior results in comparison with regular course exams. *Medical teacher*, 32(10), 845–850.
- Bouaoud, J., El Beheiry, M., Jablon, E., Schouman, T., Bertolus, C., Picard, A., Masson, J.B. and Khonsari, R.H. (2021). DIVA, a 3D virtual reality platform, improves undergraduate craniofacial trauma education. *Journal of Stomatology, Oral and Maxillofacial Surgery*, 122(4), 367–371.
- Brown, M. E., & Dueñas, A. N. (2020). A medical science educator's guide to selecting a research paradigm: building a basis for better research. *Medical Science Educator*, 30(1), 545–553.
- Brunel University of London. (2025). *Medicine MBBS*. Retrieved 24/02/2025 from <https://www.brunel.ac.uk/study/courses/medicine-mbbs>
- Bunniss, S., & Kelly, D. R. (2010). Research paradigms in medical education research. *Medical education*, 44(4), 358–366.
- Burg, G., & Finlay, A. Y. (2016). Web-based education. *Journal of the European Academy of Dermatology & Venereology*, 30(12).
- Car, L. T., Poon, S., Kyaw, B. M., Cook, D. A., Ward, V., Atun, R., Majeed, A., Johnston, J., Van der Kleij, R. M. J. J., & Molokhia, M. (2022). Digital education for health professionals: an evidence map, conceptual framework, and research agenda. *Journal of Medical Internet Research*, 24(3), e31977.
- Castillo, J., Rodríguez-Higueras, E., Belmonte, R., Rodríguez, C., López, A., & Gallart, A. (2023). Efficacy of virtual reality simulation in teaching basic life support and its retention at 6 months. *International Journal of Environmental Research and Public Health*, 20(5), 4095.
- Chan, M. M. K., Shea, Y. F., Kwok, T. T. O., & Cheung, D. S. K. (2023). Cultivating clinical reasoning: A blended learning approach. *Medical Education*, 57(2).
- Chang, C. Y., Sung, H. Y., Guo, J. L., Chang, B. Y., & Kuo, F. R. (2022). Effects of spherical video-based virtual reality on nursing students' learning performance in childbirth education training. *Interactive Learning Environments*, 30(3), 400–416.
- Chang, Y. T., Wu, K. C., Yang, H. W., Lin, C. Y., Huang, T. F., Yu, Y. C., & Hu, Y. J. (2023). Effects of different cardiopulmonary resuscitation education

- interventions among university students: A randomized controlled trial. *PloS one*, *18*(3), e0283099.
- Chao, Y. C., Hu, S. H., Chiu, H. Y., Huang, P. H., Tsai, H. T., & Chuang, Y. H. (2021). The effects of an immersive 3d interactive video program on improving student nurses' nursing skill competence: A randomized controlled trial study. *Nurse education today*, *103*, 104979.
- Chao, Y. P., Chuang, H. H., Hsin, L. J., Kang, C. J., Fang, T. J., Li, H. Y., Huang, C. G., Kuo, T. B., Yang, C. C., Shyu, H. Y. and Wang, S. L. (2021). Using a 360 virtual reality or 2D video to learn history taking and physical examination skills for undergraduate medical students: Pilot randomized controlled trial. *JMIR serious games*, *9*(4), e13124.
- Chen, B., Chang, P., Parikh, M., Jones, C., Bunting, K., Chakraborti, C., & Kahn, M. J. (2017, April). Virtual Reality Supplemental Teaching at Low-cost (VRSTL): Results of low-cost VR film as teaching adjunct for clinical teaching at the medical student level. *Journal of General Internal Medicine*, *32*, S722–S723.
- Chen, C. J., Chen, Y. C., Lee, M. Y., Wang, C. H., & Sung, H. C. (2021). Effects of three-dimensional holograms on the academic performance of nursing students in a health assessment and practice course: A pretest-intervention-posttest study. *Nurse Education Today*, *106*, 105081.
- Cheung, V. Y., Tang, Y. M., & Chan, K. K. (2023). Medical students' perception of the application of a virtual reality training model to acquire vaginal examination skills. *International Journal of Gynecology & Obstetrics*, *161*(3), 827–832.
- Chircop, A., & Cobbett, S. (2020). Gett'n on the bus: Evaluation of Sentinel City® 3.0 virtual simulation in community/population health clinical placement. *International Journal of Nursing Education Scholarship*, *17*(1).
- Chuah, J. H., Lok, B., & Black, E. (2013). Applying mixed reality to simulate vulnerable populations for practicing clinical communication skills. *IEEE transactions on visualization and computer graphics*, *19*(4), 539–546.
- Cirkony, C., Rickinson, M., Walsh, L., Gleeson, J., Salisbury, M., & Cutler, B. (2022). Reflections on conducting rapid reviews of educational research. *Educational Research*, *64*(4), 371–390.
- Claburn, O., Groves, K. E., & Jack, B. (2020). Virtual learning environment ('Ivy Street') for palliative medicine education: student and facilitator evaluation. *BMJ Supportive & Palliative Care*, *10*(3), 318–323.
- Clay, C. J., Schmitz, B. A., Balakrishnan, B., Hopfenblatt, J. P., Evans, A., & Kahng, S. (2021). Feasibility of virtual reality behavior skills training for preservice clinicians. *Journal of applied behavior analysis*, *54*(2), 547–565.
- Cobb, S., Heaney, R., Corcoran, O., & Henderson-Begg, S. (2009). The learning gains and student perceptions of a Second Life virtual lab. *Bioscience Education*, *13*(1), 1–9.

- Conradi, E., Kavia, S., Burden, D., Rice, A., Woodham, L., Beaumont, C., Savin-Baden, M. and Poulton, T. (2009). Virtual patients in a virtual world: Training paramedic students for practice. *Medical teacher*, 31(8), 713–720.
- Curran, V., Xu, X., Simmons, K., Fleet, L., Coombs, H., Porter, R., White, S., Bessell, C., Deshpandey, A., Shah, A. and Waheed, S. (2022). A phenomenological study of the use of 360 virtual reality (VR) video in pediatric and neonatal resuscitation training. *Health and technology*, 12(1), 151–159.
- Curran, V. R., Xu, X., Aydin, M. Y., & Meruvia-Pastor, O. (2023). Use of extended reality in medical education: an integrative review. *Medical Science Educator*, 33(1), 275–286.
- Deladisma, A.M., Gupta, M., Kotranza, A., Bittner IV, J.G., Imam, T., Swinson, D., Gucwa, A., Nesbit, R., Lok, B., Pugh, C. and Lind, D.S. (2009). A pilot study to integrate an immersive virtual patient with a breast complaint and breast examination simulator into a surgery clerkship. *The American journal of surgery*, 197(1), 102–106.
- Deuchler, S., Dail, Y. A., Koch, F., Buedel, C., Ackermann, H., Flockerzi, E., & Seitz, B. (2023). Efficacy of Simulator-based Slit lamp training for medical students: a prospective, randomized trial. *Ophthalmology and Therapy*, 12(4), 2171–2186.
- Deuchler, S., Scholtz, J., Ackermann, H., & Koch, F. (2022). Virtual reality microsurgery training during medical school: data from implementation of Eyesi Surgical in ophthalmology clerkship in Germany. *Investigative Ophthalmology & Visual Science*, 63(7), 3413-F0313.
- Drapkin, Z. A., Lindgren, K. A., Lopez, M. J., & Stabio, M. E. (2015). Development and assessment of a new 3D neuroanatomy teaching tool for MRI training. *Anatomical sciences education*, 8(6), 502–509.
- Drewett, O., Hann, G., Delacroix, S., Pan, X., & Fertleman, C. R. (2018). G146 Can a virtual reality communication scenario be used to teach general practitioners and trainees how to recognise and manage safeguarding issues?
- Edwards, T. C., Soussi, D., Gupta, S., Khan, S., Patel, A., Patil, A., Liddle, A.D., Cobb, J. P. and Logishetty, K. (2023). Collaborative team training in virtual reality is superior to individual learning for performing complex open surgery: a randomized controlled trial.
- Elston, D. M. (2021). The novelty effect. *Journal of the American Academy of Dermatology*, 85(3), 565–566.
- Elzie, C. A., & Shaia, J. (2021). A pilot study of the impact of virtually embodying a patient with a terminal illness. *Medical Science Educator*, 31(2), 665–675.
- Farshad-Amacker, N. A., Kubik-Huch, R. A., Kolling, C., Leo, C., & Goldhahn, J. (2023). Learning how to perform ultrasound-guided interventions with

- and without augmented reality visualization: a randomized study. *European radiology*, 33(4), 2927–2934.
- Felinska, E.A., Fuchs, T.E., Kogkas, A., Chen, Z.W., Otto, B., Kowalewski, K.F., Petersen, J., Müller-Stich, B.P., Mylonas, G. and Nickel, F. (2023). Telestration with augmented reality improves surgical performance through gaze guidance. *Surgical Endoscopy*, 37(5), 3557–3566.
- Figols Pedrosa, M., Barra Perez, A., Vidal-Alaball, J., Miro-Catalina, Q., & Forcada Arcarons, A. (2023). Use of virtual reality compared to the role-playing methodology in basic life support training: a two-arm pilot community-based randomised trial. *BMC Medical Education*, 23(1), 50.
- Flockerzi, V., Schick, B., Flockerzi, E., & Berndt, S. (2024). Simulator approaches in otorhinolaryngology—Looking beyond the ophthalmological horizon. *Acta Ophthalmologica*, 102.
- Forsberg, E., Georg, C., Ziegert, K., & Fors, U. (2011). Virtual patients for assessment of clinical reasoning in nursing—A pilot study. *Nurse education today*, 31(8), 757–762.
- Francis, E. R., Bernard, S., Nowak, M. L., Daniel, S., & Bernard, J. A. (2020). Operating room virtual reality immersion improves self-efficacy amongst preclinical physician assistant students. *Journal of surgical education*, 77(4), 947–952.
- Fukuta, J., Gill, N., Rooney, R., Coombs, A., & Murphy, D. (2021). Use of 360 video for a virtual operating theatre orientation for medical students. *Journal of surgical education*, 78(2), 391–393.
- Gan, W., Mok, T.N., Chen, J., She, G., Zha, Z., Wang, H., Li, H., Li, J. and Zheng, X. (2023). Researching the application of virtual reality in medical education: one-year follow-up of a randomized trial. *BMC Medical Education*, 23(1), 3.
- García-Seoane, J. J., Ramos-Rincón, J. M., Lara-Muñoz, J. P., López-Román, A., Cardoner-Álvarez, N., Lorenzo-Peñuelas, A., Párraga-Ramírez, M., Jiménez-Reina, L., Sanz-Álvarez, E. J., Naranjo-Hernández, A. and Valdivielso-Felices, P. (2021). Changes in the Objective Structured Clinical Examination (OSCE) of University Schools of Medicine during COVID-19. Experience with a computer-based case simulation OSCE (CCS-OSCE). *Revista Clínica Española (English Edition)*, 221(8), 456–463.
- Garg, A. (2010). Teaching Dermatology Using 3-Dimensional Virtual Reality—Reply. *Archives of Dermatology*, 146(10), 1185–1186.
- General Medical Council. (2018). Outcomes for graduates. *General Medical Council*.
- General Medical Council. (2019). Practical Skills and Procedures. *General Medical Council*.
- Giordano, N. A., Whitney, C. E., Axson, S. A., Cassidy, K., Rosado, E., & Hoyt-Brennan, A. M. (2020). A pilot study to compare virtual reality to hybrid simulation for opioid-related overdose and naloxone training. *Nurse Education Today*, 88, 104365.

- Glick, Y., Avital, B., Oppenheimer, J., Nahman, D., Wagnert-Avraham, L., Eisenkraft, A., Dym, L., Levi, D., Agur, A., Gustus, B. and Furer, A. (2021). Augmenting prehospital care. *BMJ Mil Health*, 167(3), 158–162.
- Gout, L., Hart, A., Houze-Cerfon, C. H., Sarin, R., Ciottone, G. R., & Bounes, V. (2020). Creating a novel disaster medicine virtual reality training environment. *Prehospital and disaster medicine*, 35(2), 225–228.
- Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. *Campbell systematic reviews*, 18(2), e1230.
- Hainsworth, L., Kosti, A., Lloyd, A., Kiddle, A., Bamford, R., & Hunter, I. (2022). Teaching the management of trauma patients through virtual reality. *The Annals of The Royal College of Surgeons of England*, 104(5), 330–333.
- Hale, A., Fischer, M., Schütz, L., Fuchs, H., & Leuze, C. (2022). Remote training for medical staff in low-resource environments using augmented reality. *Journal of Imaging*, 8(12), 319.
- Halfer, D., & Rosenheck, M. (2014). Virtual education: is it effective for preparing nurses for a hospital move?. *JONA: The Journal of Nursing Administration*, 44(10), 535–540.
- Hannans, J. (2023). Integrating LGBTQI+ content in nursing education using immersive virtual reality: embodying Eden. *Nursing education perspectives*, 44(5), 321–322.
- Hansen, M. (2008). Versatile, immersive, creative and dynamic virtual 3-D healthcare learning environments: a review of the literature. *Journal of medical Internet research*, 10(3), e1051.
- Hanson, J., Andersen, P., & Dunn, P. K. (2019). Effectiveness of three-dimensional visualisation on undergraduate nursing and midwifery students' knowledge and achievement in pharmacology: A mixed methods study. *Nurse Education Today*, 81, 19–25.
- Hanson, J., Andersen, P., & Dunn, P. K. (2020). The effects of a virtual learning environment compared with an individual handheld device on pharmacology knowledge acquisition, satisfaction and comfort ratings. *Nurse Education Today*, 92, 104518.
- Hardcastle, T., & Wood, A. (2018). The utility of virtual reality surgical simulation in the undergraduate otorhinolaryngology curriculum. *The Journal of Laryngology & Otology*, 132(12), 1072–1076.
- Harrison, B., Oehmen, R., Robertson, A., Robertson, B., De Cruz, P., Khan, R., & Fick, D. (2017). Through the eye of the master: The use of Virtual Reality in the teaching of surgical hand preparation. In *2017 IEEE 5th international conference on serious games and applications for health (SeGAH)* (pp. 1–6). IEEE.

- Hollister, B.M., Schopp, E.M., Telaak, S.H., Buscetta, A.J., Dolwick, A.P., Fortney, C.J., Bonham, V.L. and Persky, S. (2022). Educational considerations based on medical student use of polygenic risk information and apparent race in a simulated consultation. *Genetics in Medicine*, 24(11), 2389–2398.
- Horstmann, M., Renninger, M., Hennenlotter, J., Horstmann, C. C., & Stenzl, A. (2009). Blended E-learning in a Web-based virtual hospital: a useful tool for undergraduate education in urology. *Education for health*, 22(2), 269.
- Imai, T., Tanaka, Y., Hatanaka, Y., Suetsugu, T., Sato, Y., Matsushashi, N., Tsunekawa, K., Saiki, T., & Yoshida, K. (2022). Incorporation of virtual reality in the clinical training of medical students studying esophageal and mediastinal anatomy and surgery. *Surgery Today*, 52(8), 1212–1217.
- Isabell, W., Simons, A., & Stieglitz, S. (2020). Virtual reality. *Business & Information Systems Engineering*, 62(5), 455–461.
- Isaranuwatthai, W., Brydges, R., Carnahan, H., Backstein, D., & Dubrowski, A. (2014). Comparing the cost-effectiveness of simulation modalities: a case study of peripheral intravenous catheterization training. *Advances in Health Sciences Education*, 19(2), 219–232.
- Issleib, M., Kromer, A., Pinnschmidt, H. O., Süß-Havemann, C., & Kubitz, J. C. (2021). Virtual reality as a teaching method for resuscitation training in undergraduate first year medical students: a randomized controlled trial. *Scandinavian journal of trauma, resuscitation and emergency medicine*, 29(1), 27.
- Jayasundera, M., Myers, M., Pandian, K., & Gingell, G. (2022). Virtual reality simulation: evaluating an experiential tool for the clinical application of pathophysiology. *Medical Science Educator*, 32(6), 1575–1577.
- Jiang, H., Vimalasvaran, S., Wang, J. K., Lim, K. B., Mogali, S. R., & Car, L. T. (2022). Virtual reality in medical students' education: scoping review. *JMIR medical Education*, 8(1), e34860.
- Jones, V. F., Rowland, M. L., Brueckner-Collins, J., Mack, A., Gault, S., Richardson, A., & Hazard, M. (2014). Comparison of LGBT cultural sensitivity teaching methods using the virtual reality world of Second Life versus a traditional workshop format. *Journal of Investigative Medicine*, 62, 533–533.
- Kang, K. A., Kim, S. J., Lee, M. N., Kim, M., & Kim, S. (2020). Comparison of learning effects of virtual reality simulation on nursing students caring for children with asthma. *International journal of environmental research and public health*, 17(22), 8417.
- Kazemi, H., Rappel, J. K., Poston, T., Hai Lim, B., Burdet, E., & Leong Teo, C. (2010). Assessing suturing techniques using a virtual reality surgical simulator. *Microsurgery*, 30(6), 479–486.

- Kennedy, G. A., Pedram, S., & Sanzone, S. (2023). Improving safety outcomes through medical error reduction via virtual reality-based clinical skills training. *Safety Science, 165*, 106200.
- Kidd, L. I., Knisley, S. J., & Morgan, K. I. (2012). Effectiveness of a Second Life® simulation as a teaching strategy for undergraduate mental health nursing students. *Journal of psychosocial nursing and mental health services, 50*(7), 28–37.
- Kilteni, K., Groten, R., & Slater, M. (2012). The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments, 21*(4), 373–387.
- Kim, H. Y., Lee, J. H., & Lee, E. H. (2021). Virtual experience of perioperative patients: walking in the patients' shoes using virtual reality and blended learning. *International Journal of Environmental Research and Public Health, 18*(12), 6457.
- Kim, K., Xie, N., Hammersmith, L., Berrocal, Y., Roni, M. A., & Kim, K. S. (2023). Impact of virtual reality on Pharmacology Education: a pilot study. *Cureus, 15*(8).
- Kirkpatrick, D. L. (1959). Techniques for evaluation training programs. *Journal of the american society of training directors, 13*, 21–26.
- Kiyozumi, T., Ishigami, N., Tatsushima, D., Araki, Y., Yoshimura, Y., & Saitoh, D. (2022). Instructor development workshops for advanced life support training courses held in a fully virtual space: observational study. *JMIR Serious Games, 10*(2), e38952.
- Kockro, R. A., Amaxopoulou, C., Killeen, T., Wagner, W., Reisch, R., Schwandt, E., Gutenber, A., Giese, A., Stofft, E., & Stadie, A. T. (2015). Stereoscopic neuroanatomy lectures using a three-dimensional virtual reality environment. *Annals of Anatomy-Anatomischer Anzeiger, 201*, 91–98.
- Kolecki, R., Pregowska, A., Dabrowa, J., Skucinski, J., Pulanecki, T., Walecki, P., van Dam, P. M., Dudek, D., Richter, P., & Proniewska, K. (2022). Assessment of the utility of mixed reality in medical education. *Translational Research in Anatomy, 28*, 100214.
- Kravitz, M. B., Dadario, N. B., Arif, A., Bellido, S., Ahmed, O., Gibber, M., & Jafri, F. N. (2022). The comparative effectiveness of virtual reality versus e-module on the training of donning and doffing personal protective equipment: a randomized, simulation-based educational study. *Cureus, 14*(3).
- Kron, F. W., Fetters, M. D., Scerbo, M. W., White, C. B., Lypson, M. L., Padilla, M. A., Gliva-McConvey, G. A., Belfore Ii, L. A., West, T., & Wallace, A. M. (2017). Using a computer simulation for teaching communication skills: A blinded multisite mixed methods randomized controlled trial. *Patient education and counseling, 100*(4), 748–759.
- Kyaw, B. M., Posadzki, P., Paddock, S., Car, J., Campbell, J., & Tudor Car, L. (2019a). Effectiveness of digital education on communication skills among

- medical students: systematic review and meta-analysis by the digital health education collaboration. *Journal of medical Internet research*, 21(8), e12967.
- Kyaw, B. M., Saxena, N., Posadzki, P., Vseteckova, J., Nikolaou, C. K., George, P. P., Divakar, U., Masiello, I., Kononowicz, A. A., Zary, N., & Tudor Car, L. (2019b). Virtual reality for health professions education: systematic review and meta-analysis by the digital health education collaboration. *Journal of medical Internet research*, 21(1), e12959.
- Kyaw, B. M., Tudor Car, L., van Galen, L. S., van Agtmael, M. A., Costelloe, C. E., Ajuebor, O., Campbell, J., & Car, J. (2019c). Health professions digital education on antibiotic management: systematic review and meta-analysis by the digital health education collaboration. *Journal of medical Internet research*, 21(9), e14984.
- Lang, M., Ghandour, S., Rikard, B., Balasalle, E. K., Rouhezamin, M. R., Zhang, H., & Uppot, R. N. (2024). Medical extended reality for radiology education and training. *Journal of the American College of Radiology*, 21(10), 1583–1594.
- Lau, S., Truong, T., Guzman, J., Carrasquillo, O., Akande, O., Gunasekeran, D., Agrawal, R. V., & Sandler, S. F. (2021). Augmented reality mobile application for glaucoma education in the south bronx. *Investigative Ophthalmology & Visual Science*, 62(8), 1599–1599.
- Law, A. K. K., Hung, K. K. C., James, K. S., Kelly, A. M., & Graham, C. A. (2023). Virtual patient simulation in undergraduate emergency medicine education during COVID-19: Randomized controlled trial. *Hong Kong Journal of Emergency Medicine*, 30(6), 439–446.
- Lee, J., Kim, H., & Kron, F. (2024). Virtual education strategies in the context of sustainable health care and medical education: A topic modelling analysis of four decades of research. *Medical Education*, 58(1), 47–62.
- Lee, Y., Kim, S. K., & Eom, M. R. (2020). Usability of mental illness simulation involving scenarios with patients with schizophrenia via immersive virtual reality: A mixed methods study. *PloS one*, 15(9), e0238437.
- Lesch, H., Johnson, E., Peters, J., & Cendán, J. C. (2020). VR simulation leads to enhanced procedural confidence for surgical trainees. *Journal of surgical education*, 77(1), 213–218.
- Liaw, S. Y., Tan, J. Z., Lim, S., Zhou, W., Yap, J., Ratan, R., Ooi, S. L., Wong, S. J., Seah, B., & Chua, W. L. (2023a). Artificial intelligence in virtual reality simulation for interprofessional communication training: mixed method study. *Nurse education today*, 122, 105718.
- Liaw, S. Y., Tan, J. Z., Rusli, K. D. B., Ratan, R., Zhou, W., Lim, S., Lau, T. C., Seah, B., & Chua, W. L. (2023b). Artificial intelligence versus human-controlled doctor in virtual reality simulation for sepsis team training: randomized controlled study. *Journal of medical Internet research*, 25, e47748.

- Lorenzo-Alvarez, R., Rudolphi-Solero, T., Ruiz-Gomez, M. J., & Sendra-Portero, F. (2019). Medical student education for abdominal radiographs in a 3D virtual classroom versus traditional classroom: a randomized controlled trial. *American Journal of Roentgenology*, 213(3), 644–650.
- Lowe, J., Peng, C., Winstead-Derlega, C., & Curtis, H. (2020). 360 virtual reality pediatric mass casualty incident: A cross sectional observational study of triage and out-of-hospital intervention accuracy at a national conference. *JACEP Open*, 1(5), 974–980.
- Macnamara, A. F., Bird, K., Rigby, A., Sathyapalan, T., & Hepburn, D. (2021). High-fidelity simulation and virtual reality: an evaluation of medical students' experiences. *BMJ simulation & technology enhanced learning*, 7(6), 528.
- Macnamara, A. F., Bird, K. A., Rigby, A., Sathyapalan, T., & Hepburn, D. (2023). High-fidelity simulation and virtual reality: a mixed-methods crossover study evaluating medical students' experiences as observers. *International Journal of Healthcare Simulation*.
- Madan, A. K., Harper, J. L., Frantzides, C. T., & Tichansky, D. S. (2008). Nonsurgical skills do not predict baseline scores in inanimate box or virtual-reality trainers. *Surgical endoscopy*, 22(7), 1686–1689.
- Mansoor, M. S., Khazaei, M. R., Azizi, S. M., & Niromand, E. (2021). Comparison of the effectiveness of lecture instruction and virtual reality-based serious gaming instruction on the medical students' learning outcome about approach to coma. *BMC medical education*, 21(1), 347.
- Mather, C., & McCarthy, R. (2021). Exploring the effects of a high-fidelity environment on nursing students' confidence and performance of CPR. *Nurs. Stand*, 36, 76–82.
- McCalla, M. M., Jones, D., Grice, R. A., Love, M., Love, C., Lammert, L., & Beverly, E. A. (2023). Feasibility of a cinematic-virtual reality training program for health professional students: a single-arm pre-post study. *Journal of diabetes science and technology*, 17(5), 1181–1189.
- McClusky III, D. A., Ritter, E. M., Lederman, A. B., Gallagher, A. G., & Smith, C. D. (2005). Correlation between perceptual, visuo-spatial, and psychomotor aptitude to duration of training required to reach performance goals on the MIST-VR surgical simulator. *The American Surgeon*, 71(1), 13–21.
- McGrath, J., Kman, N., Danforth, D., Bahner, D. P., Khandelwal, S., Martin, D. R., Nagel, R., Verbeck, N., Way, D. P., & Nelson, R. (2015). Virtual alternative to the oral examination for emergency medicine residents. *Western Journal of Emergency Medicine*, 16(2), 336.
- McLaughlin, N., Rogers, J., D'Arcy, J., & Gormley, G. (2020). 'Sorry doctor... I didn't hear that...': phenomenological analysis of medical students' experiences of simulated hearing impairment through virtual reality. *BMJ Simulation & Technology Enhanced Learning*, 7(4), 207.

- Meccawy, M. (2022). Creating an immersive XR learning experience: A roadmap for educators. *Electronics*, *11*(21), 3547.
- Menendez, E., Balisa-Rocha, B., Jabbur-Lopes, M., Costa, W., Nascimento, J. R., Dosea, M., Silva, L., & Lyra Junior, D. (2015). Using a virtual patient system for the teaching of pharmaceutical care. *International journal of medical informatics*, *84*(9), 640–646.
- Mergen, M., Junga, A., Risse, B., Valkov, D., Graf, N., & Marschall, B. (2023). Immersive training of clinical decision making with AI driven virtual patients—a new VR platform called medical tr. AI. ning. *GMS Journal for Medical Education*, *40*(2), Doc18.
- Metcalf, S. (2016). Second life patient scenarios: enhancing the diversity of the nursing profession. *Creative Nursing*, *22*(3), 166–170.
- Middeke, A., Anders, S., Schuelper, M., Raupach, T., & Schuelper, N. (2018). Training of clinical reasoning with a Serious Game versus small-group problem-based learning: A prospective study. *PloS one*, *13*(9), e0203851.
- Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, *77*(12), 1321–1329.
- Mills, B., Dykstra, P., Hansen, S., Miles, A., Rankin, T., Hopper, L., Brook, L., & Bartlett, D. (2020). Virtual reality triage training can provide comparable simulation efficacy for paramedicine students compared to live simulation-based scenarios. *Prehospital Emergency Care*, *24*(4), 525–536.
- Mills, B. W., Carter, O. B. J., Rudd, C. J., Claxton, L. A., Ross, N. P., & Strobel, N. A. (2016). Effects of low-versus high-fidelity simulations on the cognitive burden and performance of entry-level paramedicine students: a mixed-methods comparison trial using eye-tracking, continuous heart rate, difficulty rating scales, video observation and interviews. *Simulation in Healthcare*, *11*(1), 10–18.
- Minukhin, D. (2020). End Of Life Virtual Reality Training: Medical Student Increased Empathic Ability.
- Mitchell, A. A., & Ivimey-Cook, E. R. (2023). Technology-enhanced simulation for healthcare professionals: A meta-analysis. *Frontiers in Medicine*, *10*, 1149048.
- Moreira, G. J., Luna-Nevarez, C., & McGovern, E. (2022). It's about enjoying the virtual experience: The role of enjoyment and engagement in the adoption of virtual reality in marketing education. *Marketing education review*, *32*(3), 224–239.
- Moro, C., Phelps, C., Redmond, P., & Stromberga, Z. (2021). HoloLens and mobile augmented reality in medical and health science education: A randomised controlled trial. *British Journal of Educational Technology*, *52*(2), 680–694.
- Moro, C., Štromberga, Z., Raikos, A., & Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical sciences education*, *10*(6), 549–559.

- Morrison, J. M., Sullivan, F., Murray, E., & Jolly, B. (1999). Evidence-based education: development of an instrument to critically appraise reports of educational interventions. *Medical Education*, 33(12), 890–893.
- Nakazawa, A., Iwamoto, M., Kurazume, R., Nunoï, M., Kobayashi, M., & Honda, M. (2023). Augmented reality-based affective training for improving care communication skill and empathy. *PloS one*, 18(7), e0288175.
- Nakhoul, G., Mehdi, A., Crane, A.D., Schold, J. D., Arrigain, S., Wardrop, R. M., Nally, J. V., Bierer, S. B., Sedor, J. R., O’Toole, J. F. and Taliercio, J. J. (2022). Assessment of a 3-Dimensional (3D) Virtual Reality (VR) Educational Tool: TH-PO010. *Journal of the American Society of Nephrology*, 33(11S), 51.
- Nas, J., Thannhauser, J., Konijnenberg, L. S., van Geuns, R. J. M., van Royen, N., Bonnes, J. L., & Brouwer, M. A. (2022). Long-term effect of face-to-face vs virtual reality cardiopulmonary resuscitation (CPR) training on willingness to perform CPR, retention of knowledge, and dissemination of CPR awareness: a secondary analysis of a randomized clinical trial. *JAMA network open*, 5(5), e2212964-e2212964.
- Nas, J., Thannhauser, J., Vart, P., van Geuns, R.-J., Muijsers, H. E. C., Mol, J.-Q., Aarts, G. W. A., Konijnenberg, L. S. F., Gommans, D. H. F., & Ahoud-Schoenmakers, S. G. A. M. (2020). Effect of face-to-face vs virtual reality training on cardiopulmonary resuscitation quality: a randomized clinical trial. *JAMA cardiology*, 5(3), 328–335.
- Navaratnam, A. V., Halai, A., Chandrasekharan, D., Mistry, R., Rogel-Salazar, J., Manjaly, J. G., Tatla, T., Singh, A., & Ramdoo, K. (2022). Utilisation of a smartphone-enabled video otoscope to train novices in otological examination and procedural skills. *The Journal of Laryngology & Otology*, 136(4), 314–320.
- Newman, K., Kahlon, P. K., & Li, S. (2021). Raising nursing student awareness of how it feels to have dementia with the use of 360° video. *Journal of Nursing Education and Practice*, 11(2).
- NHS England. (2023). NHS long term workforce plan. *NHS England, London*.
- Noll, C., von Jan, U., Raap, U., & Albrecht, U. V. (2017). Mobile augmented reality as a feature for self-oriented, blended learning in medicine: randomized controlled trial. *JMIR mHealth and uHealth*, 5(9), e7943.
- Office for Students. (2019). Virtual reality tool leads new drive to train next generation of health specialists. *Office for Students*. Retrieved 24/02/2025 from <https://www.officeforstudents.org.uk/news-blog-and-events/press-a-n-d-m-e-d-i-a/virtual-reality-tool-leads-new-drive-to-train-next-generation-of-health-specialists/>
- Omori, K., Shigemoto, N., Kitagawa, H., Nomura, T., Kaiki, Y., Miyaji, K., Akita, T., Kobayashi, T., Hattori, M., Hasunuma, N., Tanaka, J., & Ohge,

- H. (2023). Virtual reality as a learning tool for improving infection control procedures. *American Journal of Infection Control*, 51(2), 129–134.
- Padilha, J. M., Machado, P. P., Ribeiro, A., Ramos, J., & Costa, P. (2019). Clinical virtual simulation in nursing education: randomized controlled trial. *Journal of medical Internet research*, 21(3), e11529.
- Peden, R. G., Mercer, R., & Tatham, A. J. (2016). The use of head-mounted display eyeglasses for teaching surgical skills: A prospective randomised study. *International Journal of Surgery*, 34, 169–173.
- Peters, P., Lemos, M., Bonsch, A., Ooms, M., Ulbrich, M., Rashad, A., Krause, F., Lipprandt, M., Kuhlen, T. W., Rohrig, R., Holzle, F., & Puladi, B. (2023). Effect of head-mounted displays on students' acquisition of surgical suturing techniques compared to an e-learning and tutor-led course: a randomized controlled trial. *International Journal of Surgery*, 109(8), 2228–2240.
- Petrica, A., Lungeanu, D., Ciuta, A., Marza, A. M., Botea, M. O., & Mederle, O. A. (2021). Using 360-degree video for teaching emergency medicine during and beyond the COVID-19 pandemic. *Annals of medicine*, 53(1), 1520–1530.
- Pfeil, A., Klemm, P., Hueber, A. J., Hoffmann, T., Weise, T., Oelzner, P., Knop, S., Muller-Ladner, U., Lange, U., Wolf, G., Schett, G., Simon, D., & Kleyer, A. (2024). Enhancing student understanding of rheumatic disease pathologies through augmented reality: findings from a multicentre trial. *Rheumatology*, 63(7), 1949–1956.
- Pottle, J. (2019). Virtual reality and the transformation of medical education. *Future healthcare journal*, 6(3), 181–185.
- Rai, A. S., Rai, A. S., Mavrikakis, E., & Lam, W. C. (2017). Teaching binocular indirect ophthalmoscopy to novice residents using an augmented reality simulator. *Canadian journal of ophthalmology*, 52(5), 430–434.
- Rakofsky, J. J., Talbot, T. B., & Dunlop, B. W. (2020). A virtual standardized patient-based assessment tool to evaluate psychiatric residents' psychopharmacology proficiency. *Academic Psychiatry*, 44(6), 693–700.
- Ramesh, P. V., Devadas, A. K., Joshua, T., Ray, P., Ramesh, S. V., Ramesh, M. K., & Rajasekaran, R. (2022). 3D printing ophthalmology related models for enhancing learning through the concept of puzzle assembly-A comprehensive self-learning tactile tool kit. *Indian Journal of Ophthalmology*, 70(4), 1384–1386.
- Ranpariya, V. K., Huang, W. W., & Feldman, S. R. (2022). Virtual reality memory palace: An innovative dermatology education modality. *Journal of the American Academy of Dermatology*, 86(6), 1435–1437.
- Rauschnabel, P. A., Felix, R., Hinsch, C., Shahab, H., & Alt, F. (2022). What is XR? Towards a framework for augmented and virtual reality. *Computers in human behavior*, 133, 107289.
- Real, F. J., DeBlasio, D., Beck, A. F., Ollberding, N. J., Davis, D., Cruse, B., Samaan, Z., McLinden, D., & Klein, M. D. (2017). A virtual reality

- curriculum for pediatric residents decreases rates of influenza vaccine refusal. *Academic pediatrics*, 17(4), 431–435.
- Richardson, A., Bracegirdle, L., McLachlan, S. I., & Chapman, S. R. (2013). Use of a three-dimensional virtual environment to teach drug-receptor interactions. *American journal of pharmaceutical education*, 77(1), 11.
- Robb, A., Kopper, R., Ambani, R., Qayyum, F., Lind, D., Su, L. M., & Lok, B. (2013). Leveraging virtual humans to effectively prepare learners for stressful interpersonal experiences. *IEEE transactions on visualization and computer graphics*, 19(4), 662–670.
- Rodríguez-Abad, C., Martínez-Santos, A. E., & Rodríguez-González, R. (2023). Online (versus face-to-face) augmented reality experience on nursing students' leg ulcer competency: Two quasi-experimental studies. *Nurse Education in Practice*, 71, 103715.
- Rodríguez-Abad, C., Rodríguez-Gonzalez, R., & Martínez-Santos, A. E. (2022). Effectiveness of augmented reality in learning about leg ulcer care: A quasi-experimental study in nursing students. *Nurse Education Today*, 119, 105565.
- Rodriguez-Rivas, M. E., Cangas, A. J., Martin, A., Romo, J., Perez, J. C., Valdebenito, S., Cariola, L., Onetto, J., Hernandez, B., Ceric, F., Cea, P., & Corrigan, P. (2024). Reducing stigma toward people with serious mental illness through a virtual reality intervention: a randomized controlled trial. *Games for Health Journal*, 13(1), 57–64.
- Roswell, R. O., Cogburn, C. D., Tocco, J., Martinez, J., Bangeranye, C., Bailenson, J. N., Wright, M., Mieres, J. H., & Smith, L. (2020). Cultivating empathy through virtual reality: advancing conversations about racism, inequity, and climate in medicine. *Academic Medicine*, 95(12), 1882–1886.
- Rothlind, E., Fors, U., Salminen, H., Wändell, P., & Ekblad, S. (2021). Virtual patients reflecting the clinical reality of primary care—a useful tool to improve cultural competence. *BMC Medical Education*, 21(1), 270.
- Rudolphi-Solero, T., Jimenez-Zayas, A., Lorenzo-Alvarez, R., Domínguez-Pinos, D., Ruiz-Gomez, M. J., & Sendra-Portero, F. (2021). A team-based competition for undergraduate medical students to learn radiology within the virtual world Second Life. *Insights into Imaging*, 12(1), 89.
- Rudolphi-Solero, T., Lorenzo-Alvarez, R., Ruiz-Gomez, M. J., & Sendra-Portero, F. (2022). Impact of compulsory participation of medical students in a multiuser online game to learn radiological anatomy and radiological signs within the virtual world Second Life. *Anatomical Sciences Education*, 15(5), 863–876.
- Ryan, G., Rafferty, A., Murphy, J., Higgins, M. F., Mangina, E., & McAuliffe, F. M. (2023). Virtual reality learning: A randomized controlled trial assessing medical student knowledge of fetal development. *International Journal of Gynecology & Obstetrics*, 162(1), 292–299.

- Saab, M. M. (2021). Enhancing Men's Awareness of Testicular Diseases Using Virtual Reality: The E-MAT Study. *European Journal of Cancer Prevention, 31*, S6-S7.
- Sarkar, U., Lee, J. E., Nguyen, K. H., Lisker, S., & Lyles, C. R. (2021). Barriers and facilitators to the implementation of virtual reality as a pain management modality in academic, community, and safety-net settings: qualitative analysis. *Journal of medical Internet research, 23*(9), e26623.
- Sattar, M. U., Palaniappan, S., Lokman, A., Hassan, A., Shah, N., & Riaz, Z. (2019). Effects of virtual reality training on medical students' learning motivation and competency. *Pakistan journal of medical sciences, 35*(3), 852.
- Scerbo, M. W., Bliss, J. P., Schmidt, E. A., & Thompson, S. N. (2006). The efficacy of a medical virtual reality simulator for training phlebotomy. *Human factors, 48*(1), 72–84.
- Schoeb, D. S., Schwarz, J., Hein, S., Schlager, D., Pohlmann, P. F., Frankenschmidt, A., Gratzke, C., & Miernik, A. (2020). Mixed reality for teaching catheter placement to medical students: a randomized single-blinded, prospective trial. *BMC medical education, 20*(1), 510.
- Silva, R. D. D. C., Albuquerque, S. G., Muniz, A. D. V., Filho, P. P. R., Ribeiro, S., Pinheiro, P. R., & Albuquerque, V. H. C. (2017). Reducing the schizophrenia stigma: a new approach based on augmented reality. *Computational intelligence and neuroscience, 2017*(1), 2721846.
- Simons, M. R., Zurynski, Y., Cullis, J., Morgan, M. K., & Davidson, A. S. (2019). Does evidence-based medicine training improve doctors' knowledge, practice and patient outcomes? A systematic review of the evidence. *Medical teacher, 41*(5), 532–538.
- Smidt, A., Balandin, S., Sigafos, J., & Reed, V. A. (2009). The Kirkpatrick model: A useful tool for evaluating training outcomes. *Journal of Intellectual and Developmental Disability, 34*(3), 266–274.
- Stepniak, C., Wickens, B., Husein, M., Paradis, J., Ladak, H. M., Fung, K., & Agrawal, S. K. (2017). Blinded randomized controlled study of a web-based otoscopy simulator in undergraduate medical education. *The Laryngoscope, 127*(6), 1306–1311.
- Stevens, A., Hernandez, J., Johnsen, K., Dickerson, R., Raij, A., Harrison, C., DiPietro, M., Allen, B., Ferdig, R., & Foti, S. (2006). The use of virtual patients to teach medical students history taking and communication skills. *The American Journal of Surgery, 191*(6), 806–811.
- Stevens, A., Hersi, M., Garritty, C., Hartling, L., Shea, B.J., Stewart, L.A., Welch, V.A. and Tricco, A.C. (2025). Rapid review method series: interim guidance for the reporting of rapid reviews. *BMJ evidence-based medicine, 30*(2), 118–123.
- Strickland, C. D., Lowry, P. A., Petersen, B. D., & Jesse, M. K. (2015). Introduction of a virtual workstation into radiology medical student education. *American Journal of Roentgenology, 204*(3), W289-W292.

- Stromberga, Z., Phelps, C., Smith, J., & Moro, C. (2021). Teaching with disruptive technology: the use of augmented, virtual, and mixed reality (HoloLens) for disease education. In *Biomedical Visualisation: Volume 9* (pp. 147–162). Cham: Springer International Publishing.
- Sultan, L., Abuznadah, W., Al-Jifree, H., Khan, M. A., Alsaywid, B., & Ashour, F. (2019). An experimental study on usefulness of virtual reality 360 in undergraduate medical education. *Advances in medical education and practice*, 9(7), 907–916.
- Taubert, M., Webber, L., Hamilton, T., Carr, M., & Harvey, M. (2019). Virtual reality videos used in undergraduate palliative and oncology medical teaching: results of a pilot study. *BMJ supportive & palliative care*, 9(3), 281–285.
- Thomson, H. (2023). Immersive virtual reality to promote leadership among health professions students. *Journal of Medical Imaging and Radiation Sciences*, 54(1), 28–34.
- Torda, A. (2020). CLASSIE teaching—using virtual reality to incorporate medical ethics into clinical decision making. *BMC medical education*, 20(1), 326.
- Tran, C., Toth-Pal, E., Ekblad, S., Fors, U., & Salminen, H. (2020). A virtual patient model for students' interprofessional learning in primary healthcare. *PLoS One*, 15(9), e0238797.
- Trapero, I., Sánchez-Martínez, V., Cauli, O., & Buigues, C. (2023). Evaluating video virtual reality teaching for nursing students. *Medical Education*, 57(11).
- Tso, H. L., Young, J., & Yung, C. W. (2021). Comparing eyesi virtual reality simulator and traditional teaching methods for direct ophthalmoscopy: students' perspectives at Indiana University School of Medicine. *Journal of Academic Ophthalmology*, 13(01), e66-e72.
- Turan, Z., Gürol, A., & Uslu, S. (2021). A mixed-methods study exploring the effect of augmented learning for paramedic students in ECG training. *Innovations in Education and Teaching International*, 58(2), 230–241.
- University of Exeter. (2025). Using virtual reality in medical imaging. *University of Exeter*. Retrieved 24/02/2025 from https://www.exeter.ac.uk/about/transforming-education/reimagined/casestudies/virtual_reality/
- Vallée, A., Blacher, J., Cariou, A., & Sorbets, E. (2020). Blended learning compared to traditional learning in medical education: systematic review and meta-analysis. *Journal of medical Internet research*, 22(8), e16504.
- Vandeweerd, C., Luong, T., Atchapero, M., Mottelson, A., Holz, C., Makransky, G., & Böhm, R. (2022). Virtual reality reduces COVID-19 vaccine hesitancy in the wild: a randomized trial. *Scientific reports*, 12(1), 4593.
- de la Vega, P.B., Dimitri, N., Brinkerhoff, C.A., Stern, A., Damus, K., Miselis, H., Garg, P.S., Sarfaty, S. and Martinez, L.S. (2022). Virtual reality simulated learning environments: a strategy to teach interprofessional

- students about social determinants of health. *Academic Medicine*, 97(12), 1799–1803.
- Vestergaard, L. D., Løfgren, B., Jessen, C., Børlum, C., Wolff, A., Vendelboe Nielsen, H., & Vinter Krarup, N. H. (2011). Pediatric basic life support self-training is comparable to instructor-led training: a randomized manikin study.
- Vukanovic-Criley, J. M., Boker, J. R., Criley, S. R., Rajagopalan, S., & Criley, J. M. (2008). Using virtual patients to improve cardiac examination competency in medical students. *Clinical Cardiology: An International Indexed and Peer-Reviewed Journal for Advances in the Treatment of Cardiovascular Disease*, 31(7), 334–339.
- Wandell, H. F. (2010). Using a virtual reality simulator in phlebotomy training. *Laboratory Medicine*, 41(8), 463–466.
- Washington, E., & Shaw, C. (2019). The effects of a VR intervention on career interest, empathy, communication skills, and learning with second-year medical students. In *Educational Media and Technology Yearbook: Volume 42* (pp. 67–80). Cham: Springer International Publishing.
- William, A., Vidal, V. L., & John, P. (2016). Traditional Instruction versus Virtual Reality Simulation: A Comparative Study of Phlebotomy Training among Nursing Students in Kuwait. *Journal of Education and Practice*, 7(9), 18–25.
- Williams, D., Stephen, L. A., & Causton, P. (2020). Teaching interprofessional competencies using virtual simulation: A descriptive exploratory research study. *Nurse education today*, 93, 104535.
- Wilson, G., Zargar, A., Kokotkin, I., Bhaskar, J., Zargar, D., & Trompeter, A. (2020). Virtual reality and physical models in undergraduate orthopaedic education: a modified randomised crossover trial. *Orthopedic Research and Reviews*, 97–104.
- Winkler-Schwartz, A., Bajunaid, K., Mullah, M. A. S., Marwa, I., Alotaibi, F. E., Fares, J., Baggiani, M., Azarnoush, H., Zharni, G. A., Christie, S., Sabbagh, A. J., Werthner, P., & Del Maestro, R. F. (2016). Bimanual psychomotor performance in neurosurgical resident applicants assessed using NeuroTouch, a virtual reality simulator. *Journal of surgical education*, 73(6), 942–953.
- Wollscheid, S., & Tripney, J. (2021). Rapid Reviews as an Emerging Approach to Evidence Synthesis in Education. *London Review of Education*, 19(1), n1.
- Wu, Y., Mondal, P., Stewart, M., Ngo, R., & Burbridge, B. (2023). Bringing radiology education to a new reality: a pilot study of using virtual reality as a remote educational tool. *Canadian Association of Radiologists Journal*, 74(2), 251–263.
- Yang, T., Buck, S., Evans, L., & Auerbach, M. (2021). A telesimulation elective to provide medical students with pediatric patient care experiences during the COVID pandemic. *Pediatric Emergency Care*, 37(2), 119–122.

- Yeo, J. Y., & Jang, M. S. (2023). Nursing students' self-directed learning experiences in web-based virtual simulation: A qualitative study. *Japan Journal of Nursing Science*, 20(2), e12514.
- Yeung, J., Kovic, I., Vidacic, M., Skilton, E., Higgins, D., Melody, T., & Lockey, A. (2017). The school Lifesavers study—A randomised controlled trial comparing the impact of Lifesaver only, face-to-face training only, and Lifesaver with face-to-face training on CPR knowledge, skills and attitudes in UK school children. *Resuscitation*, 120, 138–145.
- Yildiz, H., & Demiray, A. (2022). Virtual reality in nursing education 3D intravenous catheterization E-learning: A randomized controlled trial. *Contemporary Nurse*, 58(2–3), 125–137.
- Yoganathan, S., Finch, D. A., Parkin, E., & Pollard, J. (2018). 360 virtual reality video for the acquisition of knot tying skills: A randomised controlled trial. *International Journal of Surgery*, 54, 24–27.
- Zackoff, M. W., Young, D., Sahay, R. D., Fei, L., Real, F. J., Guiot, A., Lehmann, C., & Klein, M. (2021). Establishing objective measures of clinical competence in undergraduate medical education through immersive virtual reality. *Academic pediatrics*, 21(3), 575–579.
- Zare-Bidaki, M., Ehteshampour, A., Reissaliakbarighomi, M., Mazinani, R., Khodaie Ardakani, M. R., Mirabzadeh, A., Alikhani, R., Noroozi, M., Momeni, F., Samani, A. D., Mehrabi Tavana, M. M., Esmaili, A., & Mousavi, S. B. (2022). Evaluating the effects of experiencing virtual reality simulation of psychosis on mental illness stigma, empathy, and knowledge in medical students. *Frontiers in Psychiatry*, 13, 880331.
- Zhao, G., Fan, M., Yuan, Y., Zhao, F., & Huang, H. (2021). The comparison of teaching efficiency between virtual reality and traditional education in medical education: a systematic review and meta-analysis. *Annals of translational medicine*, 9(3), 252.
- Zhou, L. L., Tait, G., Sandhu, S., Steiman, A., & Lake, S. (2019). Online virtual cases to teach resource stewardship. *The Clinical Teacher*, 16(3), 220–225.

SEARCH STRATEGY

Ovid MEDLINE(R) ALL <1946 to October 16, 2023>

- 1) exp Virtual Reality/5907
- 2) exp Augmented Reality/1258
- 3) extend* realit*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 277
- 4) mix* realit*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 976
- 5) augment* realit*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 4781
- 6) virtual realit*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 18970
- 7) 1 or 2 or 3 or 4 or 5 or 6 23156
- 8) exp Students, Health Occupations/88219
- 9) medic*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 3397632
- 10) health*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 4723935

- 11) nurs*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 818201
- 12) physician*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 654077
- 13) doctor*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 154737
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- 16) grad*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 1177444
- 17) pre*regist*.mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms, population supplementary concept word, anatomy supplementary concept word] 3354
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 - 24) exp curriculum/ or exp education, premedical/ or exp education, professional/ or exp clinical competence/418417
 - 25) exp Communication/367256
 - 26) exp Motor Skills/26512
 - 27) exp Teaching/93357
 - 28) exp Education, Nursing, Baccalaureate/ or exp Vocational Education/ or exp Education, Dental/ or exp Education, Medical, Continuing/ or exp Education, Dental, Graduate/ or exp Nursing Education Research/ or exp Education, Pharmacy/ or exp Education, Nursing, Continuing/ or exp Health Education/ or exp Education, Predental/ or exp Education, Public Health Professional/ or exp Education, Pharmacy, Graduate/ or exp Education, Medical/ or exp Health Education, Dental/ or exp Education, Medical, Undergraduate/ or exp Education, Nursing, Graduate/ or exp Education, Veterinary/ or Education/ or exp Education, Medical, Graduate/ or exp Education, Premedical/ or exp Education, Nursing, Associate/ or exp Education, Pharmacy, Continuing/ or exp Education, Dental, Continuing/ or exp Education, Nursing/ or exp Education, Nursing, Diploma Programs/583556
 - 29) exp Communication/367256
 - 30) exp Decision Making/233943
 - 31) exp Assertiveness/1768
 - 32) exp Diagnosis/9410971
 - 33) exp Physical Examination/1378983
 - 34) (learn* or teach* or curricul* or educat* or psychomotor* or motor* or practical* or procedur* or clinic* or technic* or skill* or behav* or knowledge* or non*technic* or human factor* or team* or communicat* or decision* or task* or situat* or escalat* or assert* or diagnos* or examin* or assess* or investigat* or interpret* or interven* or manag*). mp. [mp=title, book title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word,

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