ISSN: 2634 - 680X

Journal of Clinical Case Studies Reviews & Reports

SCIENTIFIC Research and Community

Research Article

Open Access

Improving Patient Outcomes in Clinical Skills and Simulation-Based Education: A Realist Review Examining Contributions of XR Immersive Technologies

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ABSTRACT

Background

The paper aims to examine circumstances that lead to improvement of patient outcomes by contribution of XR immersive technologies in clinical skills and simulation-based education. The realist approach that is fundamentally concerned with theory development and refinement of complex interventions is adopted to enable development of new knowledge and highlight success and areas of development [1-3].

Methods/ Design

Quality guidance and checklist of 'RAMESES' (Realist and meta-review Evidence Synthesis: Evolving Standards) were used to gain an understanding of the different contexts of how interventions worked. A realist review included secondary data analysis using a database search of MEDLINE, CINAHL, BNI, EMBASE, PubMed and Google Scholar. Main terms used were 'digital technology' 'XR in Healthcare/Extended Reality' and their related synonyms. Once key data were extracted realist analysis was undertaken to identify impact of context and underlying causal mechanisms that can lead to different outcomes.

Realist and meta-narrative review approaches are relatively new approaches to systematic review and are theory driven, guiding the process from the beginning, with data extraction and synthesis being key aspects of theory refinement [4]. Much of the focus being on interactions between interventions, Context (C), Mechanism (M) and Outcomes (O) configuration, aim to identify patterns and refine the theory.

Results

Literature search initially provided 179 inclusion-relevant papers. 37 studies that were primarily focused on research-related immersive experiences were chosen for data extraction.

Context of emerging technologies in selected studies included:

- Virtual Reality (VR)
- Augmented Reality (AR)
- Mixed Reality (MR)
- Extended Reality (XR)

These were then themed through connections and chains of inference into the following categories:

- Skills
- Knowledge
- Quality
- Personal Characteristics
- Learner Experiences
- Cost-Benefit & Justification
- Patient Safety
- Affective Outcomes

The above approaches enabled narrative development to generate new knowledge and identified best applications of XR immersive technologies in clinical skills training and simulation-based education to enhance timely, technology assisted appropriate and cost effective learning to improve patient outcomes.

Discussion
Characteristics of the immersive experiences contribute to healthcare outcomes. The complexities of these experiences can also enhance learner skills. The foundations of Artificial Intelligence (AI) are built on data, discovery, diversity of learning an assumption that human thinking can be reduced to logical steps that can be mechanised [3]. Replication of human intelligence, exist in various forms such as computing machines, rules based, machine learning, input, and output data, such as software development and smart phones. Arguably, AI evidence standards, safety and harms show failures around 'clinical benefits for patients' suggesting that solutions are human and not technical [2].

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Received: July 22, 2025; **Accepted:** July 29, 2025; **Published:** August 05, 2025

Keywords: XR in Healthcare, Immersive Technologies, Digital Innovation in Healthcare, Augmented Reality, Mixed Reality, Simulation Based Education, Clinical Skills

Introduction
The research aims to explore how XR immersive technologies in clinical skills and simulationbased education impact on improving patient outcomes. XR is an overarching term to encompass the various technologies. XR refers to extended reality which includes augmented reality (AR), mixed reality (MR) and virtual reality (VR) immersive technologies, such as haptics, interfaces, platforms, and software. VR and AR have been used for several decades in surgery [5]. In the past five years powerful and accessible high-speed, cost-effective technologies have been developed for the next-generation virtual and augmented devices [6].

Advantages of Using XR Technology
XR experiences in healthcare aim to foster independent learning and develop key skills. Simulations replicate aspects of real-world clinical situations and can provide candidates/trainees with a safe learning environment; enhancing competence in emergency medicine providers to improve patient outcomes [7]. Being able to practice skills until they reach competency or gain confidence through debrief discussion, feedback, and self-correction [8, 9].

Manikin-based high fidelity simulation training effectively improves the trainers and trainees decision-making abilities, procedural skills competencies, and patient health outcomes [7]. However, high fidelity simulation requires in-person training, which can be logistically challenging, labour intensive and is expensive. Exciting technologies, such as augmented reality (AR) and virtual reality (VR) can help address and alleviate these obstacles [7].

Advantages of Using AR and VR Technology
AR provides the ability to digitally enhance the real world by using holographic images, where-as VR uses computer-generated simulation of a three-dimensional image or environment that a person can interact with by using a head set or gloves fitted with sensors [7]. The Growing Value of XR in Healthcare report (2021) has been developed to have access to, and to help inform, emerging strategies as the global face of XR in healthcare evolves [10]. The role of AR and VR in improving and assessing clinical skills, theoretical knowledge and affective learning outcomes and competencies has been considered as beneficial for both the trainee and the assessor [11]. Allowing the trainee to 'improve decision-making skills' which can be broadcast, therefore enabling the user to be able to connect with the trainers and experts remotely in real-time for instant feedback [7].

Consideration of Using XR, AR and VR Technology
Education is notoriously difficult to evaluate and combined with the diverse settings and structures in which learning experiences are implemented, changes over time [12]. The challenge for education in healthcare is to ensure that XR immersive technologies are effective, safe, help people and most importantly are of benefit to patients.

Methods
To explore how contextual factors influence feasibility and limitations (extent) of intervention and outcomes around what works best for patients and learners under IMMERSIVE TECHNOLOGIES, a realist review was undertaken [2, 12].

Realist review is based on a realist philosophy of science, which forms underlying assumptions, methodology and quality considerations and aims to capture current expertise [4].

Study Design
The study design, a realist review, was guided by Pawson's five stages of realist review: clarifying scope (concept mining and theory development); searching for evidence; study selection; data extraction; and data synthesis [13, 14].

Clarifying Scope
Central to a realist approach an initial programme theory was developed, based on initial analysis of the literature. Only studies focusing on the contribution of one of more of the following immersive technologies were included, VR, AR, MR and XR, with emphasis on clinical skills development and simulation-based educational platforms. A single reviewer initially conducted the search, therefore there was no verification of selected papers. The review was verified by two independent reviewers. Studies were selected from academic literature, an organisation of extracted data with technologies used, theming and formation of connections and the emergent of new theory development linked to chains of inference.

Based on reviews of the initial programme theory, defined outcomes were developed from the proposed context of the contribution of immersive technologies on clinical skills and simulation-based education. Through facilitator and student engagement in terms of skills, knowledge & quality, personal characteristics & learner experience, cost-benefit & justification, patient safety, affective and patient outcomes, were proposed as emerging mechanisms.

Searching the Evidence
Searches of six databases were conducted, MEDLINE (7), CINAHL (6), BNI (36), EMBASE (20), EMCARE (5), and PubMed (105) in November 2021. Twelve broad search terms were initially developed in consultation with a subject librarian to suit individual

databases: digital technology, immersive technology, simulation-based education, virtual reality, XR in healthcare, extended reality, augmented reality, mixed reality, haptics, interfaces, innovation in healthcare, patient outcome, cost effectiveness. Additionally, after commencing full text screening, a further Google Scholar (18) search with terms including procedural and clinical skills and immersive technologies was undertaken by the researcher, providing a further seven papers completing the screening process (Appendix 1).

Seven database searches were conducted between November 2021 and completed by January 2022, providing a total of 197 potentially relevant articles which were then downloaded and screened against the inclusion and exclusion criteria. Following initial screening fifty full-text articles were reviewed and an additional thirteen papers were excluded, as they did not comment on the effect of XR in clinical skills and simulation-based education. The final selected papers were published between 2017 and 2022 and were conducted in fifteen countries: eleven in the USA, two in Australia, six in the United Kingdom, four in Singapore, three in Japan and Korea, one in Taiwan, Italy, Tokyo, Thailand, Malaysia, Canada, India, Bulgaria and Switzerland. Five studies were randomized control trials (RCT), fourteen review articles, five survey studies, four systematic reviews, three user reports, two case study reviews and one VR laboratory design, one multi-institutional study, one combined analysis on data and one questionnaire.

Search findings were downloaded into Zotero for screening, which helped to then formulate the final research question. The inclusion criteria included: no date range due to the newness of technologies, published in English language, full study reports, published within a peer reviewed academic journal, full text available online or via library services and a global healthcare study population.

Study Selection
The titles and abstracts of the articles were independently screened against the inclusion and exclusion criteria and once duplicates were removed shared via Zotero. Only studies that described immersive experiences and technologies within healthcare (including the plethora of terms VR, AR, MR and XR) and their outcomes were included (Appendix 2). A realist method was followed where-by studies were selected based on their usefulness in answering the research question. As this field of study has new emerging technologies this could be otherwise limiting if based on quality and study design alone.

Data Extraction
Quality guidance and checklist of 'RAMESES' (Realist and Meta-review Evidence Synthesis: Evolving Standards) were used to gain an understanding of the different contexts of how interventions worked following realist synthesis [4, 15].

Realist evaluation is a form of theory-driven evaluation, based on a realist philosophy of science that addresses the questions, 'what works, for whom, under what circumstances, and how' [15, 16]. Programme theory questions were used to guide the review and data extraction process by using an outcome-focused theoretical framework concerned with uncovering 'what works.' This was refined through stakeholder engagement, multidisciplinary community in healthcare and links to a 'Digital Innovations Group' at University Hospitals Birmingham (UHB). Reference group question formulation, tool development, and evidence synthesis, critique and challenge to the method and emerging findings.

By extracting and synthesising the evidence, study characteristics (author, publication, year, study methodology), contexts, details intervention, context, mechanism and outcomes (CMO) configurations are created. The realist review seeks to consider links between context and mechanisms, to then generate the observed outcome(s). The mechanism defined as 'underlying entities, processes, or structures which operate contexts to generate outcomes of interest' [16]. Approaches allow systematic exploration of how and why complex interventions work, findings will be collated to populate the evaluative framework with evidence, creating a hypothesis linked to chains of inference. Organisation of extracted data into evidence tables, theming and formulation of chains of inference, links, and new knowledge formulation.

A chain of inference is a connection that can be made across articles based on the themes identified:

- **Step One:** Data extraction tables organised into theory area and questions
- **Step Two:** Data themed – emerging issues considered as relevant conditions for change agency
- **Step Three:** Chains of inference/connections across extracted data and themes to build up a cumulative picture
- **Step Four:** New knowledge formation (mechanism, context, outcome chains) (CMO)

Example: change agents who are adequately supported and resourced (XR Technologies *context) who role model the practices they espouse (Clinical Skills & SBE emerging themes *mechanism) may impact more positively on achieving evidence-informed healthcare (Improving Patient *outcomes).

Data Synthesis
The data from all thirty-seven studies were explored for patterns of context, mechanisms, and outcomes to abstract key study characteristics to create CMO configurations. Extracted data was organised into evidence tables for theming, identifying connections and links to the research question, allowing formulation of chains of inference and hypothesis (Appendix Three). CMO patterns were drafted and compared, evidence synthesis noted differences to help understand and highlight any issues, grounded on realist methods [17-20]. This allowed identification of frequent patterns for theme development of skills, knowledge utilisation, quality, personal characteristics, learner experience, cost-benefits & justification, patient safety and affective outcomes.

Emerging issues considered as relevant conditions for change agency include facilitator and learner confidence, years of experience, level of qualification, willingness to work collaboratively. Cumulating into a larger list of factors including embedded culture, generational influences, willingness to change and try new ways of working, interest, resources, leadership, partnerships, and supportive networks. The review focuses on gaining an understanding of the mechanisms by which the intervention works or fails to work, thus providing an explanation rather than to form a judgement, about how it works [17]. Being represented as content and mechanism to equal the outcomes process of systematically and transparently synthesizing literature [18, 19].

Results
The reviewer focused on simple questions to develop an outcome-focused theoretical framework because a realist synthesis is concerned with uncovering 'what works': What is the intended

use? Why do you need it? What is your current solution? Who is going to use it and how? What is the impact if it makes mistakes? How will we measure if it works? In order for new knowledge generation change agents who are adequately supported and resourced (XR Technologies: variation of virtual worlds *context) who role model the practices they espouse (Clinical Skills & SBE: skills, knowledge, characteristics, cost, safety *mechanism and interventions) may impact more positively on achieving evidence-informed healthcare (Affective Learning Outcomes and Improving Patient Care *outcomes).

Based on key terms and concepts related to various interventions, knowledge, and strategy and to draw upon experience, provides some explanation about the subject matter [20]. Thus, promoting evidence-informed healthcare from emerging theory areas in technology and education. Programme theory questions raised address characteristics, impact, and interactions. Key mechanisms identified has seen the contribution of various forms of XR technologies as relevant and of value, with resources of structure, supervision and support featuring as a high requirement by facilitators and learners. Self-efficacy, previous experience, organisational culture, and time to conduct the skill or training, with quality supervision linked to proficiency.

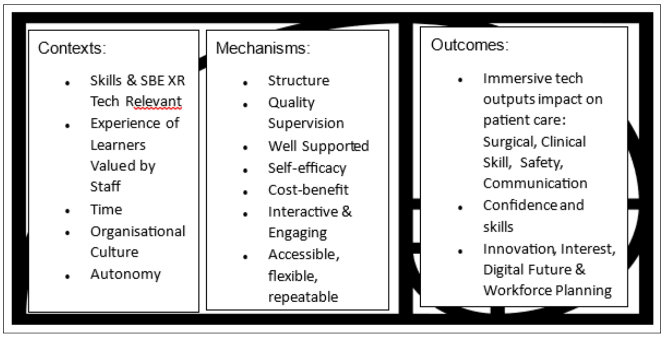
Key features consistently led to positive outcomes of contexts-mechanism correlation. Firstly, with the provision of resources, such as being user friendly technologies, engaging, interactive, providing an environment inducive to learning and importantly cost-effective justifications. Secondly, quality supervision from knowledgeable supervisors/educators, able to guide processes, monitor progress and provide detailed and effective feedback to learners.

Thirdly, a degree of autonomy in accessing educational platforms with protected time [1-3, 21].

Table 1: Key Findings

Benefits of XR Technologies: • Foster independent learning and develop key skills • Emergent of more high speed, cost effective technologies are being developed which are more powerful and more widely accessible • Provide candidates/trainees with a safe learning environment; enhancing competence in emergency medicine providers to improve patient outcomes • The role of AR and VR in improving and assessing clinical skills, theoretical knowledge and affective learning outcomes and competencies has been considered as beneficial for both the trainee and the assessor • Innovative teaching tool • International and global reaching • 3D models and interactive 360º videos • Spatial visualisation • High degree of realism • Complete learner engagement • Evidence for feasibility, usability, tolerability • No statistical difference in time-to-critical actions for VR vs. standard HF manikin • Not limited by time and space constraints • Offers additional practice opportunities.
Considerations: • Cost of fitting a VR lab, software and hardware, lab operation and maintenance • Optimise battery life, reports of discomfort, overheating, software issues, poor signal strength impacts on image quality • Trainees become over reliant on device(s), hinder abilities & learning if devices unavailable • For less tech savvy learners can be anxiety provoking • Data Protection & Security streaming via secure or encrypted servers, impact cost.

Table 2: Realist Review Modified Theory for Why, How and Under what Circumstances Do XR Technologies in Clinical Skills and Simulation-Based Education Improve Patient Outcomes:



Discussion

Characteristics of the immersive experiences contribute to healthcare outcomes. The complexities of these experiences can also enhance learner skills. The foundations of Artificial Intelligence (AI) are built on data, discovery, diversity of learning and an assumption that human thinking can be reduced to logical steps that can be mechanised [3]. Replication of human intelligence, exist in various forms such as computing machines, rules based, machine learning, input, and output data, such as software development and smartphones. Arguably, AI evidence standards, safety and harms show failures around 'clinical benefits for patients' suggesting that solutions are human and not technical [2].

This study depicts an adapted theory as to why, how and under what circumstances XR technologies can impact on the healthcare system via technological advancements and educational platforms to provide patient benefits. Through described experiences and findings, involving the engagement of multidisciplinary healthcare staff, in a range of quality improvement projects, literature reviews and research projects, to scope potential different outcomes. Findings are consistent with earlier reviews for healthcare professionals and draw upon course development, quality assurance and supported learning [21-24]. The synthesis of literature, nationally and internationally has shown that experiences must provide support, supervision, time and commitment for learning success [22-26]. Recognising the need for flexible learning modalities, emphasized by the 2020 COVID-19 pandemic, for clinicians to gain competencies remotely, rapidly and reliably [26, 27]. Findings highlight that the attributes of experienced, knowledgeable, supportive supervisors have been identified as key elements for the provision of quality training and for student satisfaction.

Limitations of the Study

There are, however, suggested limitations to Realist and Meta-narrative Reviews, the extent to which guidelines, standards and checklists can capture quality. Some qualitative researchers are dismissive of a 'technical checklist' approach for a method of quality assurance in systematic review cited in Protocol RAMESES. However, formal quality criteria are likely to add to the overall quality of outputs in this field [27, 28]. The researcher was only able to select published articles, which can lead to publication bias, with limited resource and time constraints [28]. Quality assurance is dependent on reviewers' explicitness and reflexivity to question what is going well, going less well, and to engage in group learning activities. To work on the premise that one needs to understand how interventions work in different contexts, and why.

Justification of the Method Used

Rycroft-Malone et al (2012) developed an approach that is fundamentally embedded in realist synthesis, this being theory led, purposive, iterative, and with stake holder involvement [14, 29]. This all-embracing approach captures the complexities of real-life and time implementation. Findings from the study are transferable and are stakeholder driven, to facilitate engagement and inclusion from multiple perspectives. Thus, requiring an equal focus on what works, and does not work. To learn from failures and to maximise healthcare learning and resources, adapted for different learners, through different digital immersive learning activities. The focus on positive outcomes in the reviewed studies may be a limitation, although as Table 1 indicates, considerations have been identified.

Conclusion

Using a realist approach to collate and summarise existing literature on the interventions of XR technologies in healthcare, has provided the opportunity to develop insightful conclusions of complex interventions, processes and outcomes. Virtual worlds have been shown to be more effective in improving cognitive outcomes in theoretical knowledge, suggesting that virtual worlds can be used as an alternative or complementary method of teaching [29].

Currently the cognitive technological developments available, such as VR/AR headsets and smart phones, have not been designed with the end- user in mind and cannot be incorporated into the clinical real-world [30, 31]. Flexible thinking to address and deal with such complexities, rewards potential for more pragmatic conclusions, with continued advancements in technology. To develop in-depth knowledge and skills, provide access to quality supervision, structure, and support are all relevant, valuable, and build self-efficacy. Autonomy and protected time to engage in XR immersive technologies will build upon experiences and impact on clinical practice, to generate achievement of improved patient outcomes.

Acknowledgements

Evidence Search: Digital Innovation in Healthcare/Simulation Based Education/Measuring Patient Outcome(s). Phil O'Reilly. 24th November 2021. Birmingham, UK: University Hospitals Birmingham (UHB) Library and Knowledge Service.

Conflict of Interest: None

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