Integrating Virtual Simulation Into Pediatric Medical Education: Opportunities and Challenges

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Abstract

Virtual simulation is rapidly becoming a core component of medical education, yet its optimal integration into pediatric curricula remains incompletely understood. Recent reviews suggest that virtual simulation, including virtual reality (VR) and serious games, can improve clinical skills, confidence, and preparation for the clinical environment in undergraduate and postgraduate learners, particularly in imaging-rich and procedure-intensive domains,,. In pediatrics and neonatology, simulation already enhances crisis resource management and systems-based practice, but most programs still rely on high-fidelity manikins rather than immersive virtual platforms,,. This article synthesizes current evidence on virtual simulation in undergraduate and pediatric medical education, outlines practical approaches for curriculum integration, and compares virtual simulation with traditional high-fidelity manikin-based training. We highlight implementation barriers, including faculty development, cost, and validity evidence, and propose a stepwise model for aligning virtual simulation with competency-based medical education and workplace-based assessments,,. Future work should prioritize rigorous outcomes research and context-specific design for low- and middle-income settings,,.

Keywords: virtual simulation, medical education, pediatrics, competency-based, assessment, VR, serious games, curriculum integration

Introduction

The digital transformation of health care has accelerated interest in virtual simulation (VS), including virtual reality (VR), augmented reality, and computer-based serious games, as scalable tools for medical education. VS can recreate realistic clinical scenarios on a computer screen to provide immersive, interactive, and risk-free environments, enabling repeated practice of procedures and clinical decision-making without patient harm,. In undergraduate settings, VS has been integrated into diverse learning contexts such as anatomy, procedural training, radiology, and interprofessional education, and is associated with improved preparation for clinical environments and higher learner confidence,.

In pediatrics and neonatal medicine, simulation-based education has a well-established role in training teams for high-risk, low-frequency events and in maintaining competence in critical care and resuscitation,,. Reviews of pediatric simulation-based education (P-SBE) conclude that simulation is effective in improving proficiency and competence of providers caring for children and newborns, while emphasizing the need for stronger evidence on validity and reliability of simulation scenarios and assessment tools,,,. At the same time, competency-based medical education (CBME) and workplace-based assessment (WBA) demand robust, authentic assessment data, often structured around entrustable professional activities (EPAs),.

The convergence of VS, pediatric simulation, and CBME presents both opportunities and challenges. Virtual platforms may support large-scale, standardized, and data-rich assessment of clinical reasoning and technical skills, but their integration into existing curricula, particularly in resource-limited settings, remains complex,,. This article focuses on how virtual simulation can be meaningfully integrated into pediatric and undergraduate medical education within a CBME framework, comparing VS to traditional high-fidelity manikin-based simulation and identifying key implementation considerations,,,,,.

Methods

This narrative review was structured to inform curriculum design rather than to exhaustively catalog all VS applications. We purposively sampled recent peer-reviewed literature (primarily 2021–2025) on virtual simulation, pediatric simulation-based education, and competency-based medical education, with emphasis on scoping and systematic reviews, as well as illustrative primary studies in CBME and WBA,,, – ,,.

Sources were examined for (1) educational contexts where VS has been applied, (2) reported learning and system outcomes, (3) characteristics and validation of pediatric simulation programs, and (4) frameworks for CBME and WBA implementation. Data were synthesized descriptively to derive practical recommendations for integrating VS into pediatric and undergraduate curricula and to construct a comparative table of VS and high-fidelity manikin-based simulation. This approach was chosen to produce directly applicable guidance for medical educators rather than formal meta-analytic estimates.

Results

Educational Roles of Virtual Simulation in Undergraduate Medicine

Across undergraduate medical education, VS has been used to teach anatomy, procedural skills, radiology, emergency care, and interprofessional teamwork,. VR and serious games allow learners to practice tasks such as imaging interpretation, basic life support, and clinical reasoning in structured, gamified environments, often with automated feedback and performance tracking,. In radiology teaching, VS systems

emulating CT, MRI, and ultrasound workflows enable students to gain hands-on experience while avoiding unnecessary radiation exposure, and have been associated with improved preparation for clinical rotations and greater confidence.

VS-based training generally appears well accepted by students, who report high engagement, improved spatial and anatomic visualization, and enhanced procedural confidence,. Studies summarized in recent scoping reviews indicate that VS can support acquisition of practical competencies under safe, controlled conditions and can facilitate multi-user, interprofessional learning across institutions. However, the heterogeneity of platforms and outcomes measures complicates direct comparison of effect sizes, and robust data on long-term retention and patient-level outcomes are still limited,.

Pediatric Simulation-Based Education and its Extension into Virtual Domains

Pediatric and neonatal simulation traditionally rely on high-fidelity manikins and in situ scenarios to train teams in resuscitation, crisis management, and systems-level safety. Reviews of P-SBE demonstrate that simulation-based education improves clinical performance, learner confidence, and the ability to identify latent safety threats within pediatric intensive care and emergency settings,,. Simulation aligns well with adult learning principles by promoting experiential, problem-centered learning in realistic contexts, and has been embedded into accreditation requirements for pediatric critical care training.

A recent systematic review of pediatric simulation-based education highlighted that most research has focused on technical analysis of educational methods and target populations, with relatively less attention to the content and validation processes of simulation scenarios. The authors concluded that P-SBE is effective but called for clearer criteria for validity and reliability, as well as structured development processes to ensure high-quality scenarios and programs,. While VS is less extensively studied in pediatrics than in adult or generic undergraduate domains, early applications suggest potential for extending manikin-based training with VR-enhanced scenarios, remote participation, and serious games tailored to pediatric emergencies,.

Competency-Based Medical Education, Workplace Assessment, and Simulation

CBME frameworks define training outcomes as specific competencies and often operationalize these via entrustable professional activities that represent core clinical tasks of unsupervised practice,. Workplace-based assessments such as mini-clinical evaluation exercises, direct observation tools, and EPA-based instruments are central for collecting evidence of competence in authentic clinical environments,. However, WBA systems face challenges including assessor bias, variable reliability, and cultural reluctance to fully entrust trainees, especially in high-stakes settings,.

Simulation, including VS, can supplement WBA by providing standardized, repeatable scenarios where performance across cognitive, psychomotor, and affective domains

can be observed and documented. Reviews of WBA emphasize the need for rigorous, validity-informed tools that align with CBME principles and generate meaningful assessment data,. Emerging work using natural language processing to evaluate narrative feedback within EPA platforms demonstrates how digital ecosystems can support scalable analysis of competence development, suggesting a convergence between data-rich simulation environments and CBME assessment infrastructures,. Integrating VS into these systems may enable fine-grained tracking of performance trajectories, provided that scenarios and metrics are carefully aligned with competency frameworks,,.

Comparison of Virtual Simulation and High-Fidelity Manikin-Based Simulation

The literature suggests complementary strengths and limitations of VS and traditional high-fidelity manikin-based simulation in pediatrics and undergraduate education,,,,.

Table 1. Key characteristics of virtual simulation and high-fidelity manikin-based simulation in medical education

Dimension	Virtual simulation (VS)	High-fidelity manikin-based simulation (HF)
Learning environment	Computer-based, immersive, often remote-capable, scalable to many learners ,	Physical simulation center or in situ clinical space with equipment , ,
Typical modalities	VR/AR headsets, screen-based serious games, virtual patients, imaging simulators ,	Life-sized manikins, task trainers, full-scale team scenarios , ,
Strengths in pediatrics	Safe practice of rare scenarios, remote access, iterative decision-making ,	Rich team communication, hands-on procedures, systems testing , ,
Assessment possibilities	Automated performance logs, in-game metrics, standardized cases ,	Direct observation, rich behavioral and team interaction data , ,
Resource requirements	Hardware, software licenses, IT support; potentially lower marginal cost per learner ,	Dedicated space, manikins, consumables, faculty facilitators ,
Evidence base in pediatrics	Growing but still limited; more data in undergraduate general contexts , ,	More established in pediatric critical care and resuscitation , ,
Suitability for LMICs	Promising for scalable access but constrained by infrastructure ,	Effective but often limited by cost and maintenance , ,

Discussion

This narrative synthesis suggests that virtual simulation has matured into a versatile pedagogical strategy in undergraduate medical education and is poised to augment existing pediatric simulation programs. VS can recreate realistic clinical scenarios through VR, AR, and serious games, offering interactive, risk-free environments that support repeated practice of clinical reasoning and procedures,. In radiology and

imaging, VS specifically addresses safety constraints by allowing learners to engage deeply with CT, MRI, and ultrasound workflows without radiation exposure, while improving readiness for clinical rotations. These characteristics align strongly with CBME goals of ensuring that learners reach clearly defined competencies through deliberate practice and feedback,.

In pediatrics and neonatology, simulation-based education already demonstrates benefits in technical performance, crisis resource management, and systems-level safety, and has become integral to training in intensive care and emergency settings,,. Systematic reviews highlight that P-SBE improves proficiency and competence among providers caring for children but simultaneously reveal gaps in the validation and reliability of simulation scenarios and outcome measures,. Virtual simulation can address some of these gaps by enabling rigorous standardization of scenarios, detailed performance logging, and remote participation, which are particularly valuable in low- and middle-income countries where access to simulation centers and faculty may be limited,,,.

However, the integration of VS into CBME and WBA systems demands careful alignment with competency frameworks and attention to psychometric quality. CBME relies on high-quality, authentic assessment data, often captured through EPA-based workplace assessments,. While VS can generate extensive process data, educators must ensure that metrics truly reflect meaningful competence rather than superficial game performance. Recent work applying natural language processing to narrative comments within EPA platforms illustrates the potential of digital tools for large-scale analysis of competence development, but also underscores that such tools should complement, not replace, expert judgment,. Similarly, VS should be positioned as an adjunct to, rather than a substitute for, real-world WBA and high-fidelity manikin-based training, particularly for complex team communication and systems testing in pediatric settings,,,.

From an implementation perspective, VS and high-fidelity manikin-based simulation each present distinct resource and cultural challenges. VS requires investment in hardware, software, and IT support, and may face barriers related to usability, cybersickness, and faculty familiarity with digital platforms,. High-fidelity manikin-based programs demand dedicated space, maintenance, and intensive faculty facilitation, which can be difficult to sustain, especially in resource-limited environments,,,. Hybrid models that combine VS for scalable cognitive and procedural rehearsal with periodic high-fidelity team simulations for interpersonal and systems skills may offer a pragmatic path forward. In LMICs, low-cost VS solutions, including mobile-compatible serious games and web-based platforms, could be strategically deployed to extend the reach of pediatric emergency and critical care training while maximizing limited simulation infrastructure,,,.

Future research should prioritize rigorous evaluation of VS in pediatric contexts, including randomized or quasi-experimental studies that link simulation performance to clinical or patient safety outcomes. Validation studies are needed to establish the content, construct, and predictive validity of virtual pediatric scenarios and to clarify how VS-based assessment scores can be incorporated into high-stakes CBME decisions,,,. In parallel, design-based research that engages learners, faculty, and patients' families in co-creating culturally sensitive, contextually appropriate VS content will be essential, particularly for global child health and neonatal care,,,.

Conclusion

Virtual simulation, *competency-based*, pediatrics, assessment, integration, innovation, curriculum

Virtual simulation is emerging as a powerful partner to traditional pediatric simulation, offering immersive, scalable, and data-rich learning environments that align closely with the aims of competency-based medical education and modern workplace-based assessment. When thoughtfully integrated with high-fidelity manikin-based training and authentic clinical assessments, VS can expand access to high-quality pediatric education, particularly for rare and high-risk scenarios and in resource-constrained settings. To realize this promise, medical educators should adopt hybrid curricular models, invest in faculty development for both digital and in situ simulation, and rigorously evaluate the validity and impact of virtual scenarios on learner competence and patient outcomes. The most compelling future for pediatric medical education lies in creatively blending virtual and physical simulations into a cohesive learning ecosystem that prepares trainees to deliver safer, smarter, and more equitable care to children worldwide.

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