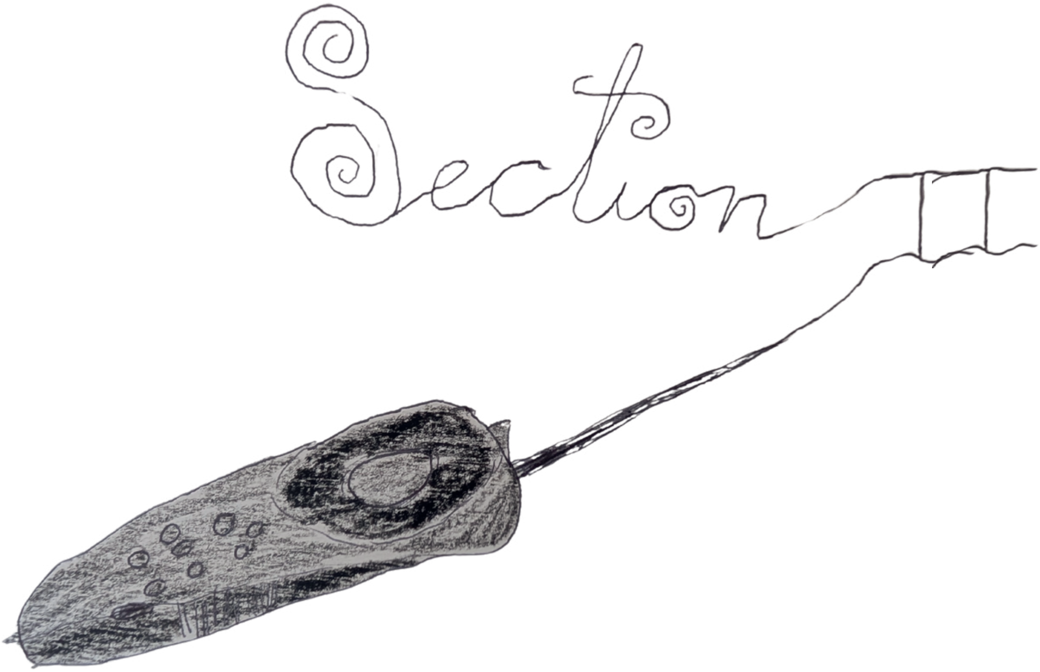

Communication in High-Stress Situations

1

FROM THEORY TO PRACTICE: SIMULATION IN ANAESTHESIOLOGY THROUGH ACTIVE LEARNING EXPERIENCES

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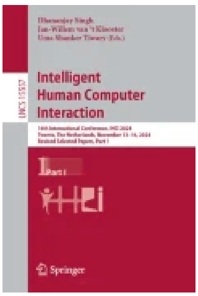

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ABSTRACT

Simulation training has emerged as a cornerstone of medical education in anesthesiology, providing an immersive and experiential learning environment for healthcare professionals in training. In recent years, virtual reality has introduced a groundbreaking paradigm to simulation-based training, uncovering many benefits for educational developers, teachers and learners. By enabling high-fidelity practice in situational awareness, decision-making, and multitiered response systems, VR offers an ecological training platform for clinical skills within a safe yet highly authentic environment. This article offers an overview of the current landscape of simulation education in medical settings, addressing challenges faced by educational developers. Additionally, this study provides a comparative analysis of more traditional manikin-based simulations and VR simulations, highlighting their respective strengths and limitations in medical training.

INTRODUCTION

Simulation in medical education serves as a cornerstone in preparing anesthesiologists for their future roles by equipping them with essential knowledge and skills. Simulation is a methodology, rather than a technology, aimed at substituting or enhancing real experiences with guided experiences. Central to this preparation is the utilization of clinical scenarios to foster effective learning (1-3). Simulation-based learning experiences (SBLE) have emerged as a pivotal tool, offering a secure environment for trainees to gain practical experience in managing medical emergencies or rare complications within a controlled setting, thus minimizing risks to real patients (4-6).

For anesthesiologists, managing acutely deteriorating patients demands a combination of technical and nontechnical skills within high-stress and unpredictable settings. Technical competencies include skills such as tracheal intubation, difficult airway management, vascular catheter placement, and regional anesthesia. Extensive medical knowledge covers applied physiology, differential diagnoses and drug dosages. Nontechnical skills may include action triage, effective teamwork and crisis resource management (CRM) (7). Crisis resource management is part of human factor competencies and refers to interpersonal and cognitive behaviors that contribute to optimal team performance. CRM originated in the aviation industry, where human error was established to be a major cause of aviation accidents in the 1970s (8). Crucially, proficiency in situational awareness, decision-making, teamwork, communication, and leadership, as underscored by the Institute of Medicine Committee on Quality of Health Care, remains indispensable in clinical practice. Improved patient outcomes often depend on the implementation of multitiered rapid response systems, underlining the importance of effective CRM training (9). Weller established the ecological validity of simulated CRM training in anesthesiology training (10).

The process of learning encompasses internal changes in learners' attitudes, beliefs, behaviors, and knowledge acquisition (2). Effective medical education demands adaptability from educational developers to meet the evolving demands of the healthcare landscape. Traditional pedagogical approaches, such as didactic lectures and bedside demonstrations, have long been relied upon; however, they present limitations, including minimal learner engagement and insufficient development of practical competencies tailored to diverse learning styles. Recognizing that knowledge is constructed within social contexts, fostering active engagement among learners becomes paramount (2, 11). Kolb's experiential learning cycle provides insights into the cognitive processes essential for skill development, offering a framework for effective teaching and learning (12).

As technology advances, new modalities like virtual simulations, and game-based learning have emerged. While these methods offer advantages, their add-on effectiveness against traditional teaching modalities such as clinical courses or bedside teaching, and their impact on clinical skill development remains uncertain. Thus, rigorous evaluation of these newer methods becomes imperative as they gain widespread adoption.

This research article seeks to elucidate the rationale for evaluating new simulation modalities amidst limited existing evidence. By exploring educational theoretic frameworks and elucidating the effectiveness of different teaching modalities, educational developers, educational institutions, and policymakers can design curricula that effectively cultivate the future generation of competent anesthesiologists.

Design

The current study evaluates two simulation modalities—manikin-based and VR-based—through a comparative analysis focused on their respective advantages in terms of fidelity, educational impact, and practical feasibility. This framework is intended to provide insights for educators and curriculum developers to inform the design and implementation of simulation-based education programs that effectively address the diverse learning needs in anesthesiology training. Additionally, the study examines the current state of simulation education, challenges associated with each modality, and potential solutions for optimizing future applications of these simulation methods.

Current State of Simulation Education

Manikin-based simulation

The gold standard of current simulation education in anesthesiology is manikin simulation. It generally involves an initial instructional briefing, explaining the clinical case and roles of participants, a lived simulation experience where participants work on the case study with the guidance of the trainer, followed by a debriefing phase allowing participants and trainers to evaluate the simulation, as shown in **Figure 1**.

Figure 1. Manikin simulation

The initial briefing serves multifaceted pedagogical purposes. First, they are instrumental in elucidating the overarching goals of exercise. By outlining specific learning objectives, participants gain clarity on what skills or knowledge they are expected to acquire or improve upon during the simulation. This enhances participant engagement and facilitates targeted learning outcomes (13). Moreover, they allocate distinct roles to participants, fostering a collaborative learning environment. Each participant is encouraged to actively contribute their insights, observations, and reflections during the simulation experience. Through this participatory approach, participants may benefit from diverse perspectives offered by their peers.

The simulation experience itself, guided by a trained facilitator or trainer, serves as a pivotal pedagogic tool in manikin simulation training. Unlike more traditional didactic methods, simulations immerse participants in realistic scenarios, providing them with hands-on experience in a controlled but authentic environment. Under the guidance of the trainer, participants navigate through various clinical challenges and decision points, applying theoretical knowledge to practical situations. This experiential learning approach enables participants to bridge the gap between theory and practice by practicing their critical thinking, problem-solving, and decision-making skills. By actively engaging in simulated scenarios, participants develop the confidence and competence necessary to handle similar situations in real-world settings. According to the principles of cognitive load theory (CLT) (14), there is a limit on how much information one can process simultaneously, impacting information storage and retrieval. A trainer may not know beforehand how the trainees will perform during the scenario; hence, he/she may not know beforehand how they want the scenario to evolve. This highlights the importance of the adaptability of a scenario that is possible with manikin simulation, enabling a more effective and valuable learning experience.

Following the simulation experience, debriefing sessions offer participants an opportunity to reflect on their lived experience and evaluate their performance. Unlike traditional evaluations, which may focus solely on outcomes, debriefing encourages participants to delve deeper into their thought processes, emotions, and actions during the simulation (6). During debriefing, both participants and the trainer engage in a comprehensive evaluation of the simulation experience. Participants articulated their thoughts, feelings, and reactions to the scenario, identifying strengths, areas for improvement, and lessons learned. This reflective process may enhance self-awareness and self-directed learning. By leveraging the expertise of the trainer, participants gain valuable insights into best practices, evidence-based strategies, and alternative approaches to problem solving. Through this collaborative endeavor, manikin simulation training achieves its pedagogic objectives of enhancing clinical skills, promoting teamwork, and ultimately improving patient outcomes (15, 16).

VR-based simulation and game-based learning

VR is a computer-generated simulation of an environment that immerses users in a simulated three-dimensional, interactive experience. Immersive VR uses a head-mounted display projecting in front of the eyes, allowing users to focus on display without interaction with the outside world. It offers novel capabilities that provide new qualitative support for educators and trainees, as it can be used independent of geography, time and space, and it is cost-effective (17, 18).

Immersive VR can produce a visceral feeling of being in a simulated world, a form of spatial immersion called *presence* (17, 19). Additionally, in virtual interactions, participants' avatars can affect their attitude, perception and behavior in conscious or unconscious matter, which is known as the *Proteus effect* (20, 21). Users tend to align their behavior with the traits of their avatars, adapting to virtual identities that may differ from their real-life selves. For instance, individuals who embody avatars with physically attractive features tend to engage in more confident and assertive behavior, mirroring the perceived traits of their avatars (22).

Today's VR simulation programs often use preset scenarios (23-26). Standardized patients (SPs) or standardized scenarios have been utilized for procedural skills assessment and nontechnical skills development (18). Prewritten scenarios offer a structured approach to medical training and assessment. These scenarios are designed to replicate diverse clinical encounters and challenges, providing learners with opportunities to practice decision-making, critical thinking, and teamwork in a controlled environment. Especially in the case of learning strict protocols, such as cardiopulmonary resuscitation and basic life support training, VR simulation programs are apt to create easy standardized assessment options (27, 28).

Current VR simulation programs generally encompass an initial possibility to learn how to train in VR simulation, which is also called onboarding (29). After this initialization, participants often receive an online briefing describing the clinical scenario and roles, followed by the VR simulation and evaluative debriefing, as depicted in **Figure 2**. The briefing and debriefing are generally digitalized, with little interaction with the trainer (27, 28, 30).

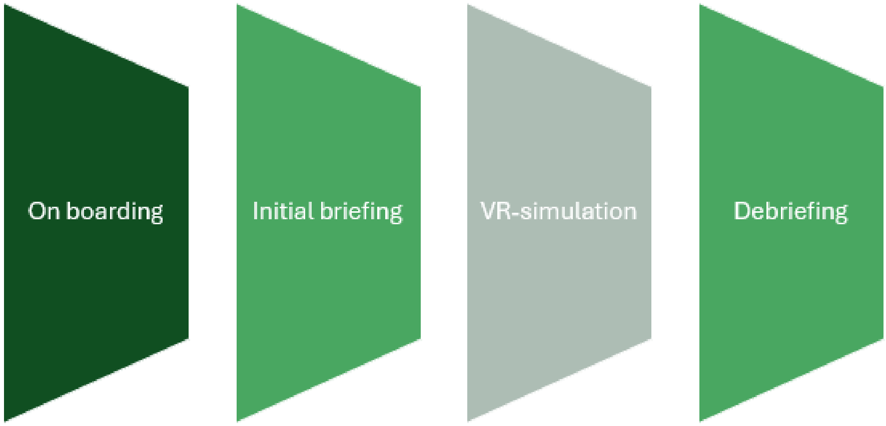

Figure 2. VR simulation

Challenges in Simulation Education

To address the challenges encountered during simulation-based learning experiences, we explore key educational aspects that can impede effective learning experiences and their specific implications for both manikin and VR simulations, as shown in **Figure 3**.

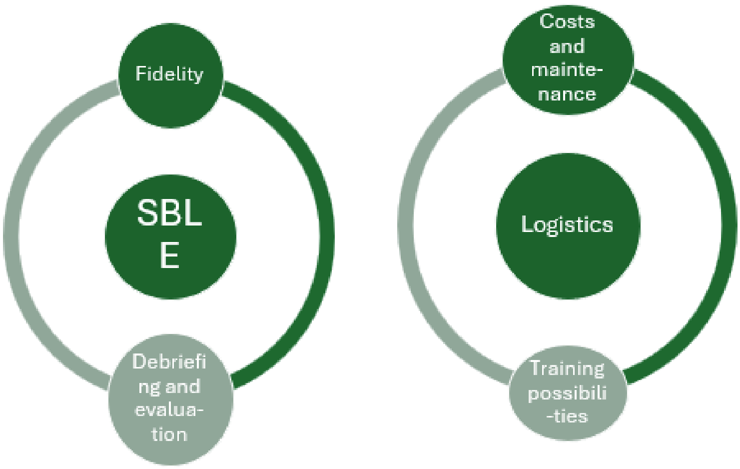

Figure 3. Schematic view of key elements of simulation-based learning experiences (left) and their logistical challenges (right). SBLE: simulation-based learning experience.

Simulation-based learning experience

By adopting a constructivist framework, realism enhances the active learning process. Both manikin simulation and VR simulation are designed to be as real as possible, enabling the feeling of *presence* and immersion. *Fidelity* refers to how accurately the simulated world reflects the real world. In VR simulations, a higher degree of freedom (DOF) refers to the range of motion or movement. Modern VR allows movement along three axes (x, y, z) and rotation around those axes (6-DOF), providing a high-fidelity, generally well-tolerated system that limits simulation nausea or sickness. Another adaptation to VR can be provided by a sufficient amount of time to adapt to the simulator conditions (31).

Fidelity and immersion

Higher fidelity simulators are able to provide physical, psychological, and conceptual fidelity (32).

Physical fidelity

Physical fidelity is facilitated by audio, kinesthetic, and visual elements. Kinesthetic and tactile feedback remains a challenge in both manikin simulation and VR simulation. Technical procedures in simulation often lack the true skin and tissue feedback experienced by real patients. To address this issue, manikin simulations are incorporating more sophisticated materials, such as soft plastic and rubber, to better mimic human skin and tissue. Similarly, VR simulations are advancing with controllers featuring various tactile feedback options and the emergence of hypersensitive haptic gloves to enhance the sense of touch and realism within virtual environments.

Psychological fidelity

Psychological fidelity pertains to the extent to which a simulation activity elicits emotional responses from participants as if the experience were real. In manekin-based simulations, achieving psychological fidelity can be challenging due to the inherent artificiality of the physical environment and limitations of simulator manikins, which may hinder full immersion and emotional engagement. Similarly, in VR simulations, challenges in psychological fidelity may arise from issues such as simulation sickness, technical constraints, and limitations in creating truly immersive virtual experiences that evoke genuine emotional responses.

Conceptual fidelity

Conceptual fidelity reflects the essential principles, behaviors, and relationships inherent in real-world systems. As CRM revolves around effective team communication, the conceptual fidelity of group interactions plays a crucial role. Manikin simulation easily enables group training sessions. Up to six participants may train in the same space. This facilitates effective communication, that is, communication with the message being understood as intended. Challenges in manikin simulation related to conceptual fidelity may include limitations in scenario design and the veracity of patient simulators, which may impact the accuracy and authenticity of the simulation. In VR simulations, challenges in conceptual fidelity may stem from the complexity of accurately representing authentic scenarios in virtual environments, requiring careful scenario design and content expert input to ensure fidelity to real-world principles and behaviors. Additionally, CRM training requires high-fidelity avatars that are able to reflect realistic facial expressions and non-verbal and para-verbal elements associated with effective information exchange (33, 34).

Evaluation and debriefing

Standardized evaluation

Assessment of clinical competency has evolved, favoring the "performance as competence paradigm" over traditional assessments based solely on theoretical knowledge. Entrusted professional activities (EPAs) translate competence-based training into manageable entities describing the knowledge, skills, and attitudes needed to perform an activity. EPAs have been used for standardized specialist training. Throughout the curriculum, EPAs are being incorporated, and according to explorative studies, they can be effectively evaluated in simulation-based education (35, 36).

However, insufficient research has been conducted on the implementation of EPAs within the curriculum of anesthesia residents in simulation education. Whether EPAs can be successfully used in manikin-based or VR simulations has yet to be validated.

Debriefing

Simulation debriefing is a crucial element of effective learning experiences (37). Debriefing is a guided reflection on emotional and simulation experiences, learning outcomes, and possible plans for action. It is strongly underpinned by the experiential learning model theory of Kolb, which facilitates reflective observation, abstract conceptualization, and active experimentation (12).

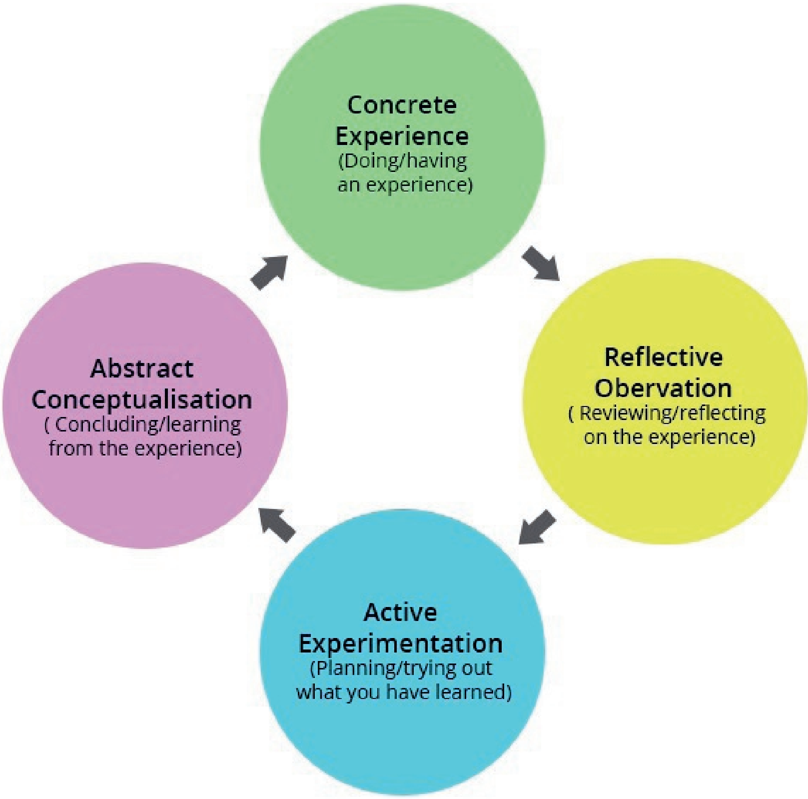

Figure 4. Kolb's experiential learning model

However, a lack of psychological safety or ineffective debriefing may impede its effectiveness (38). Debriefing can be facilitator-guided or self-guided, and it can occur during or after a simulation (39). Debriefing heavily relies on the competence of the debriefer in the case of facilitator-guided debriefing. An effective debriefer acts as a facilitator, guides reflective learning, creates a safe learning environment, and encourages self-reflection. Although several conversational structures may be used, they all highlight the importance of guiding from the beginning, examining events, and summarizing possible learning points (39).

Cognitive aids such as cue cards may facilitate self-assessment practices and are commonly used for anesthesiology training programs.

Traditional manikin-based simulation settings typically involve facilitator-guided in-person debriefing sessions, as participants are physically present. However, VR simulations may involve participants who are not in the same room, who necessitate a virtual debriefing room, or who use self-guided debriefing methods. Research does not prioritize one method over the other, and effective teaching of nontechnical skills can be achieved through formative self-assessment (40).

Organization

Costs and maintenance

The adoption of VR technology can be limited due to the high upfront costs of purchasing the hardware and software needed. A cost analysis was performed by Mills et al., indicating that VR training is more economically advantageous than manikin-based simulation (41). Although there is insufficient evidence to demonstrate clear cost-effectiveness, many research studies indicate that VR techniques are cost-effective (17, 42, 43).

The costs of manikin training are high due to the initial investment required for purchasing the manikins themselves, as well as ongoing expenses for maintenance and repair in case of damage (44). Additionally, there are costs associated with replacing consumable items used during training sessions, such as medical supplies and equipment.

Training possibilities

Manikin-based simulation has certain limitations, particularly concerning training logistics. It requires scheduling anesthesia residents and trainers to be available during working hours and securing access to the simulation room, which must remain unoccupied during the training session. Coordinating all individuals to be present in the same place at the same time can be challenging. Hygienic restrictions may further complicate manikin-based simulation, as was evident during the COVID-19 pandemic, when individuals were not allowed to be in a small room together.

In contrast, VR offers the potential for remote training, allowing participants from different centers to participate. Moreover, VR simulations can be conducted independently of real-time participation by trainers because of the availability of asynchronous preset VR simulations. These features alleviate some of the logistical challenges associated with manikin-based training and offer more flexibility in training opportunities.

DISCUSSION AND CONCLUSION

Discussion

In traditional clinical environments, the focus on patient safety often limits student-centered learning opportunities. Simulation activities offer a unique opportunity to tailor learning experiences to students' needs while maintaining a safe environment for skill development. The transferability of learning in simulations is of prime interest to educators. Simulation activities that closely resemble real life add a degree of authenticity that allows learners to use the knowledge and skills they develop in the simulated setting and apply them in the clinical arena.

In discussing the current state of simulation education, it is evident that both manikin-based simulation and VR simulation offer unique advantages and face distinct challenges. Manikin simulation provides a realistic physical representation of team members, fostering hands-on practice of clinical skills and teamwork. However, its fidelity is limited, particularly in terms of psychological and conceptual aspects. Conversely, VR simulation offers an immersive learning environment with significant potential for scalability. The ability to implement standardized scenarios can be advantageous in strictly protocolled procedures such as advanced life support training. However, this standardization may be disadvantageous for more sophisticated training, where the adaptability of the simulation is crucial for optimizing cognitive load and nontechnical skills training, such as CRM training. Additionally, VR simulation involves initial cost barriers and challenges related to simulation sickness and the adaptability of scenarios.

However, educational developers must carefully balance fidelity levels because high fidelity does not always equal better performance (32, 45). Therefore, thoughtful planning is crucial to avoid the misuse of resources and maintain a balanced cost–benefit ratio in simulation-based education.

The ultimate goal of simulation education should be to improve learning outcomes. Although extensive research indicates that simulation education can enhance residents' skills, knowledge, and behavior, there is limited evidence to suggest that it directly leads to better learning outcomes. In this light, the Kirkpatrick model classifies different levels of educational intervention outcomes and is commonly used to evaluate training (46, 47).

Conclusion

Simulation-based education, encompassing manikin or VR modalities, is pivotal in medical training, offering a controlled, safe environment for skill acquisition and refinement. While manikin simulations excel in providing realistic, hands-on practice, their limitations in fidelity and high operational costs cannot be overlooked. VR simulations, on the other hand, offer immersive and scalable training solutions, albeit with challenges related to initial costs and achieving high psychological fidelity in team training.

To maximize the benefits of simulation-based education, educational developers must consider the balance between the fidelity of simulations and their practical implementation. High-fidelity simulators should be critically assessed to determine whether they offer significant educational advantages over low-fidelity models. Both mannekin-based simulation and VR simulation can complement each other.

There are several ways in which VR can complement manikin-based simulation education. Collaboration among institutes can expand access to VR training, while standardized scenarios and assessment tools ensure consistency. Integrating simulation training into competency-based frameworks such as EPAs provides a structured approach to skill development.

Future research should focus on integrating simulation training into competency-based frameworks such as EPAs to provide a structured approach to skill development and evaluate improvements in patient outcomes. By leveraging the strengths of both manikin and VR simulations, medical education can be enhanced, which may ultimately lead to improved patient outcomes and more competent anesthesiologists.

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The authors have no competing interests to declare that are relevant to the content of this article.

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