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Demystifying simulators for educators in healthcare

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ABSTRACT

When entering the world of simulation development and scenario design for the first time, healthcare educators are often confronted with the perplexing diversity of simulation, which includes a vast array of educational experiences for learners. This essay seeks to demystify the growing number of technologies and simulators (commonly known as simulation modalities). Simulators can be classified as computer-based simulation, simulated participants (SP), simulated clinical immersion or procedural simulation, in addition to 'mixed' and 'hybrid' simulations. Each modality has intrinsic benefits and limitations, but ultimately their use must be guided by the desired learning outcomes of the learning experience, together with the appropriate realism required for the simulation. No matter the simulator being used, the ultimate experience of the learner is still arguably wholly dependent on good curriculum development, instructional design and scenario delivery.

What this essay adds:

- An overview of currently available technologies and simulators.
- Presentation of an effective manner of conceptualizing different simulators.
- Review of different simulators, delineating uses, benefits and limitations.
- Guidance for navigating choice of simulator for meaningful learning experiences.
- A commentary on determination of 'fidelity' or 'realism'.

Introduction

Simulation is a technique used by healthcare educators around the world, involving the creation of situations or environments to allow learners to experience a representation of a real event to practise, learn, evaluate, test or gain understanding of both systems and/or human actions [1]. When entering the world of simulation development and scenario design for the first time, educators come to realize the sheer diversity of simulation – it can be so many things in so many settings, and for so many purposes. Chiniara et al. [2] write that simulation is not a 'monolithic concept' and includes vastly different educational experiences for learners, which contribute to learning across multiple domains, including cognitive, psychomotor or affective. One of the key contributors towards the diversity of application of simulation is the growing number and range of available technologies and modalities. These range from simple part-task trainer models to highly sophisticated computerized programs and models. This essay seeks to demystify simulators (or simulation modalities) used in healthcare simulation, and further evaluate the relevant benefits and limitations to enable educators who are new to simulation to navigate their diversity to best design a meaningful learning experience.

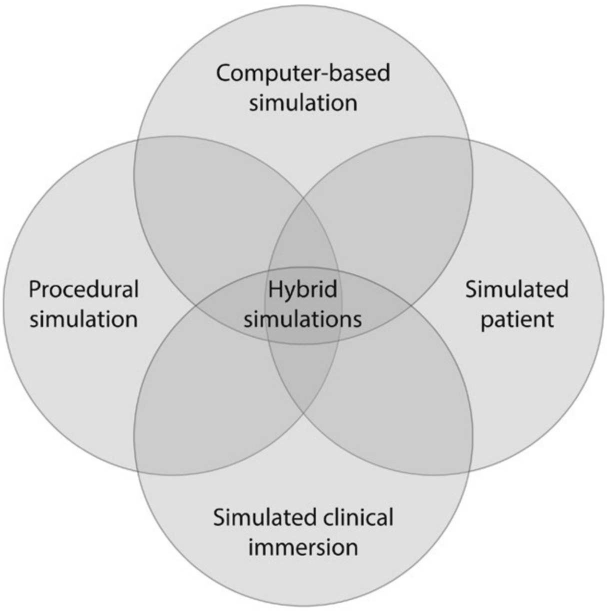
The essay will address the following related to simulators: (1) the background to their use in the context of instructional design and creating learning experiences, (2) a commentary on determination of 'fidelity' or 'realism', (3) a review of the types of simulators, their benefits and limitations, and (4) some guidance for choosing simulators to best create meaningful learning experiences.

Background

Chiniara et al. [2] include simulation modality as one of four levels in their taxonomy for instructional design to assist educators in creating appropriate simulation learning experiences. They explain how a simulation modality represents the high-level description of the simulation experience itself and includes four modalities (computer-based simulation, simulated patient [SP], simulated clinical immersion and procedural simulation) in addition to 'mixed', also known as 'hybrid' simulations [2] (see Figure 1). It is this categorization that enables the application of modalities targeted to specific learning outcomes.

Chiniara et al. [2] highlight how simulation itself is one of several 'instructional media' which describe the primary mode of teaching. Unlike other media like lectures or textbooks, the distinguishable characteristics of simulation include the imitation of reality and its interactive nature.

Figure 1: The four simulation modalities, showing areas of overlap constituting hybrid simulations.[2] Source: Chiniara G, Cole G, Brisbin K, et al. Simulation in healthcare: a taxonomy and a conceptual framework for instructional design and media selection. Med Teach. 2013 Aug;35(8):e1380–95. Reprinted by permission of the publisher (Taylor & Francis Ltd, http://www.tandfonline.com).



Matching the right simulator to the desired learning outcome is a vital, though complex and challenging step in the curriculum development process. The intended knowledge, skills and attitudes of the learners, together with their level of expertise, determines the modality best adapted for a particular learning session [3]. In line with outcome-based education (OBE) models [4], Chiniara et al. highlight the importance of learning outcomes in designing curricula and choosing appropriate teaching methods [2], though recognize the difficulties in applying more broad outcomes or competencies to simulation. As an example, when learners begin practising a new skill, educators should consider removing or limiting 'distractions' such as a patient's pain or movement or staff logistics [5]. This enables a low-risk environment for learning which allows for mastery of the relevant skill while also permitting errors, a combination that ultimately has been shown to improve long-term skill [5,7]. These skills should then be able to be transferred successfully to higher-level simulation modalities, and most importantly, to clinical practice.[7,8]

It is important to introduce the concept of 'realism' or 'fidelity' in simulation, and how these fit in conversation with selection of an appropriate simulation modality. The two terms are often used interchangeably, due to a lack of consensus of definitions. In general use, they describe the extent to which a particular simulator or simulation appears or behaves in a manner matched with the system being simulated [5,9]. Given the widespread confusion and interchangeability of the two terms, the authors have made a conscious decision to use the term 'realism' for this essay, but recognize that both terms are fair to use in other literature. Realism is an intrinsic feature of any simulation, and the measured realism of any experience can certainly affect learning [4]. Though at first it might seem logical to imagine that 'high realism' modalities always deliver high-quality learning, it's not so straightforward. Many argue this is a misleading notion, as we shouldn't use broad terms such as 'high' or 'low' realism due to realism being a multidimensional continuum, encompassing patient (physical), environmental and psychological domains [5].

When selecting the most appropriate simulation modalities for a learning activity, the 'level of realism' required is dependent on the type of task (e.g. techniques and procedures vs. clinical reasoning and patient management vs. teamwork and crisis management) together with the level of experience of the learner [8]. Patrick [10] demonstrated how simple simulators such as cardboard models can achieve high-quality learning of cognitive tasks and procedures, and that complex and often expensive technologies are unnecessary and even inappropriate for beginners learning a basic skill. In contrast, the more advanced learner usually requires a simulator which supports high levels of practice of tasks at high speeds [5]. Across all levels, though different types of simulators can be utilized and sometimes combined to increase realism.

In addition, the standard against which we should be measuring realism is, contrary to popular belief, not actually the real world, which is far too large and impossible to describe. Instead, we should reference against 'the minimal characteristics of real-world features that are needed for a given educational experience', as was reported by the Fidelity Implementation Study Group formed by the Simulation Interoperability Standards Organization (SISO) [6]. For example, a part-task training model arm selected as a simulation modality for intravenous cannulation might have adequate realism if the anatomy of the veins as well as the tactile elements of the technique are realistic, but only if this targets the predetermined learning objectives. If, on the other hand, the objectives of this same learning experience included communication skills, then a significant amount of realism would be lacking, resulting in a poor-quality learning experience. Therefore, the realism standard should be established by referencing the desired learning objectives and matching them to the real-world features [2,6]. Determining the required level of realism enables educators to appropriately select simulation modalities for learning experiences.

Simulation modalities

While there are many ways of classifying individual simulation modalities [5], this paper again references Chiniara et al.'s classification (see Figure 1), where there is intentional overlap depicted [2]. Each modality will be considered separately here, with discussions around benefits and limitations to each (summarized in Table 1), but it is important to illuminate how in modern practice, hybrid simulation is becoming increasingly common, where multiple simulation modalities are used at the same time to achieve multiple learning outcomes, for example, performing a technical skill at the same time as practising communication [11].

Selecting the appropriate simulator for achieving the desired educational goals is a crucial yet intricate and demanding phase within the curriculum development process. The specific knowledge, abilities and mind-sets that learners are meant to acquire, as well as their level of proficiency, dictate the most suitable approach for a given learning session. Models of outcome-based education (OBE) emphasize the significance of learning outcomes in curriculum design and the selection of suitable teaching methods, while also acknowledging the challenges involved in applying broader outcomes or competencies to simulations. Table 2 can be used as a tool to help choose a suitable simulation modality for the different learning outcome domains, with the preferred modality indicated.

Computer-based simulation

Computer-based simulation modalities allow learners to interact with a simulated system and/or virtual patients usually via a screen-based interface [2]. It has been a predominant mode of simulation activities during the COVID-19 pandemic. The system, typically involving a virtual patient, can model human physiology and pharmacology to respond to actions input by the user who may be making decisions on treatment and management, and can then observe the consequences of these actions [5]. A general strength of computer-based simulations is that they provide a flexible, reproducible and accessible learning experience. They can be relatively inexpensive for an institution, though the wide range of available products naturally leads to an even wider range of costs. Computer-based simulation has great advantage in learning settings with reduced clinical exposure (e.g. due to COVID-19 restrictions, large student cohorts or students geographically spread out). Additionally, it can effectively address any limitations to face-to-face simulation such as scheduling challenges or reduced opportunity for repetitive practice. The other major benefit seen is the utilization of live video-link technologies, such as Zoom, which can bring together learners and educators from all around the world at a single point in time to participate in a simulation-based education session with real-time observation, feedback and debriefing.

Recent advances in computer-based simulation have born the modalities of virtual reality (VR) and its sophisticated spin-offs, augmented reality (AR) and mixed reality (MR). Maran and Glavin [5] depict VR as the ultimate computer-based technology, which targets all the senses with presentation of virtual objects within a virtual environment which is practically identical to real life, usually using a VR headset. VR is often used in combination with part-task trainers to allow physical haptic feedback for users. The classic example of how this technology is being used is for laparoscopic and endoscopic dexterity trainers [5].

Some benefits to the use of VR include the increased accessibility for learners given that fewer, if any, faculty are usually required to deliver a learning experience. Learners generally are a single user not having to perform in front of others, and may feel like playing a game, fostering greater psychological safety. Additionally, thanks to the computer-based nature of the modality, set-up is rapid, does not require specialized facilities and the scenarios themselves are repeatable, enabling repeated practice.

Obvious limitations to VR include initial outlay of cost towards hardware, software and ongoing updates. Additionally, it may not be technology which is fit for purpose, depending on learning outcomes, for example, clinical examination. In terms of teaching and feedback, the virtual patients and virtual 'teachers' presumably can only give programmed responses so learners may miss out on targeted feedback to improve future performance. Finally, from a practical stance, VR can be very disorientating for new users, often leading to motion sickness and vertigo. Learners suffering in this regard require acclimatization and certainly won't enjoy the process, creating a very psychologically unsafe experience.

Bajwa et al. [12] have described the recent rapid upward trend in the use of VR products for simulation-based education, in particular the utilization of eXtended reality (XR), which includes AR and MR. AR is slightly different to VR in that it augments the user's visual and auditory perception of the physical environment they are in (as opposed to a virtual environment in VR) by superimposing digital content over the natural environment [13]. Many of the same benefits and limitations are shared with VR in terms of accessibility versus cost, but an additional benefit lies in the value added to the learner's interaction with the 'real world' by receiving

Table 1: Comparison summary of simulation modalities

Simulation modality	Benefits	Limitations
Computer-based simulation	-Flexible, reproducible, self-directed, accessible -Relatively inexpensive (N.B. wide range of cost) -Enables remote participation -Enables repeated practice	- Dependent on technology and connectivity. - Limited 'programmed' feedback
-Virtual reality (VR)	-Increased accessibility, no faculty necessary -Solo use fosters psychological safety -Doesn't require special facilities	- Initial cost (hardware, software, updates) - Can cause nausea/vertigo
-Augmented reality (AR)	-Increased accessibility -Solo user -User receives 'real time' feedback for the 'real world'	- Initial cost - Ethical/moral questions of acceptability in the workplace - Scarcity of applications
-Mixed reality (MR)	-Increased accessibility -Solo user -'Real time' feedback -Exciting potential for visual and spatial learning	- Blurred similarities/differences with VR and AR - Cost, availability, capability - Imprecise realism
Simulated participants (SPs)	- Best replication of real patients in a controlled, reproducible environment. - Highly repeatable, standardized conditions - Ability to provide considered, targeted feedback - Not dependent on physical environment	- Variability of working with individuals to support learning - Consideration of safe work environment for SPs including psychological safety - Requires resources for SP training and development - Frequency and intensity of SP role can cause performance fatigue
Simulated clinical immersion	- High realism, resembling actual work environment	- Requires high-realism physical environment (simulation lab or in-situ clinical environment) - Resource and cost load
Procedural simulation	- Common - Diverse - Enables replication of actual behaviours	- Replicate only part of a 'system'
-Part-task trainers	- Portable, simple - Relatively inexpensive - Most institutions have multiple models - Appropriate for beginners - Avoids harm to real patients	- No patient feedback - Varied realism (simple suturing block vs. complex airway models for intubation) - Susceptible to wear and tear
-Manikins	- Low-risk modality to learn and practise skills - Presents entire human body	- Range of presented realism
Low-technology manikins	- Lower cost - More portable - Enables moulage - No electricity needed	- Less tactile feedback - Usually requires learning 'buy-in' to realism
High-technology manikins	- Increased immersive potential - Advanced physiological functions and interactive features - Adaptable to specific learning requirements	- High cost (purchase and maintenance). - Less portable - Needs electricity - Requires training/ orientation to use and interact with - Often not used to their full potential

'real time' feedback. Potential limitations include potential ethical and moral debates surrounding acceptability in the workplace, and within society in general. Additionally, at the time of writing this review, there is a scarcity of AR app designs available.

As a further offshoot from the above, MR is an interactive simulator in which real physical objects and virtual computer-generated content interact with each other in real time [14]. It's easy to confuse these computer-based modalities, and the similarities and differences are certainly blurry at times. Therefore, many of the same benefits and limitations of general computer-based simulations and VR/AR technologies can be applied to MR. Suffice to say, important benefits of MR are that it has exciting potential to assist with visual and spatial learning, and perhaps have a role in developing new paradigms, tools and techniques for future use. Again, the overarching limitation to this modality is cost, availability and capability. In addition, because this technology is still practically in its infancy, the realism is imprecise at best and still has a long way to go.

Simulated participants

SPs are the simulation modality that arguably best replicates encounters with real patients [2,15,16]. The term 'simulated participant' reflects an update on the term 'simulated patient' first proposed by Bearman and Nestel

Table 2: Selection tool for simulation modalities matched to learning outcomes

Learning outcome domain	Simulator selection
Rote knowledge	Clinical knowledge - Computer-based simulation (preferred) - Simulated participants - Non-simulation media Non-clinical knowledge - Non-simulation media (preferred) - Procedural simulation
Techniques and procedures	Self-instruction - If motor practice necessary ○ Procedural simulation ○ Virtual reality (preferred) - No practice necessary ○ Computer-based simulation (preferred) ○ Non-simulation media (videos, web-based training) Instructor-led - Where beliefs and attitudes are important to learning outcomes ○ Simulated clinical immersion ○ Simulated participants - No belief/attitude outcomes ○ Procedural simulation
History, physical exam and patient counselling	Self-instruction - Computer-based simulation: ○ Virtual patient (preferred) - Simulated participant (with feedback from participant) - Non-simulation media ○ Non-interactive (textbooks, videos, etc.) ○ Web-based training Instructor-led - Simulated participant (preferred) - Simulated clinical immersion - Computer-based simulation
Clinical reasoning and patient management	Self-instruction - Computer-based simulation ○ Virtual Patient (preferred) Instructor-led - Simulated participant (preferred) - Simulated clinical immersion - Computer-based simulation
Teamwork and crisis management (patient safety competencies)	Self-instruction - Computer-based simulation: ○ Virtual reality (preferred) - Non-simulation media ○ Non-interactive demonstration Instructor-led - Simulated clinical immersion (preferred)
Ethics and beliefs	- Simulated clinical immersion (preferred) - Simulated participants (preferred) - Computer-based simulation - Non-simulation media

in 2014 [17] and later adopted by Lewis et al. [18] in the ASPE Standards of Best Practice. First introduced as early as the 1960s [19], learners in healthcare can build skills in communication, examination and clinical reasoning through interacting with someone playing the role of a patient. By working with SPs portraying themselves as healthcare professionals (sometimes known as confederates), learners can develop interpersonal and interprofessional skills, particularly in high-technology simulations. The confederate helps guide or facilitate the simulation and provide a framework for collaborative practice [20]. Whilst most agree that working with SPs is not the strongest modality for practicing psychomotor skills, combining the modality with part-task trainers in a hybrid simulation (see Figure 1) can integrate procedural and communication learning objectives and increase realism. Interestingly, in the early 1990s, Barrows [21] introduced the idea that SPs offer a unique benefit in being environmentally independent. He argued that the environment plays very little role in the educational experience, and educators can work with SPs in any nonclinical area to achieve the same learning outcomes [2,21]. This idea aligns with Kneebone's work which related to the notion of 'circles of focus' in simulation practice [22]. 'Circles of focus' refers to the gradient of required realism in simulation due to a clinician's attention being focused on what is most important to them, with the rest blurring into the periphery.[22]

The overall benefit of SPs is their contribution to experiential learning and towards creating a 'safe' learning environment and context for learners to interact with patients and team members in a controlled and reproducible manner [19]. SPs can, of course, be trained to produce highly repeatable and standardized conditions, and have the capacity to provide considered feedback to learners, which makes their work useful in both formative and summative assessments. Limitations to working with SPs revolve around the fact that the modality relies on working with a human being for learning who also requires a safe work environment, both psychological and physical. Depending on the simulation, consideration also needs to be given to potential exposure to hazardous conditions within clinical environments. Finding appropriately skilled SPs can be challenging, and there is a significant time- and resource-intensive aspect to role and scenario development and SP training. Additionally, there is a trend towards including real patients in some phases of SP methodology to ensure that SPs reflect the perspective of a real patient rather than clinician's viewpoint [23–25].

Simulated clinical immersion

Simulated clinical immersion is a complex modality where participants are exposed to specific clinical problems, in a setting with high environmental realism [2]. The simulated environment resembles the actual work environment and has a direct effect on the educational experience and plays a role in achieving the determined learning outcomes, in contrast to sole SP simulations not depending on environment, as discussed above. The classic example of simulated clinical immersion is a resuscitation scenario set in a crowded, noisy emergency department to teach crisis resource management. Another example would be an environmental emergency, such as a fire, in a simulated operating theatre, to practise management of a complex emergency. When using this modality, the environment can be either the actual clinical setting, or a purpose-built simulation facility. It's important to note that the 'environment' being simulated includes more than the physical setting. Aspects of the simulation include personnel, equipment, sounds, smells, lighting, etc., which combine to ultimately create a 'social' learning experience. This social learning experience distinguishes simulated clinical immersion from other simulation modalities [2,26]. Benefits of simulated clinical immersion lie in experiencing higher psychological realism due to creating the simulated environment. Limitations include resource load and cost.

Procedural simulation

Finally, procedural simulation is perhaps the most common, and diverse, modality used in simulation. Procedural simulation predominantly serves the psychomotor domain of learning objectives and is used for participants to learn and improve upon technical and procedural skills [2]. It lets learners replicate actual behaviours, movements and the sequence of actions that are involved in the real-life procedure. Examples of procedural simulation include part-task trainers and manikins.

Part-task trainers replicate only part of a system or environment [5]. They can resemble an area of the human body, such as an arm for IV cannulation, or a set of teeth for dental work, but this is not a definite requirement. Low-technology trainers tend to be portable, simple and relatively inexpensive; therefore, most institutions will usually have multiple models. They are appropriate for beginners to repetitively practise a procedure with reasonable realism to safely make mistakes and develop confidence and expertise without any risk of injury to a patient. The limitations in using these trainers are that there is no patient feedback, nor usually any feedback from the simulator.

Higher-technology trainers enable learners to practise a more advanced task, such as difficult endotracheal intubation. Though they are usually still portable, the increased realism sometimes means these trainers tend to often be slightly more complex and fragile. They are more expensive to not only purchase, but also service and repair. Again, they enable learners to repetitively practice invasive procedures without the risk of harm to a patient.

Manikins are human-shaped models used in a variety of procedural simulation situations. Like part-task trainers, they aim to provide learners with a low-risk environment to learn and practise skills, but unlike part-task trainers, manikins usually present the human body in its entirety, which affects the psychology of the learner. Manikins range from low to high technology, with the most realistic of manikin, for example, the Laerdal SimMan3G, being very expensive and manufactured using the latest technology. Such manikins are able to move, speak, react and perform a large variety of physiological functions. A low-technology manikin is much simpler and less expensive, but it can still have a variety of uses. For example, Resusci-Anne is a low-technology manikin that was designed in the 1960s for teaching cardiopulmonary resuscitation and is still in widespread use today [27].

The benefits of a low-technology manikin are they are more portable than their high-technology counterparts, and easier to maintain. They rarely require electricity, and they are usually easy to dress to apply moulage to build realism for a scenario. The limitations include a lack of tactile feedback, such as pulse and breathing, when compared to the higher-technology manikins.

High-technology manikins have a wide range of interactive features which cannot be achieved with a basic manikin, such as pupillary responses, changes to airway and chest anatomy, auditory feedback to chest auscultations, altered physiological parameters and capacity for invasive procedures such as emergency front-of-neck access or chest drain insertion. This constellation of features allows more data to be fed into a scenario, allowing more diagnostics than a low-technology manikin. These manikins are not without limitations, however. They are expensive to purchase and maintain. The hardware is often very heavy and complicated, requiring power. Additionally, their transport requires disassembly and the risk of breaking individual parts. Any learners interacting with high-technology manikins must be oriented to the manikin to understand the data it is providing to them and its inherent limitations of use. Most manikins still require a microphone input to provide the patient's voice. The technology requires proprietary software, which requires training for use.

Conclusion

The inherent diversity of types of simulation is one of its strength as an educational tool in healthcare. 'Simulation modality' is a broad descriptor of the simulation experience and includes four modalities: computer-based simulation, SPs, simulated clinical immersion and procedural simulation, in addition to mixed and hybrid simulations. Each modality has intrinsic benefits and limitations, but ultimately their use must be guided by the desired learning outcomes of the learning experience, together with the appropriate realism required for the simulation. Over time, simulation modalities have adapted and emerged due to advances in technology. However, after demystifying the growing number of technologies and modalities, the healthcare simulation community must hold strong to the underlying educational theory of simulation and not let arbitrary technological developments dictate the direction of the future of simulation. No matter the simulation modality in use, the ultimate experience of the learner is still arguably wholly dependent on good curriculum development, instructional design and scenario delivery.

Declarations

Authors' contributions

BG is undertaking formal studies in healthcare simulation with DN as supervisor. BG devised the concept and wrote the first draft. DN edited the first draft and added table 1.

BG further refined the text and tables. DN approved the submitted manuscript.

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