

Low- to high-fidelity simulation – a continuum of medical education?

N J Maran* & R J Glavin

Context Changes in medical training and culture have reduced the acceptability of the traditional apprenticeship style training in medicine and influenced the growth of clinical skills training. Simulation is an educational technique that allows interactive, and at times immersive, activity by recreating all or part of a clinical experience without exposing patients to the associated risks. The number and range of commercially available technologies used in simulation for education of health care professionals is growing exponentially. These range from simple part-task training models to highly sophisticated computer driven models.

Aim This paper will review the range of currently available simulators and the educational processes that

underpin simulation training. The use of different levels of simulation in a continuum of training will be discussed. Although simulation is relatively new to medicine, simulators have been used extensively for training and assessment in many other domains, most notably the aviation industry. Some parallels and differences will be highlighted.

Keywords education, medical, undergraduate/methods/standards; *patient simulation; curriculum; clinical competence/*standards.

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Introduction

Events such as the 'Bristol Enquiry' have challenged traditional apprenticeship-style training and stimulated the development of methods of training and assessment which do not involve patients.^{1–3} At undergraduate level, the amount of clinical skills training has increased dramatically in order to produce junior doctors who are prepared for practice.⁴ As numbers entering training increases, more students are competing for an inadequate number of clinical placements. It is therefore imperative that students have a good grounding in basic practical and interpersonal skills prior to entering the clinical environment so that, once there, they can maximise further learning opportunities.⁵ As length of medical training decreases and the number of conditions with which the medical practitioner is expected to deal increases, simulation is being called on to 'plug the gap'. This may be the only way to allow those in

training grades the experience of managing less common conditions and to allow more experienced practitioners to keep their skills up to date. Simulation is not intended to replace the need for learning in the clinical environment, but through improved preparation, to enhance the clinical experience and improve patient care. It is important therefore that simulation training at any level be integrated with clinical practice.

General principles of simulation

Simulators are designed to reproduce some aspect of the working environment. This may vary from the replication of an aspect of a task, e.g. venous cannulation, through increasing levels of complexity to the recreation of an entire working environment such as the operating theatre.⁶ The advantages of using simulators in training and assessment are summarised in Fig. 1.⁷

Simulation produces a risk-free environment in which learners can successfully master the skills relevant to clinical practice. It also permits errors of either diagnosis or management to be allowed to develop and followed through to their natural conclusion.

The educational processes that underpin simulator training are deliberate practice, reflection and feedback.

Scottish Clinical Simulation Centre, Stirling Royal Infirmary, Livilands Gate, Stirling, UK

*Correspondence: Dr Nicola J Maran, Scottish Clinical Simulation Centre, Livilands Gate, Stirling, FK8 2AU. Tel.: 01786 434480; Fax: 01786 446026; E-mail: simulator@scsc.co.uk

Key learning points

Simulation offers a safe environment in which learners may develop and improve skills through sustained deliberate practice.

The range of medical simulator devices continues to grow with technological advances and pressure to increase non-patient based training.

Appropriate simulators must be chosen to address identified key skills or techniques.

Sound educational principles must underpin the educational programmes in which simulators are used.

Integration of simulator based training with clinical practice at all levels is key to successful delivery of training.

- Risks to patients and learners are avoided
- Undesired interference is reduced
- Tasks/scenarios can be created to demand
- Skills can be practised repeatedly
- Training can be tailored to individuals
- Retention and accuracy are increased
- Transfer of training from classroom to real situation is enhanced
- Standards against which to evaluate student performance and diagnose educational needs are enhanced

Figure 1 Advantages of simulators.

First, the skill(s) or procedure(s) to be taught must be identified and training objectives developed. Then the appropriate training device must be selected. In the early stages, a task may be simplified by removing distractions such as patient movement or discomfort. At novice level, a new skill should first be correctly demonstrated and thereafter, the learner allowed time for rehearsal. Practice must be sustained and deliberate, using set aims and objectives with specific informative feedback.^{8,9} This has been shown to improve long-term skills acquisition.^{10,11} Skills learned on a simulator should transfer positively both between differing levels of simulator and, more importantly, from the simulator to the clinical environment.¹² Any differences between the execution of a skill on the simulator and in the clinical environment must be made clear to the learner to avoid negative transfer.

This process of experience followed by reflection illustrates how simulation addresses many of the principles of adult learning¹³ and can contribute to the experiential learning cycle.¹⁴ Experiential learning

is an active process in which the learner constructs knowledge by linking new information and new experiences with previous knowledge and understanding. Through simulation, episodes of experience can be created 'on demand'. Reflection-in-action occurs during any professional challenge and simulators can help to increase this by providing the learner with situations that vary from the normal or from the expected. Reflection-on-action occurs afterwards and allows the learner to draw on their own previous experience and perhaps the experiences of others in a group, as a resource for learning.¹⁵

By comparing the performance of groups of individuals at the same level, performance standards can be agreed and educational needs assessed.

Trainers must themselves be fully competent in the skill, and they should be aware of the strengths and limitations of any training medium they use. Trainer training may be required. The effectiveness of the training should be evaluated with particular reference to the transfer of skills.

Simulator fidelity

Inevitably, in any discussion of simulation, the term 'fidelity' will be used to describe some aspect of the reality of the experience. However, lack of consistency in the use of the term has led to much confusion. Fidelity is the extent to which the appearance and behaviour of the simulator/simulation match the appearance and behaviour of the simulated system.¹⁶ Miller was the first to make the important distinction between engineering fidelity and psychological fidelity.¹⁷ Engineering, or physical fidelity is the degree to which the training device or environment replicates the physical characteristics of the real task. Increasing the engineering fidelity of the simulator inevitably leads to increases in cost and, beyond certain levels, increasing the fidelity of the training device will produce only small improvements in performance over a simpler device.

Of much greater importance is the concept of psychological or functional fidelity. This is the degree to which the skill or skills in the real task are captured in the simulated task. The level of fidelity required depends on the type of task and stage of training and influences skills transfer.¹² For example, a number of studies have demonstrated that high transfer can be achieved with simple simulators (including paper exercises or simple cardboard models) when training cognitive tasks and procedures.¹⁸ Complex training aids are not appropriate where novices are learning the basic skills involved in a task. However, in the case of

developing fine motor skills, the simulator should accurately reproduce the movements required to avoid negative transfer.¹⁹ At advanced levels of training complex tasks, simulators should support high levels of practice of the task(s) at high speeds. It is vital that the correct cues are provided to support high level decision-making. At all levels, different genres of simulators can be combined to increase both engineering and psychological fidelity.

The spectrum of clinical simulators

Many different classifications of simulation devices exist.^{20,21} A comprehensive listing of current simulation devices is available on an excellent US website.²² For this review, we have used an adaptation of their classification system. The potential use of each level of simulator within this spectrum is illustrated using the example of a trainee anaesthetist learning to use an epidural block for pain relief (Fig. 2).

Part task trainers

Part task trainers are designed to replicate only part of the environment. They will often, but not necessarily, resemble anatomical areas of the body. These models are most commonly used to train basic psychomotor skills, such as cannulation or venepuncture. They are relatively inexpensive and therefore training centres will usually have multiple models.

‘Using a model of the back and spinal column, the anatomical landmarks and psychomotor skills required to identify the epidural space and site the catheter may be developed.’

The ‘Harvey’ cardiology simulator combines a life-size manikin with jugular venous, carotid and peripheral pulses and realistic heart sounds audible over the precordium with computer generated modelling of cardiovascular physiology. The manikin is able to produce realistic symptom complexes which, when

- Part task trainers
- Computer based systems
- Virtual reality and haptic systems
- Simulated patients
- Simulated environments
- Integrated simulators
 - Instructor driven simulators
 - Model driven simulators

Figure 2 Classification of simulators.

used with educational programmes, can be demonstrated to improve diagnostic skills and training in cardiology.^{23,24}

Computer based systems

Computer systems can be used to model aspects of human physiology or pharmacology, simulated tasks or environments and allow interaction with these through a computer interface. The main focus of learning is on using information to make treatment decisions and observing these in action. These systems generally produce data on student interaction and can therefore provide the student with feedback during or after the interaction. This allows for independent learning. Computer based systems are relatively inexpensive and can be used by multiple learners. Some web-based programs such as the *Webset* project are now available, allowing learners to work in groups with real time feedback provided on-line.²⁵

‘CD-ROM based systems may be used to increase understanding of the physiological changes which occur with increasing epidural block height and the nature of the dynamic changes which may occur with pharmacological interventions used for treatment.’

Virtual reality and haptic systems

Virtual reality is the ultimate computer based technology. Its main aim is to present virtual objects or environments to all human senses in a way which is identical to their natural counterpart. Improvements in computing technology and in the development of techniques for acquiring data (e.g. medical imaging) have supported the growth in this area. Such computer-generated models are often combined with part task trainers to allow a physical interaction to take place within the virtual environment. Where haptic (touch) feedback is used to produce a feeling of resistance when using instruments within the simulated environment, this creates the illusion that the operator is coming into physical contact with the model.²⁶ This technology is used extensively in the growing field of laparoscopic and endoscopic dexterity trainers. The use of simulators in surgical training was recently reviewed by Kneebone.²¹

‘New training devices with forced feedback improve the subtlety of ‘feel’ of loss of resistance when passing through ligaments in order to identify the epidural space. This may improve motor skills and lead to increased transfer to clinical practice.’

Simulated patients

Simulated patients are arguably the highest 'fidelity' simulators. However, their use is mainly restricted to the teaching of communication and interpersonal skills. They are used extensively in the undergraduate curriculum.²⁷ While psychomotor and communication skills are often taught in isolation, the two are clearly inseparable in the clinical environment and increasingly, combinations of part task trainers and simulated patients are being used to integrate these skills in training and increase the psychological fidelity of aspects of technical skills training.²⁸ This may help to improve transfer to the clinical environment.

'Simulated patients may be used to develop the communication skills of discussing the technique, advantages, disadvantages and potential complications of epidural blockade with a patient. By combining a part task epidural trainer with a simulated patient, the integration of the communication and psychomotor aspects of the skill, such as the importance of patient positioning and dealing with discomfort while carrying out the practical procedure, can be rehearsed.'

Simulated environment

Recreating the working environment in which multi-professional teams can work together in the form of the simulated ward has been shown to be a powerful learning experience and gives an opportunity for learners to examine their roles within a team.²⁹ The creation of a realistic working environment is often used to increase the psychological fidelity of scenarios when using higher level simulators.^{6,7}

Integrated simulators

Integrated simulators combine part or whole body manikins on which to carry out interventions with computers, which 'drive' the manikin to produce physical signs and feed physiological signals to monitors. The degree of engineering fidelity will depend upon both the level of sophistication of the manikin and that of the computer that drives it. Although many terms are used to describe this level of simulator, they are most easily classified in terms of the level of computer modelling.

Model driven ('high fidelity') patient simulators combine sophisticated life-like manikins with computer programmes driven by scientifically derived complex mathematical models of respiratory and cardiovascular physiology and extensive pharmacological modelling

of drugs to produce a dynamic system. The METI Human Patient Simulator (HPS), Emergency care simulator (ECS), PaediaSim and the MedSim Patient,³⁰ are examples of commercially available high fidelity simulators. These simulators allow clinicians to interact with the 'patient' as they would in the real clinical environment. Loudspeakers in the manikin's head create the impression of the 'patient' talking, and physical signs including pulses, breath and heart sounds, pupillary reactions and urine output are produced. Physiological signals generated by the manikin are fed to routine clinical monitors allowing simple (ECG, non-invasive blood pressure, oxygen saturation) and complex (CVP, pulmonary artery and intracranial pressure) monitoring to be carried out. Injected drugs will be automatically 'sensed' and have appropriate effects through the interaction between pharmacological and physiological models. In response to changing information from the patient and monitors, the clinician may be prompted to carry out therapeutic interventions such as the administration of oxygen, endotracheal intubation or chest drain insertion. Scenarios are generally pre-programmed but the dynamic modelling will 'automatically' have the appropriate physiological or pharmacodynamic effects. For example, increasing the inspired oxygen concentration will increase oxygen saturation, the administration of fluid will correct signs of hypovolaemia and the administration of adrenaline will cause increases in blood pressure and heart rate.

Due to their complexity, model-driven simulators are very costly, both in terms of purchase and running costs, and they therefore tend to be based in specialist centres. However, the number of such simulators and their use in the educational curriculum is growing rapidly.³¹

Instructor driven ('intermediate fidelity') simulators combine part or full body manikins with less complex computer programs. The models used range from simple resuscitation style manikins such as that used in the ACCESS anaesthesia simulator system,³² to sophisticated manikins allowing multiple interventions such as the Laerdal 'SimMan' and Gaunard 'Noelle' obstetric simulator. In general the computer software produces physiological signals that are displayed on a computer screen rather than standard clinical monitor and an instructor is required to adjust signs to reflect patient responses. This is a rapidly growing area of simulator development and due to their relatively low cost, many of these simulators have been purchased for training at regional or individual hospital level.

Both model- and instructor-driven simulators can be controlled from a remote site, as the simulator or

monitors produce most of the necessary information required to support clinical decision-making. When recreating the conditions of rapid change and uncertainty associated with the management of emergency situations, it is vital that the 'clinical' clues are accurately reproduced so that the learner is not misled by physiological changes which are incompatible with the situation being portrayed. Model-driven simulators make the dynamic interaction and feedback less operator-dependent and hence more complex scenarios can be undertaken. Although the engineering fidelity of these simulators is generally high, their psychological fidelity is improved by setting the simulator within a realistic clinical environment with appropriate resources, including staff.⁶ Debriefing using video review after such scenarios can focus both around the cognitive processes involved in recognition of the problem (decision making and situation awareness) and the implementation of management guidelines. At a technical level, this examines the ability of the learner to apply rules and precompiled responses in a stressful situation. It also allows the learner to focus on the social aspects of non-technical skills such as team working, interpersonal communication and task management which are required to achieve completion of the task in a group setting.

Some of the more portable models may be used within a real clinical environment to carry out on-site training of teams or 'mock drills'.

The addition of the dimension of 'stress' of a complex skill in a dynamic and uncertain situation and the combination of technical and non-technical skills required to deal with the situation effectively typifies the experience presented by the 'high fidelity' simulators. While the application of stress to the learning environment before the learner has achieved competence in the basic skills (as can happen with early exposure to the clinical environment) will lead to deterioration of performance, the under-performance of trainees during

simulated scenarios has been ascribed to a lack of stress associated with the real event ('adrenaline gap').

Table 1 compares the general characteristics of the different available simulators.

'Integrated simulators give an opportunity to rehearse the management of serious potential complications of epidural blockade, such as local anaesthetic toxicity and total spinal anaesthesia, within a realistic environment using all available resources. The dynamic modelling of the model driven simulators allows an improved recreation of the rapidly changing clinical situation and the uncertainty associated with diagnosis of such problems prior to implementation of treatment drills. Use of portable models such as SimMan allows such drills to be carried out in real clinical environments when aspects of local procedures, systems and team-working can be evaluated.'

The use of simulators in assessment

The formative assessment of performance is an essential component of deliberate practice. However, summative assessment using part task trainers, low fidelity simulators and simulated patients is the basis of many objective structured clinical examinations (OSCEs).³³ The majority of evaluations relate to basic psychomotor and communication skills with a competency based approach. The challenge of evaluating higher levels of expertise with the OSCE has been raised.³⁴ However, where summative assessment is to be used, the outcome measures must be valid and reliable. Such robust criteria have been produced for use in OSCE examinations at local and national level.³⁵

As the skills become more complex, so the challenge of assessment increases. Indeed, the more realistic the simulator environment, the more that the challenge of assessment equates to the challenge of performance

	Physical body	Automated responses	Performance feedback	Independent learning	Cost
Part task trainers	some	no	no	yes	low
Computer programs	no	yes	yes	yes	low
VR/haptic	some	some	yes	yes	high
Simulated patients	yes	no	yes	no	medium
Integrated simulators					
Model driven	yes	yes	no	no	high
Instructor driven	yes	no	no	no	medium

Table 1 General characteristics of simulators

Adapted from PSU simulation website with permission. (There may be exceptions in each category.)

assessment in the workplace. 'High fidelity' simulators have been used effectively to assess technical skills,^{36,37} and many scoring systems have been used in an attempt to assess behavioural aspects of practice.^{38,39} Until recently, none of the scoring systems used for the assessment of non-technical skills in the simulator has demonstrated adequate validity or reliability to be used for high stakes assessment.⁴⁰ A system that was recently developed for the assessment of anaesthetists' non-technical skills may address some of these issues.⁴¹

Many analogies are drawn between the use of simulators for training and assessment in aviation and medicine. However, there are many important differences. Aircraft simulators accurately replicate the instrumentation and environment of the cockpit. The visual input of the 'view' from the cockpit is recreated on a screen using virtual reality computer graphics and the sensation of movement of the aircraft replicated using hydraulics which move the entire simulator 'cockpit'. The fidelity of such simulators is such that, after training, if a pilot can fly a particular model of plane on the simulator then he or she will be capable of flying the real aircraft. There are several reasons why this is so. First, the mathematical models used to 'drive' the simulator are highly accurate, as data are generated from the laws of physics and extensive experimental data. It is therefore easier to predict how an aeroplane will react to any given problem or intervention. Second, pilots rely on instruments to obtain a lot of information and this information is supplemented by visual input from the cockpit 'view'. Third, aeroplanes will respond in a very similar manner; one 747-400 should behave in the same way as another 747-400. Assessment tools are used for licensing and regulation and hence have been robustly tested for validity and reliability. This means that the fidelity and accuracy of flight simulators is such that they can be used for assessment purposes.

The same is not true of high fidelity patient simulators. Here the modelling is fairly limited, predominantly to that of the cardiovascular and respiratory systems and the data from which the models are programmed comes from healthy volunteers. The creation of 'pathophysiology' using the simulator models is therefore subject to the biases and interpretation of the scenario writer. Unlike a 747-400, human beings differ vastly even in response to relatively simple interventions such as the same weight-related dose of a sedative drug. In addition, the vital but more subtle clinical clues which are used daily in clinical practice such as changes in facial expression, muscle tone and skin colour and texture are not replicated.

A pilot can attempt a procedure on a flight simulator and be confident that under similar conditions the real

aeroplane will behave in that way. Therefore, the performance of a pilot during a simulator assessment can be extrapolated to 'real' life. Unfortunately, the unpredictability and complexity of the human patient, the lack of physiological data from pathological states and the limitations of current simulators are such that 'high stakes' assessment cannot currently be carried out using medical high fidelity simulators.

Conclusions

Changes in working patterns and the safety culture within medicine are forcing a fundamental review of medical training and are leading to increased demand for non-patient based training. The number of commercially available simulators continues to grow as technological developments continue to improve. However, we must not allow technology to drive the educational agenda but rather pursue the development of technology which will assist in developing areas of identified training need. Any simulator device can only ever be as good as the educational programme in which it is embedded and many simulators are purchased every year and then under-utilised due to lack of educational goals to underpin their use. Some simulator manufacturers are now beginning to address this need by providing educational support material with their devices; however, educators must continue to work to ensure the integration of laboratory based training to the clinical environment. Further challenges lie in the development of improved methods of assessment in order to evaluate the contribution that simulators make to training and ultimately to the quality of patient care.

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