The history of simulation in medical education and possible future directions

Paul Bradley

INTRODUCTION Clinical simulation is on the point of having a significant impact on health care education across professional boundaries and in both the undergraduate and postgraduate arenas.

SCOPE OF SIMULATION The use of simulation spans a spectrum of sophistication, from the simple reproduction of isolated body parts through to complex human interactions portrayed by simulated patients or high-fidelity human patient simulators replicating whole body appearance and variable physiological parameters.

GROWTH OF SIMULATION After a prolonged gestation, recent advances have made available affordable technologies that permit the reproduction of clinical events with sufficient fidelity to permit the engagement of learners in a realistic and meaningful way. At the same time, reforms in undergraduate and postgraduate education, combined with political and societal pressures, have promoted a safety-conscious culture where simulation provides a means of risk-free learning in complex, critical or rare situations. Furthermore, the importance of team-based and interprofessional approaches to learning and health care can be promoted.

CONCLUSION However, at the present time the quantity and quality of research in this area of medical education is limited. Such research is needed to enable educators to justify the cost and effort involved in simulation and to confirm the benefit of this mode of learning in terms of the outcomes achieved through this process.

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INTRODUCTION

Simulation has been defined as:

> 'The technique of imitating the behaviour of some situation or process (whether economic, military, mechanical, etc.) by means of a suitably analogous situation or apparatus, especially for the purpose of study or personnel training.'[1]

Within this definition is included a large range of activities that are rightly regarded as being a part of the spectrum of clinical simulation.

Simulation, in its many guises, is now widespread in many fields of human endeavour. The history of simulation stretches back over centuries. The military has been a longterm user of simulation: chess probably represents one of the earliest attempts at war gaming; jousting permitted knights to hone battlefield skills, and the 18th century *Kriegspeil* represented a development with more face validity, which has led to modern, complex, computerised warfare simulations. The modern aviation industry has developed high-fidelity flight simulation and has led on improving the non-technical skills of teams through crew resource management programmes. Similarly, the space programme has made extensive use of simulation for training and testing. The nuclear power industry, with its adverse experience of how bad things can be when they go wrong, such as at Three Mile Island and Chernobyl, is another business with a major commitment to simulation. What these

Overview

What is already known on this subject

Simulation is not a new phenomenon in clinical learning. It has been gradually establishing a role in health care education, although there has been limited research of sufficient quality to provide a robust evidence base.

What this study adds

This paper reviews the development and range of simulation in both undergraduate and postgraduate education. It describes the influences that have seen simulation expand across the spectrum of sophistication within health care education and examines possible future directions.

Suggestions for further research

More quality research is required in this field, as in other areas of medical education, to establish an evidence base upon which these developments can be based and judged.

groups have in common is that, for each of them, training or systems testing in the real world would be too costly or too dangerous to undertake. It is not surprising therefore that the medical profession should take steps to adopt the principles of high-reliability organisations. Indeed, what may be more surprising is how long it has taken to get here.

THE HISTORY OF CLINICAL SIMULATION

Clinical simulation does, in fact, span the centuries; for example, models have long been used to help students learn about anatomical structures. The modern era of medical simulation has its origins in the second half of the 20th century. Three distinct movements can be identified that have spurred the development of clinical simulation.

The first, which occurred slightly earlier than the high-fidelity simulation developments and at the near opposite end of the spectrum, concerns the work of Åsmund Lærdal. This cannot be underestimated in terms of its importance to the field and to humanity itself. Working with anaesthetists, Lærdal, a Norwegian publisher and toy manufacturer, developed the 'Resusci-Anne', the part-task trainer that was to revolutionise resuscitation training through the widespread availability of a low-cost, effective training model.[2] Since then, such simulation has evolved steadily, with an increasingly sophisticated range of manikins and models used in support of resuscitation and basic skills training becoming available.

The second movement is quintessentially associated with modern simulation and concerns the development of sophisticated simulators dedicated to the reproduction of aspects of the human patient. The earliest of these was the Sim One, developed by Abrahamson and Denson in the late 1960s.[3] The manikin had a number of sophisticated features:

> 'It breathes; has a heart beat, temporal and carotid pulse (all synchronised), and blood pressure; opens and closes its mouth; blinks its eyes; and responds to four intravenously administered drugs and two gases (oxygen and nitrous oxide) administered through mask or tube. The physiologic responses to what is done to him are in real time and occur ''automatically'' as part of a computer program.'[4]

However, the Sim One failed to achieve acceptance, despite promising early reports of its effectiveness in training. This was largely because the need for anything other than apprenticeship-based training had not yet been defined and, secondly, because the cost of the technology at the time did not permit more than one example to be produced. In the 1980s, the feasibility of producing high-fidelity simulators was resurrected by two groups, the first at Stanford University and the other at the University of Florida. The former group, led by David Gaba, developed the comprehensive anaesthesia simulation environment (CASE)[5] and the latter, led by Michael Good and JS Gravenstein, developed the Gainesville anaesthesia simulator (GAS).[6] The CASE was later to be commercialised as Medsim and the GAS eventually became the Medical Education Technologies, Inc. (METI). The Stanford team focused significant attention on the development of team-based working in realistic simulation environments and incorporated the aviation model of crew resource management into the anaesthesia crisis resource management (ACRM) curriculum, leading to significant developments in clinical team-based training.[7] These simulators and some European counterparts (from Holland, Denmark and the UK) form or have formed the basis for today's modern moderate to high-fidelity simulator (Table 1). They have been at the forefront of the development of high-fidelity simulation; led by the anaesthesia community these manikins have been central to the understanding and development of simulation-based learning and training to date.

The third major movement has been that of medical education reform, which, in the latter part of the century, began an ongoing process that continues today. Some of this change has been driven by worldwide recognition of the need for students to be prepared as effective junior doctors after their undergraduate education.[8–11] The recognition of information overload within the undergraduate curriculum, at the expense of the learning of clinical and communication skills, has seen the widespread adoption of programmes in clinical skills learning and the development of clinical skills education facilities to support that learning.[12–14] Changes to postgraduate training have also come about as the need to adopt a sounder educational approach, coupled with a more streamlined process, has emerged. The need for continuing medical education after higher specialist training and the drive to revalidation has also been a significant part of this process. This has seen a rise in the use of simulator methodologies in both undergraduate and postgraduate education. Although much of this learning is at the lower end of the simulation spectrum, increasing attention is being paid to high-fidelity simulation as a means of providing safe, protected, educationally sound experience to undergraduate students, postgraduate trainees and established practitioners. Indeed, it has been argued that these changes are long overdue and that they represent an essential element of an ethically cognisant education.[15]

Table 1 Features of a modern moderate to high-fidelity human patient simulator

Complete human body	
Capable of 'speech'	
Structure and function	
Complete integrated physiology/pharmacology model (high-fidelity)	
Open/close mouth	Trismus
Realistic airway	Pharyngeal oedema
Respiratory chest (± abdominal wall movements	Appropriate anatomical landmarks
Lungs capable of spontaneous, assisted or mechanical ventilation	± consumption of O_2, exhalation of CO_2 and uptake of anaesthetic gases
Tongue swelling	Difficult airways
Synchronised breath sounds	Bowel sounds
Monitoring	
Pulses palpable	
Synchronised with heart sounds	
Blood pressure measurable	
Variety of physiological outputs to standard monitors	
Pulse oximetry	
Procedures	
Defibrillation	Pneumothorax decompression
Cardioversion	Cricothyroidotomy
External pacing	Pericardiocentesis
Venepuncture	Chest drain insertion
Cannulation	Intramuscular injection
Urinary catheterisation	

DRIVES TO SIMULATION

Figure 1 shows the major drives of the late 20th century behind the adoption of simulation. The movements that have provided the impetus towards the use of simulations are varied but they resonate throughout many health care systems.

It has been widely recognised that students have been ill-prepared for their roles as young doctors. In addition to their well documented deficiencies in a range of skills,[16–19] there have been reports of stress resulting from inadequate preparation for their roles.[20] These skill deficiencies have occurred alongside a changing pattern of health care delivery, which has seen significant changes to the clinical experience of undergraduates.[21,22] In the postgraduate arena, working time restrictions have raised concerns about junior doctor training[23–25] and the move towards a more streamlined, shorter duration of higher professional training has also caused concern

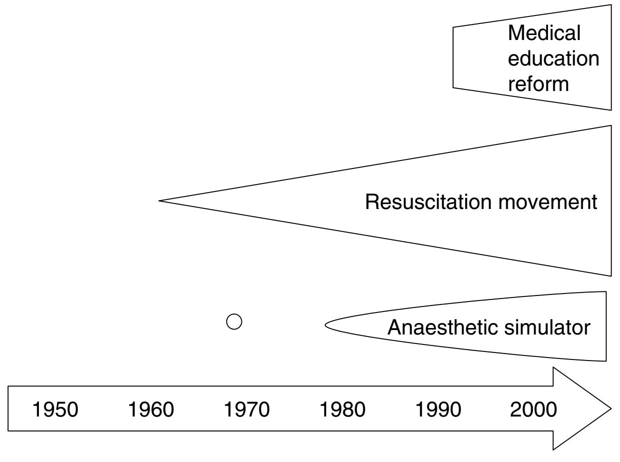

Figure 1 The major movements of the late 20th century driving the adoption of simulation

about the amount of direct clinical experience it is possible to provide.[26,27] In the light of decreasing time available for higher training, the case has been made for planned exposure to simulated cases to ensure that sufficient material is covered.[28] Such approaches are underwritten by the drive to clinical governance that has emerged over the past decade; this requires strategies that support education and training in support of quality improvement.[29] Similarly, the publications *To Err is Human*[30] and *An Organisation with a Memory*[31] have brought the agenda of patient safety to the fore and stressed the need for an institutional approach to overcoming institutional, individual and cultural barriers; within this approach the inclusion of simulation is readily apparent, with lessons from the domain of anaesthesia providing significant guidance.[32] Within these development models, significant emphasis is placed on effective team working and, with the drive to interprofessional education,[33,34] it is also apparent that these factors further stimulate simulation as a vehicle for progressing these agendas and preparing a workforce that exhibits capability and not simply competence.[35] As well as these drivers, there are also important background factors acting continuously on the systems. These include not only societal expectations and political pressures from governments, but also the profession itself as it strives to meet the demands of modern day health care.

Figure 2 shows the background to learning through clinical simulation and the factors that drive it.

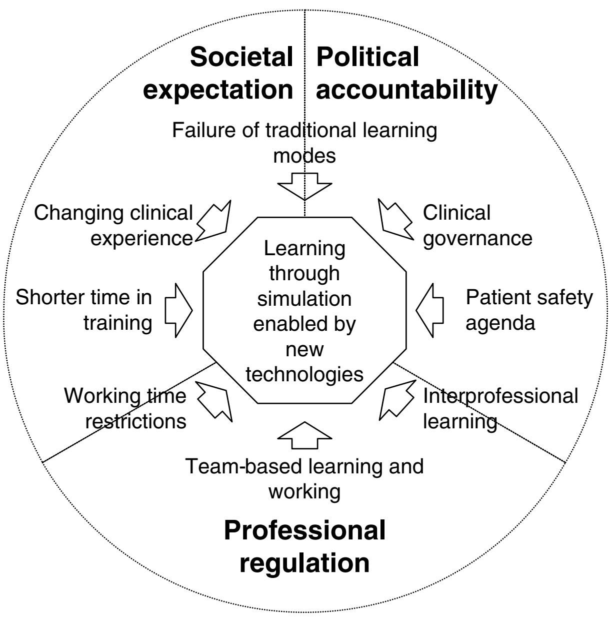

Figure 2 Drives and background to learning through clinical simulation

However, it is only over the last 40 years or so that simulation has emerged as a gathering force in the development of medical education and has become increasingly recognised as having great potential in delivering elements of health care education.

SIMULATOR TYPES

The technologies that have been at the heart of the drive to incorporate simulation are not all high-technology in nature or computerised. Most simulators in use today are at the low-technology end of the spectrum and are used in the high-volume, basic skills learning arena associated with undergraduate and early postgraduate health care professional development. Table 2 shows how the range of simulators can be categorised.[36,37]

PART-TASK TRAINERS

These models are meant to represent only a part of the real thing and will often comprise a limb or body part or structure. These are usually used to aid the acquisition of technical, procedural or psychomotor skills, such as venepuncture, ophthalmoscopy and catheterisation; there are more sophisticated part-task simulators, such as the Harvey and the Simulator-K, which are high-fidelity cardiovascular systems designed to help learners recognise common auscultatory cardiac findings,[38,39] as well as trainers designed to develop basic and sophisticated surgical techniques. They allow the learner to focus on the isolated task, but can be used in combination to enhance the learning experience: for example, a female pelvic examination trainer may be used along with an anatomical model of the pelvis to reinforce learning of the underlying anatomy. Some provide feedback (visual, auditory or printed) to the learner on the quality of their performance (e.g. simple clicking to represent adequate depth of chest

Table 2 Classification of simulators[36,37]

Part-task trainers	
Computer-based systems	
Virtual reality and haptic systems	Precision placement Simple manipulation
Complex manipulation	
Simulated patients	
Simulated environments	
Integrated simulators	
Instructor-driven simulators	
Model-driven simulators	

compression in cardiopulmonary resuscitation). Although it is not part of their original purpose, they can be imaginatively used along with simulated patients (SPs) to provide learners with realistic clinical scenarios in which both technical and communication skills are combined.[40]

COMPUTER-BASED SYSTEMS

Multimedia programmes

U-Medic is a CD-ROM based multimedia programme that partners the Harvey and presents an extensive cardiovascular curriculum incorporating cardiac auscultation and cardiovascular imaging in its presentation. Programmes such as this, incorporating audio and video, are used in a fairly commonplace manner as adjuncts to formal teaching and learning.

Interactive systems

These systems often provide the user with an interface that presents physiological or pharmacological variables that can be manipulated through the user's actions, providing feedback on decisions made and actions taken.

Virtual reality and haptic systems

More sophisticated application of computer technology is encountered in virtual reality (VR) and haptic systems. Virtual reality refers to the recreation of environments or objects as a complex, computer-generated image; haptic systems refer to those replicating the kinaesthetic and tactile perception. Often VR and haptic systems are combined with some form of part-task trainer; the products that are currently available support vascular access training, endoscopy training and laparoscopic surgical techniques. Kneebone describes a subcategorisation of computer-based VR simulators: precision placement (e.g. vascular access), simple manipulation (e.g. sigmoidoscopy) and complex manipulation (e.g. anastomosis).[37] He also describes a higher level of integrated procedures, which are in keeping with fully integrated, high-fidelity simulators.

SIMULATED PATIENTS AND ENVIRONMENTS

Simulated patients have over the last two to three decades become commonplace in medical education, particularly in undergraduate communication skills learning. The SP may be a professional actor trained to present a history and sometimes to mimic physical signs, or a patient who has received training to present his or her history in a standardised, reliable manner. They have also been used in assessment as replacements for real patients and as assessors themselves.[41] Occasionally, the learners themselves may act as SPs through role-play.[42]

The recreation of the environment in which the activity is going to take place is common in simulation and clinical skills centres. Within reason, the ability to situate the activity in a realistic environment would be expected to increase the learner's engagement with the simulation and to enhance the suspension of disbelief. Although, for team training in particular, it might be argued that training *in situ* within the normal clinical environment can provide individuals and systems with real experience upon which to reflect, the impact on clinical activity and the distraction of ongoing work may create too much peripheral distraction to learning.

INTEGRATED SIMULATORS

These simulators combine a manikin (usually a whole body) with sophisticated computer controls that can be manipulated to provide various physiological parameter outputs that can be physical (such as a pulse rate or respiratory movements) or electrical (presented as monitor readouts). These parameters may be automatically controlled by a physiological and pharmacological model incorporated within the software or may respond to instructor inventions in response to actions of learners. The sophistication of these simulators and their costs vary. The METI and the Medsim are high-fidelity simulators that have been at the forefront of work in anaesthetic simulation. More recently, the SimMan, a moderate-fidelity simulator, has become available at a much lower cost, enabling an unprecedented growth in the use of this level of simulation.

WHY USE SIMULATION?

All this being said, we are still left with the question: why use simulation? The proponents for simulation make a reasoned and cogent argument for the use of simulation. Simulation provides a safe, supportive educational environment.[43] It allows users at all levels, from novice to expert, to practise and develop skills with the knowledge that mistakes carry no penalties or fear of harm to patients or learners. It encourages the acquisition of skills through experience,[44] ideally in a realistic situation or environment, and can stimulate reflection on performance.[45] Learners can develop at their own rate and individual learning and rates of learning styles can be accommodated. Simulation can facilitate on-demand learning and scenarios can be created as required.[46] Furthermore, training through simulation may facilitate the transfer of skills to the real world setting of the clinical environment. It also has the potential to be a valuable formative and summative assessment tool. The potential benefits of simulation are shown in Table 3.

Simulation has several potential applications at all levels of the professional development of individuals, as well as in supporting professional practice and continuing professional development. As a technique, simulation can support undergraduates in the acquisition of a range of basic clinical (history content, physical examination and procedural) and communication skills. Teamwork and interprofessional learning can similarly be the subject of simulated activities. It also has the potential to both support and quality assure ongoing professional development. Some of these applications are outlined in Table 4.

However, despite the rhetoric and the recognised potential of simulation to be used widely in support of health care education at all levels and across all disciplines, this is not likely to be realised without evidence to support the widespread adoption of this technique.

THEORY AND RESEARCH

The medical education community has been much criticised of late for adopting and implementing educational innovations without sound evidence for their efficacy.[47] The field of simulation is similarly under the microscope for the same reason. As Table 5 shows, the field itself is theory-rich[48] and such an abundant conceptualisation of learning should help us understand how learning is taking place and how it can be supported through simulation.

It is evident that the literature on simulation is growing rapidly (Fig. 3); however, the evidence emerging from the literature is limited. A recent 'Best Evidence Medical Education' (BEME) review of effective learning through high-fidelity simulation identified only 109 articles (from 670) that were sufficiently robust to be included in the process.[49] The chief findings of the successful elements of high-fidelity mediated learning are summarised in Table 6. It is apparent that much of what has been and is being written is limited in scope to reporting evaluations, usually at the lower end of the Kirkpatrick criteria,[50] in common with much medical education literature.[51]

POSSIBLE FUTURE DIRECTIONS

There are needs for research that has a better methodological base and for medical education to learn from other disciplines. This applies to the

Table 3 The benefits of simulation[36]

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

Table 4 Potential application of simulation

Routine learning and rehearsal of clinical and communication skills at all levels
Routine basic training of individuals and teams
Practice of complex clinical situations
Training of teams in crisis resource management
Rehearsal of serious and/or rare events
Rehearsal of planned, novel or infrequent interventions
Induction into new clinical environments and use of equipment
Design and testing of new clinical equipment
Performance assessment of staff at all levels
Refresher training of staff at all levels

Table 5 Relevant learning theories[48]

Behaviourism
Constructivism
Social constructivism
Reflective learning
Situated learning
Activity theory

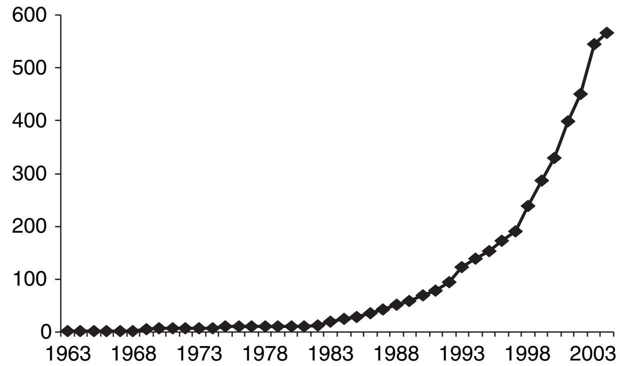

Figure 3 Cumulative growth in simulation literature (Source: Boston Simulation Centre)

Table 6 The features of high-fidelity simulation that affect learning[49]

Providing feedback
Allowing repetitive practice
Integrating within curriculum
Providing a range of difficulties
Being adaptable; allowing multiple learning strategies
Providing a range of clinical scenarios
Providing a safe, educationally supportive learning environment
Active learning based on individualised needs
Defined outcomes
Simulator validity as a realistic recreation of complex clinical situations

continuum of simulation as much as it does to other aspects of medical education.[52–55] Medical education is an expensive undertaking; like other aspects of health care it demands attention to the cost justification of the outcomes of the process; without such evidence, simulation, for example, is unlikely to persuade those who manage the funding of the potential benefits. Without commitment to an evidence base, at best simulation will retain a peripheral place in education and training; at worst the process will stagnate for the lack of forceful argument in its favour.

The need for outcomes-based education is increasingly accepted in general medical education[56,57] and in clinical skills learning[58] – simulation is no exception to this. Having defined outcomes facilitates the investigation of the interventions intended to produce learning and the achievement of these outcomes.

In terms of the research methods that support the investigation of learning through simulation, both the scientific and interpretative paradigms offer researchers appropriate approaches. Neither should be viewed as superior to the other; rather they should be aligned with the appropriate theoretical stance to provide different and complimentary research perspectives proving different, but equally relevant, evidence regarding the learning facilitated by the simulated processes in all their guises.[48] The problems pertaining to small sample sizes need to be overcome through collaboration between educational institutions.

Assuming that evidence will be forthcoming, what direction will clinical simulation take? It seems likely that the three movements described earlier will coalesce and that the process will continue to grow and have an important part to play in the future. It is, however, important not to think of simulation as disintegrating into separate low-fidelity/high-fidelity dichotomies with SPs somewhere else off the scale.[59] The level and type of simulation will need to be adapted to the educational needs of the learner and the design and intended outcomes of the programme; for example, high-fidelity simulation with the METI is inappropriate for developing learner skills in breaking bad news and learning team-based, non-technical skills is unlikely to be facilitated through the use of an upper limb intended for venepuncture!

Figure 4 shows a representation of a broad-based clinical simulation movement. This envisages widespread adaptation by many target groups and disciplines. Low to high-fidelity simulation is supported

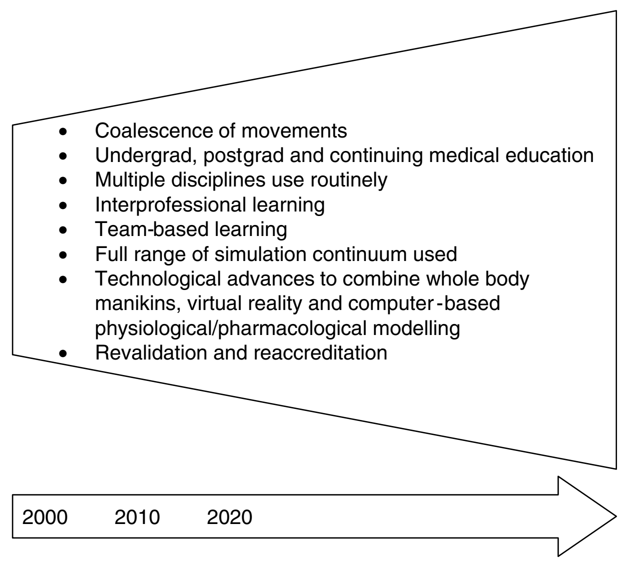

Figure 4 Representation of the future, broadening base of learning through simulation

across the full continuum. Such an uptake of simulation would have major consequences for health care education and delivery institutions. The vision for simulation in the future has been explored eloquently and honestly by Gaba[60] but the final outcome remains to be seen.

CONCLUSION

Clinical simulation is a technique that enables the learning and training of individuals and teams through the re-creation of some aspect of the real clinical situation. It exists as a spectrum of educational activities involving not just technological and computerised facilities, but including important human interactions. These interactions may be one-to-one (e.g. as role-plays or with SPs), within teams or between teams. It is important not to disintegrate simulation into a dichotomy between low- and high-fidelity, but to regard it as a continuum with roles to fulfil at all levels of seniority within and between professional groups. However, the evidence to date that has appeared in the literature tends to be of a low-level evaluative nature, weak in methodology and of limited generalisability. Robust research is required to underpin simulation as a worthwhile educational strategy. This research needs to be focused on higher level outcomes in order to provide convincing evidence across the whole spectrum of the efficacy and effectiveness of simulation-based education.

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