

Simulation-based Training at the University of Pittsburgh

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Abstract

The following article reviews the experience of using human simulators for medical education at the University of Pittsburgh in the Department of Anesthesiology and Critical Care Medicine. The intent of the authors is to provide the reader with an overview of 1) what human simulators can do, 2) the components of a simulation training facility, 3) some of the economic considerations in operating a simulation training facility, and 4) how this centre is made use of.

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Introduction

In the domain of medical education of both the general public and healthcare professionals, the next decade will present both challenges and opportunities centred on training issues and technologies. Since the introduction of external cardiopulmonary resuscitation in 1960 through to the establishment of International Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care^{1,2} with associated extensive efforts in public training of these skills, the numbers of lives saved have remained suboptimal.³ The weakest link in the chain of survival is the life supporting first aid by lay bystanders. The central issue in this area is the development of effective training methods in skill acquisition and retention as well as the motivation to learn and use these skills.³ In the prehospital management of patients by paramedics, emergency medical technicians and flight nurses, there is an ever-broadening trend for the prehospital application of increasingly complicated therapeutic procedures and medications. Yet associated with this have been a host of training related failures in applying the knowledge, skill and judgement associated with these improvements in patient care leading to significant adverse outcomes.⁴ In the hospital professional healthcare domain, the Institute of Medicine (IOM, USA) released in December of 1999 a landmark report on medical error and patient safety entitled "To Err is Human: Building a Safer Health System."⁵ It implied that medical error in the US hospitals might be the 8th to 5th leading cause of death

in the United States. Total national costs of preventable adverse events were estimated to be between US\$17 billion and US\$29 billion. It recommended, among other things, the creation of a governmental centre for patient safety with regulatory powers and funding of at least US\$100 million (research, etc.), funding centres of excellence, development of patient safety programme and performance standards for healthcare professionals, and establish interdisciplinary team training programme that incorporate training methods such as simulation.

Although the use of simulation technology, including multimedia computer programs, only now is gaining wider acceptance in medicine, such technology is well established in other disciplines. Examples include the use of flight simulators for pilots and astronauts,⁶⁻⁸ military training exercises,⁹ management training for business executives,^{10,11} and technical operations for nuclear power plants.¹² Simulations place trainees in life-like situations that provide immediate feedback about questions, decisions and actions. Flight simulators closely approximate in-flight situations, and the airline industry has demonstrated that they improve pilot skills.^{13,14}

Simulation at the University of Pittsburgh

A. Background

In the early 1990s, Dr Peter Winter, as our chairman, realised the importance of establishing a simulator centre for training of personnel in the Department of

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Anesthesiology/Critical Care Medicine (CCM) in Pittsburgh. The simulator obtained for this purpose, essentially the only one available at the time, was very expensive and cost over US\$250,000. Additional equipment was obtained, including computers and the centre was launched on the third floor of Montefiore Hospital. Arrangements were made to simulate an operating room (OR), (Fig. 1) an intensive care unit (ICU) bed, or bay in the emergency room. Anaesthesia machines, monitors and ventilators were obtained to complete the picture. Over the next 4 years, a number of faculty were involved in the development of a broad range of curricula and performance evaluation tools including Internet, CD-ROM, Palm-based, and digital video-based components. Drs Rene Gonzales and John Schaefer also designed a more functional, affordable and portable version of a difficult airway. A Texas company, recently acquired by the Laerdal Corporation, undertook commercial manufacturing of this new simulator.

B. Simulators and Partial Task Trainers

At the University of Pittsburgh, Department of Anesthesiology and Critical Care Medicine (CCM), Human Simulation Center, we use the Laerdal Inc. SimMan (Fig. 2) for a full-scale patient simulation. The key features of this simulator include 1) affordability, 2) simplicity of operation by instructors, 3) portability, and 4) high fidelity.

One can either talk through the simulator or activate pre-recorded sounds. Carotid, radial and femoral pulses are palpable. The simulator breathes and exhales carbon dioxide for qualitative measurement. The anatomy of the airway and lung compliance can be varied dynamically to facilitate difficult airway management training. The simulator supports all major airway devices, cricothyrotomy and needle decompression of a pneumothorax. The bronchial tree is accurate down to the segmental level to facilitate fibreoptic bronchoscopy training. Breath, heart and bowel sounds can be auscultated, and a variety of abnormalities can be activated. Blood pressure can be obtained either manually or automatically. The simulator functionality supports external defibrillation or external pacing. The simulator system includes a flat screen monitor with haemodynamic invasive monitoring, capnography and touch-screen functionality. A standard laptop is enough to run the simulator software. The software features an intuitive windows-based operating system with a short learning curve. The simulator can be operated from the computer with feedback from sensors located within the simulator that records and informs the operator as to the actions of the trainee. The system can also be operated via intuitive, remote, wireless, control units that support a number of programmable features. The user interface supports direct

control of the physiologic output along with a catalogue of over 1000 cardiac rhythms. Physiologic responses can either be controlled directly or preprogrammed as a series of non-linear trends. Open-ended programming of complicated clinical scenarios is supported through a simplified, rules based, scenario programming system that is easy to learn.

The Laerdal AirMan (Fig. 3) is a simulator limited to support high quality difficult airway management training in a simplified, very portable, low cost platform. This simulator allows the instructor to produce the following situations: restricted mouth opening, restricted neck mobility, tongue swelling, pharyngeal swelling, laryngospasm of the vocal cords, poor unilateral or bilateral pulmonary compliance. Additional features of the simulated patient include various interchangeable sets of teeth of varying size and prominence and thus, variable degrees of interference to laryngoscopy; an anatomically correct cricothyroid "membrane" made of replaceable polymer tape which can be punctured and cannulated; inflatable lungs which can be ventilated by conventional means or by transtracheal jet, provided appropriate equipment and technique are used; pneumothorax which can be simulated, and can be reversed if the trainee performs appropriate treatment modalities (needle decompression); a very realistic tracheobronchial tree to allow training in fibreoptic endoscopy, and insertion of double-lumen tubes and bronchial blockers, a mechanism for spontaneous respiration, which allows the instructor to control the respiratory rate and pattern and to produce apnoea or coughing; a simulated pulse oximeter monitor which is directly controlled by the instructor and provides additional realistic visual and auditory feedback for the trainee, a source of carbon dioxide (CO₂) gas is connected to the distal portion of the lower respiratory tract and exhaled CO₂ can thus be detected during proper ventilation, subcutaneous silicone rubber veins to allow intravenous cannulation and administration of medications; and a concealed speaker which allows the simulated patient to "speak" or "cough" (actually, an instructor speaks through a remote microphone).

This comprehensive airway management training system can therefore be used for basic airway management training (i.e., bag-mask ventilation, insertion of oral or nasal pharyngeal airways, and endotracheal intubation via the oral or nasal routes). Alternatively, by activating the concealed abnormal airway mechanisms individually or in combinations, a spectrum of dynamic difficult airway scenarios can be created which simulate any portion of the ASA Airway Algorithm,¹⁵ such as the "cannot intubate but can ventilate" situation, which can then be advanced to the "cannot intubate, cannot ventilate (emergency pathway)" situation.

Scenarios can be run either uninterruptedly in “real time,” or may be paused or suspended to make teaching points and then re-started. These scenarios can be standardised and are reproducible for educational research and performance measurement.

C. Facility Layout

The University of Pittsburgh, Department of Anesthesiology and CCM, Human Simulation Center occupies approximately 1800 sq ft including 7 rooms on the third floor of the Montefiore Hospital. The main simulation theatre (Fig. 1) is separated from an adjacent control room with a large one-way mirror for observation. This theatre can be configured as an OR, patient room, ICU or emergency room. The equipment for this room was essentially obtained at no cost from “retired” equipment in the hospital or donated from manufacturers. Most supplies were obtained at no cost from expired drugs or disposable setups from the hospital. A number of props were either created locally or were commercially available at low cost such as remote power switching controls from Radio Shack or non-toxic smoke generators (fire in the OR).

The control room (Fig. 4) houses the audiovisual equipment as discussed in the following section, as well as a desk, computer, printer and files for the technologist.

The conference room includes an area for debriefing trainees through directed review of videotaped performances and didactic presentations on relevant medical topics. It is set up such that one can observe on a large television screen what is occurring in the main theatre to facilitate educational involvement of those trainees not participating in the ongoing simulation scenario. Teaching aids such as an audiovisual projector for PowerPoint or Internet curriculum, a slide projector, posters, etc are used to facilitate learning in this room.

Another room adjacent to the control room with its own one-way mirror is utilised for Advanced Cardiac Life Support (ACLS) courses, as a second simulation theatre (Fig. 5), or skill-based training area. Audiovisual support for this room is similar to that of the main simulation theatre. One of the attractive features of the Laerdal “Heart Code” ACLS training system is that it allows self paced, independent learning such that the technologist can simultaneously support training courses in both areas.

An Airway Skills Laboratory (Fig. 6) is located in a room across the hall from the control room and is essentially an independent training area. The simplicity of operation of the Laerdal AirMan simulator is particularly beneficial in supporting training efforts in this room as it allows high level, difficult airway management simulation training with minimal training from an instructor and with minimal support from the technologist. Audiovisual support in this

room includes videotaping of training sessions similar to that in the main theatre and teaching aids similar to those in the conference room. Toilet and storage facilities make up the rest of the rooms. These facilities ensure flexibility of operation of the centre and the comfort of the anxious trainees.

D. Audiovisual Functionality

Most simulation centres apply the same fundamental concepts to audiovisual support.

- 1) Usually two cameras are pointed at 90° angles to the centre of action with one being recorded at a time.
- 2) The patient monitor is converted to a video signal with a scan converter so that the trainee performance and the condition of the patient can be recorded.
- 3) Microphones including a ceiling microphone and a lapel microphone, and an output from the simulator’s voice are entered into either a stand alone audio mixer or as part of a mixer board such that all aspects of communication as it pertains to performance are recorded in a balanced output on the videotape.
- 4) A mixer board allows combining the video picture of the simulation with the video picture of the patient monitor as a picture in a picture along with the balanced audio output. This combination provides all aspects of the clinical situation and trainee performance into one videotape for debriefing and research purposes.
- 5) To facilitate the smooth coordination of role-playing in a dynamic full-scale simulation training, two-way communication headsets are indispensable.

E. Economics

The capital and operational costs of our centre are somewhat representative of the general considerations of the economics of simulation training endeavours. The figures listed in Tables I and II represent the general capital and operational costs of the University of Pittsburgh, Human Simulation Center. The capital costs of simulators are greatly influenced by the type of simulator purchased along with the various accessories, ranging from US\$28,000 to US\$250,000. At our centre we use one each of the Laerdal Inc. full-scale patient simulator SimMan, the difficult airway simulator AirMan, and the Heart Code ACLS training system to support the programmes listed in section F. The most basic audiovisual costs include 2 large televisions, 2 videotape recorders, a video camera, a mixer board, and a video converter for the patient monitor, and a wireless microphone. As described in section D, this represents the minimal amount of equipment needed to capture the key aspects of a performance and then playing back the videotape for debriefing. Table I lists the current configuration of equipment that has evolved over the last 5 years from modest beginnings.

TABLE I: ESTIMATED CAPITAL BUDGET COSTS

Category	Description	Unit cost	Number of units	Ext. price
Simulators				
	SimMan	25,000.00	1	\$25,000.00
	AirMan	15,000.00	1	\$15,000.00
	HeartCode	7,000.00	1	\$7,000.00
	<i>Subtotal</i>			\$47,000.00
Audiovisual				
	pan tilt zoom	2,670.00	1	\$2,670.00
	fixed camera	610.00	4	\$2,440.00
	digital mixer	1,500.00	1	\$1,500.00
	digital VCR	3,300.00	2	\$6,600.00
	SVHS deck	3,500.00	1	\$3,500.00
	VCR	290.00	4	\$1,160.00
	rack mount	300.00	2	\$600.00
	A/V distribution	380.00	1	\$380.00
	amplifier			
	wireless microphone	995.00	1	\$995.00
	wireless com.	4,000.00	1	\$4,000.00
	ceiling microphone	245.00	3	\$735.00
	27" monitor	650.00	3	\$1,950.00
	13" monitor	470.00	1	\$470.00
	desk microphone	50.00	2	\$100.00
	headsets	129.00	1	\$129.00
	manual switchers	150.00	1	\$150.00
	audio mixer	1,187.00	1	\$1,187.00
	scan converter	400.00	2	\$800.00
	LCD projector	4,950.00	1	\$4,950.00
	title maker	680.00	1	\$680.00
	labour/miscellaneous			\$5,000.00
	<i>Subtotal</i>			\$39,996.00
Computers				
	laptop/desktop	4,000.00	3	\$12,000.00
	Software			
	<i>Subtotal</i>			\$12,000.00
Furniture & renovation costs				
	{ \$120 per sq ft x 1800 sq ft }			\$216,000.00
	<i>Subtotal</i>			\$216,000.00
	Total Capital Costs			\$314,996.00

Operational costs can also vary widely depending on rental costs, support labour salaries (technologist or secretarial), how faculty time is accounted for, etc. The technologist in our centre supports the operation through:

- 1) operating the simulator,
- 2) operating the audiovisual equipment,
- 3) coordinating scheduling of multiple courses,
- 4) assisting in programming of simulations,
- 5) setting up for and cleaning up after a specific course, maintaining inventory of supplies, and
- 6) basic servicing of equipment, etc.

If these duties were required to be performed by the faculty at our centre, the labour costs of the faculty member's time would far exceed that of the full-time technologist. This would also affect the efficiency of running a course in that the amount of time actually training versus spent

TABLE II: ESTIMATED OPERATIONAL BUDGET

Account name	Subcategory name	Yearly cost
Salaries		
	Technologist	\$41,039.08
	Administrative Secretary (part time)	\$16,230.89
	*salary support	
	Director	\$0.00
<i>Subtotal</i>		\$57,269.97
Operational Costs		
Rent (per year)		\$34,427.08
Telephone (per year)		\$200.00
Office supplies		\$800.00
Postage		\$150.00
Parking		\$780.00
Food & drinks		\$333.33
Other supplies		
	video tapes	\$285.71
	gases syringes	\$500.00
	airway equip	\$700.00
	fake blood & drugs	\$200.00
	moulage	\$200.00
	miscellaneous	\$600.00
Total		\$96,446.09

*Note: this does not include faculty time costs

performing administrative tasks would decrease. This is not to say that for a less ambitious programme it might make more sense to run a programme without a technologist. With the simulators we are using, a number of courses can and are run by the individual faculty instructor. While not listed, faculty time probably represents the largest ongoing operational cost. We personally do not accept this as a cost of running a simulation centre, but rather the cost of teaching associated with the educational missions of the department involved akin to other efforts such as traditional lectures or training workshops. There arguably is a cost for the administrative overhead of a director for a centre depending on the amount of time committed. The cost of operating the centre (not including instructor time) is between US\$60 and US\$70 per hour of operation at the simulation centre which for reference can be compared to the cost of OR time at approximately US\$33 per minute where training in a broad number of areas occurs.

F. Training Programmes

The following specific programmes represent the planned expansion of existing programmes, anticipated new programmes, the expansion of training to include teaching and educational research interests beyond the existing Simulation Center in the Department of Anesthesiology and CCM to create the much larger Simulation Institute for Education and Research with an expanded and different mission.

Fig. 1.

Fig. 5.

Fig.2.

Fig. 6.

Fig.3.

Fig. 7.

1) Medical Student Education

Anesthesiology and CCM as specialties have been at the forefront of incorporating new educational technologies such as simulation and the use of the Internet in medical student education. The scientific content of these disciplines forms an integral part of so many other medical disciplines. The involved faculty members are broadly trained to educate medical students in the basic sciences of physiology, pharmacology, and pathology in the context of integration into competent clinical practice. New educational technologies, such as simulation, offer an evolutionary opportunity to enhance and improve the skills of trainees

Fig.4.

and medical students at less risk to patients.

- (i) Year I—Summer Preceptorship in Anesthesiology: This is a work-study programme, combining OR technical work with a first exposure to clinical medicine offered to approximately 2 to 4 students per year. Basic simulator training involves setting up an OR, technical aspects of monitoring, basic airway management and performance of a basic general anaesthesia induction.
- (ii) Year II—Clinical Procedures: Includes all 150 students in the second year class. Overall objectives are to train medical students in performing technical procedures related to the practice of medicine (e.g. placing central venous lines, using invasive monitoring and providing basic life support). Incorporation of simulation particularly in various areas of teaching invasive monitoring and basic life support is provided by a multi-disciplinary group of instructors.
- (iii) Year III—Surgery and Perioperative Medicine Clerkship: Includes all 150 students in the third year class. Overall objectives are to train medical students in anaesthesia and perioperative medicine. This emphasises the content of modern anaesthesiology and perioperative medicine as it affects integration of basic sciences in clinical practice, and the professional competence and knowledge of any physician, regardless of his field of expertise.
- (iv) Year III—Acute In-Patient Medicine Course: Includes all 150 students in the third year class. Overall objectives are to train medical students in the fundamentals of managing the acutely ill patient. This course integrates the principles of respiratory and cardiovascular system functions with actual clinical care.
- (v) Year IV—Electives in Anaesthesiology: Includes approximately 65 fourth year students per year with simulator-based curriculum reinforcing elective clinical rotations in general, cardiac, thoracic and neurologic anaesthesia.
- (vi) Year IV—Critical Care Medicine Course: Includes approximately 65 fourth year students per year with simulator-based curriculum reinforcing elective rotation in CCM.

II) Resident Training Programmes

New educational technology such as simulation holds the promise of helping to provide resident physicians with an intellectually rewarding experience while improving public welfare in a more fiscally efficient learning process.

- (i) Introduction to Anaesthesiology: All new anaesthesiology residents go through an orientation course using simulation-based training, including orientation to the OR environment, safety procedures and patient

care.

- (ii) Difficult Airway Management Training: All anaesthesiology residents and fellows participate yearly in this simulation and Intranet-based training to develop a working knowledge of the American Society of Anesthesiologists guidelines for approach to the difficult airway (Fig. 7).
- (iii) Fiberoptic Bronchoscopy Training: All anaesthesiology residents and fellows participate yearly in this simulation and Intranet-based training to develop basic and advanced fiberoptic bronchoscopy skills.
- (iv) Anaesthesia Crisis Leadership Training: All anaesthesiology residents, fellows and student nurse anaesthetists participate yearly in this simulation and Intranet-based training to develop an understanding of potential medical errors and practise crisis management skills.
- (v) Paediatric Crisis Management: This is a multidisciplinary training programme, offered once per year, that uses simulation to facilitate crisis management training in paediatric trauma care for anaesthesia, surgical and nursing personnel.
- (vi) Management of Critical Events in Obstetrics: This is a multidisciplinary training programme for senior Obstetric and Gynaecology, and Anaesthesiology residents that use simulation to provide experiences in the management of obstetric critical events.

III) Continuing Medical Education Programmes

The public is demanding increased patient safety through governmental regulation and medical legal liability influences. To survive in the competitive health care marketplace, hospitals and managed care institutions are increasingly valuing clinical excellence, with continuing medical education playing an important role. Medical schools are embracing increasing roles and responsibilities in the continuing education of practising physicians. Practising physicians are demanding to learn more at less expense and inconvenience. Advanced educational programmes using simulation, interactive video and Internet-based curricula offer improved alternatives to these needs.

The Future

Based on the success of the training programmes developed within the Department of Anesthesiology and CCM, a number of other departments (Surgery, Medicine, Emergency Medicine) as well as the Schools of Medicine and Nursing, and the hospital administration have expressed interest in expanding the programme through a larger, interdisciplinary facility with coordinated effort. This would be coupled with an interdisciplinary effort in educational research and an expanded continuing medical education effort centred on patient safety training issues.

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