# A Typology of Simulators for Medical Education

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**The growth of simulation technology has brought about rapid innovation in medical education systems. The task of developing and programming these systems is complex. To simplify the process, we developed a typology of medical simulators which allows critical elements to be identified and characterized. The analysis identifies the patient, the procedure, the physician, and the professor as essential elements in any medical education simulator. The level of interactivity of these elements determines the "realism" of the simulator. The development of a fully interactive simulator for ultrasound education will be presented.**
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**KEY WORDS: simulation, medical education, ultrasound**

THE FIELD of medical simulation is growing rapidly. Early simulators focused on patients and allowed the physician to practice on this patient. Other types of educational simulators have focused on diseases, and the response to clinical intervention. As computer technology becomes more powerful, simulators will be developed that present complex, interactive, and life-like experiences that assist the process of medical education and the training of residents. We developed a comprehensive typology of medical simulation interactions that facilitates the development of realistic simulators.

The development of a real-time simulator for teaching ultrasonography techniques and interpretation was accomplished by our group. The proposed typology is based on requirements suggested by users. This typology should assist other groups developing simulators for medical education and training. This article elaborates the model, and the history of simulator development. We also describe the development of the ultrasonography simulator.

## THE ANALYTIC FRAMEWORK

We examined and discarded several methods of classifying types of educational simulators. The most useful typology incorporates the elements of the clinical experience, and describes how these elements interact with the user. For our purposes, we use four elements that can be represented as four "Ps."

The elements of the analysis include:

$P_1$ = the patient and/or the disease process
$P_2$ = the procedure, diagnostic test, or equipment being used
$P_3$ = the physician or paraprofessional
$P_4$ = the professor or expert practitioner
p = passive element
a = active element
i = interactive element

Each element of the simulator can be either passive, active, or interactive. A passive element usually is provided to enhance the setting or "realism" of the simulator. Active elements change during the simulation in a programmed way. These elements enhance the simulation, and can provoke responses from the student. Interactive elements change in response to actions taken by the student or by any other element of the simulation. Any simulated element can be substituted for a real one. In most simulations the ($P_3$) element is "real" and represents the student. There are some situations in which the physician would be simulated, as in an expert system. The typology leads to classifications that have programming implications. These elements allow the development of a pattern language for simulator development that is reproducible and consistent across many models. Currently, the specific data for each simulator element must be encoded in a database or program. We envision a time when multiple simulators may share the same data structures, thereby eliminating expensive data collection and programming costs.

The four "P" types allow the developer to assess how realistic the simulation must be to achieve its educational goals. This process should be useful to other teams developing training simulators, expert-systems, and educational models in the field of medical diagnostic equipment.

The typology focuses our attention specifically on the training environment and uses the traditional environment to create an educational format for the future. We also can estimate the computational requirements for both interactive processes and

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*0897-1889/97/1003-1065$3.00/0*

passive data. We give examples of some common types of simulators later in this article.

## HISTORY OF MEDICAL SIMULATION

The first medical simulators were simple models of human patients. From antiquity, these representations in clay and stone were used to demonstrate clinical features of disease states and their effects on humans. Models have been found from many cultures and continents. These models have been used in some cultures as a "diagnostic" instrument, allowing women to consult male physicians while maintaining social laws of modesty. Models are used today to help students learn the anatomy of the musculoskeletal system and organ systems.

Active models that attempt to reproduce living anatomy or physiology are recent developments. The famous "Harvey" mannikin was developed at the University of Miami and is able to recreate many of the physical findings of the cardiology examination, including palpation, auscultation, and electrocardiography. More recently, interactive models have been developed that respond to actions taken by a student or physician. Until recently, these simulations were two-dimensional computer programs that acted more like a textbook than a patient. Computer simulations have the advantage of allowing a student to make judgments, and also to make errors. The process of iterative learning through assessment, evaluation, decision making, and error correction creates a much stronger learning environment than does passive instruction.

Simulators have been proposed as ideal tools for assessment of students for clinical skills. Programmed patients and simulated clinical situations, including mock disaster drills, have been used extensively for education and evaluation. These "life-like" simulations are expensive and lack reproducibility. A fully interactive and functional "3Pi" simulator ($P_{1i}$, $P_{2i}$, $P_{3i}$) would be the most specific tool available for teaching and measurement of clinical skills. Such a simulator meets the goals of an objective and standardized examination for clinical competence. This system is superior to examinations that use "standard patients" because it permits the quantitative measurement of competence, as well as reproducing the same objective findings.

The "classroom of the future" probably will contain several kinds of simulators in addition to textual and visual learning tools. This educational environment will allow students to enter the clinical years better prepared and with a higher skill level. For the advanced student or postgraduate, we will have a more concise and comprehensive method of retraining or incorporating new clinical procedures into their skill set. This will assist the process of credentialling and competency evaluation, which is a major task for regulatory bodies and medical institutions. The classroom of the future can form the basis of a clinical skills unit for continuing education of medical personnel. Similar to the use of periodic flight training for airline pilots, this unit will assist practitioners throughout their careers. The simulator will be more than a "living" textbook, it will be a part of the practice of medicine. The simulator environment will be a standard platform for curriculum development in institutions of medical education.

## USE OF SIMULATION IN ULTRASONOGRAPHY EDUCATION

Ultrasonography education has followed a typical historical pattern, even though the science and practice of sonography is less than 30 years old. Initially, most teaching programs in ultrasonography followed a traditional apprenticeship model of "see one, do one, teach one." These programs were hospital based, usually associated with innovative schools and institutions. As the field developed, many programs developed an academic base, with early exposure to clinical patients. In the recent past, programs have expanded their academic offerings. This often has led to a decrease in clinical time because of financial and personnel constraints. Using the ultrasonography educational simulator, clinical experience can begin in the early stages of ultrasonography education. This allows academic programs to combine classroom work with early clinical exposure. New programs have been developed to reach out to practitioners in the field. Simulator-based education is suited ideally for incorporation in distance learning programs and continuing medical education.

For an educational simulator to achieve the level of clinical realism necessary for medical learning, it must overcome the limitations of "virtual reality." Many virtual environments today are limited to cartoon-like images. This level of simplification will have to be overcome. The ultrasonography simulator uses real scans to overcome this limitation. Adding freedom of movement along with random access to images, the UltraSim (Medsim USA Inc) allows life-like scanning techniques. Machine controls and operator settings function in real time, allowing the student to make mistakes and to correct them.

Education applications of simulation can be used for preclinical teaching. Simulators also can be used to teach the function of diagnostic instruments. Students can learn "knobology," sonographic anatomy, and eye–hand coordination. Once the students achieve the basic level of skills required, they progress to more advanced educational objectives. In anatomy, the student learns not only basic structure, appearance, and pattern recognition, but also the elusive "range of normal variation" that makes human beings both variable and interesting. The student can proceed to the identification of abnormal pathologic conditions. For advanced education and postgraduate students, simulators allow the learning of specialized techniques, which include invasive examinations, biopsies, catheter placement, and so on.

Students entering clinical rotations have varying levels of knowledge about clinical material. Using the simulator, the professor can assess preclinical competence. The simulator can assist in the measurement of progress during clinical rotations. This technology also lends itself to identifying strengths and weaknesses of the individual and preparing customized remedial programs. The goal of clinical education has been expressed as translating "know-how" into "knows-how." The simulator also can assess the student's ability to "show-how" well these skills have been learned.

## EXAMPLES OF SIMULATOR TYPES

To understand how the typology works, we need to look at some samples. The most common setting for clinical education occurs when a team "makes rounds" on patients in a clinic or hospital. This setting includes the patient, an attending physician, and one or more students. To fully simulate this interaction (ie, to recreate it), we would have to develop ($P_1P_2P_3P_4$) or "Four Pi" simulator. Each of these elements is fully interactive. Such a simulator would constitute an expert system for clinical interactions.

### P (One P) Simulator

A "One P" simulator includes anatomical models such as the "Ressuci" dolls that are used for training in cardiopulmonary resuscitation (CPR). These mannequins can be passive, active, or interactive based on the level of training. Simple mouth-to-mouth breathing and chest compression is taught on a passive simulator ($P_{1p}$). More advanced models may simulate wounds or the result of wounds such as a pneumothorax injury. If the wound simulated bleeding, or air movement, then it would be a ($P_{1a}$) simulator.

### PP (Two P) Simulator

Advanced CPR with cardiac life support is taught on a mannequin combined with a computer program that simulates the electrocardiogram. In this case, both the patient and the diagnostic test are being simulated. This is a ($P_{1a}$ $P_{2a}$) simulator. If the electrocardiographic portion of the simulator has been programmed to respond to the administration of medications or to electrocardioversion, then this would be a ($P_{1a}$ $P_{2I}$) simulator.

### PPP (Three P) Simulator

The UltraSim ultrasonography educational simulator is an example of a "Three P" simulator. The UltraSim includes a mannequin and software that simulate the patient interactively. The machine looks and feels like a standard ultrasonography unit, although it has no ultrasonographic capabilities. In addition, in the expert mode, the UltraSim can simulate the interaction between a student and a professor. Using a three-dimensional positioning program, the unit will guide the student in the skills necessary to obtain accurate ultrasonographic scans. Thus, the UltraSim is a ($P_{1i}$ $P_{2i}$ $P_{4i}$) simulator.

### PPPP (Four P) Expert Systems

Although the need for "Four P" simulators is rare, the analysis shows that such a machine would be an expert system, with all elements of clinical interaction represented. From a theoretical point of view, this machine could be used to study the economic and cost-benefit aspects of the health care process. It also could be used to assess the functioning of other simulators or diagnostic tools. Such a simulator could be considered the "dream machine" of an HMO administrator, "no patients, no doctors."

## SUMMARY

Presentation of the key design elements of a medical educational simulator. Discussion of the types of medical simulators, and their role in medicine.