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Computer and web-enabled simulations for anesthesiology training and credentialing☆

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Abstract Although mannequin patient simulator-based training and credentialing has received extensive favorable attention during the last decade, some critics have argued that the expense and the logistics of participating in such exercises may limit the recommendation of widespread mandatory use of this technology. The ubiquitous availability of personal computers and the World Wide Web makes computer and web-enabled simulation an alternative technology that may address some of these criticisms. In this article, the history, technology, application, and future use of computer and web-enabled simulation for anesthesiology training and credentialing is discussed.

1. Introduction

The introduction of the IBM Personal Computer (PC) in 1981 and Macintosh in 1984 heralded the revolution that made personal computers ubiquitous. When Tim Berners-Lee created the first web pages in 1989, he invented what was to become the World Wide Web, commonly known as the web. Both developments have profoundly affected society, including anesthesiology.

Computer simulations, also known as computer-based trainers (CBT), are simulations that run on a computer (mainframe, minicomputer [1], or personal), although most current computer simulations in anesthesiology run on personal computers. Computer simulations use a display (such as a computer, projection, or touch screen display) to externalize the output of the simulation that explains why they are also called screen-based simulators or, more broadly, display-based simulators. Usually, user input is accomplished via a pointing device such as a mouse and/or the keyboard by entering data in data entry boxes. In the case of a touch screen, the user's finger can be the input "device."

Web-enabled simulations also run on computers and, as such, are a subset of computer simulations. Major differences are that web-enabled simulations are used through web browsers such as Internet Explorer, Firefox, and Safari, and the same simulation program file can be used by Windows and Mac personal computers. In the interest of focusing on the latest widely adopted technology, this article will focus more on web-enabled simulations than on more established computer simulations that already have an extensive body of literature. Computer simulations that are not yet widely used in anesthesiology such as immersive environments and virtual reality with heads-up displays and haptic gloves will not be covered.

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It is important to distinguish between an animation and a simulation and use these terms consistently. An animation consists of displaying a preordained sequence of graphical frames (pictures) in quick succession to create the optical illusion of movement (caused by the phenomenon of persistence of vision), for example, a ventilator bellows cycling up and down. In a pure animation, such as a TV cartoon, there is no user interactivity. The script in an animation is hard-coded and unfolds in the predetermined sequence, irrespective of what the user does or does not do. A display-based simulation may or may not use animation. For example, some simulations use numerical or text outputs and graphical plots or icons and symbols to output the consequences of user interventions and make no use of animation. Other simulations are based on animations whereby the displayed animation is driven by a script and/or mathematical model, and the displayed animation changes in real time in response to user interventions such as the Virtual Anesthesia Machine (VAM) simulation [2]. For example, a user adjustment of the ventilator frequency via a pointing device such as a mouse results in an immediate change in the observed frequency of the bellows animation.

2. History of computer and web-enabled simulations in anesthesiology

Researchers in anesthesiology were quick to capitalize on the advent of the personal computer and the web to create computer and, later web-enabled, simulations for anesthesiology training.

2.1. Computer simulations

Pioneers in computer simulation in anesthesiology include Smith [3], Beneken [1], Schwid [4], Philip [5], Engel [6], and Goldman [7]. Decades of pioneering work of Smith [3] in modeling is embodied in the commercial Body simulation where a detailed model allows administration of intravenous lines, fluids, injected and inhaled drugs and agents, and adjustment of anesthesia machine and ventilator settings. The Body simulation is available for anesthesia, critical care, and first responders. Schwid [4] has developed and successfully commercialized a set of computer simulations covering various topics such as anesthesia, Advanced Cardiac Life Support (ACLS), bioterrorism, critical care, hemodynamics, neonatal, Pediatric Advanced Life Support, and sedation. Philip [5] has continued improving the original Gasman program for teaching, simulating, and experimenting with anesthesia uptake and distribution. Gasman graphically simulates the pharmacokinetics of anesthesia administration by depicting the time course of anesthesia uptake in each body compartment (lungs, heart, brain) and the breathing circuit and vaporizer.

2.2. Web-enabled simulations

The VAM simulation [2] was originally created for internal use for training of University of Florida (Gainesville, Fla) anesthesia residents on the anesthesia machine. The VAM team selected Director (then a Macromedia, now an Adobe product, San Jose, CA) for an authoring platform because it had powerful animation capabilities, could be used to create web-enabled simulations, and importantly, unlike other authoring platforms at the time, did not charge a royalty for distribution of materials created with Director.

The royalty issue was relevant because once director was selected, it meant that the simulations could be ported to the web, and the decision was made to provide equitable access worldwide to this patient safety material by sharing the VAM free of charge via the web [8]. Having to pay a royalty each time the VAM simulation was used would have effectively torpedoed the philanthropic aspect of sharing VAM free of charge outside the University of Florida. Another consideration contributing to the philanthropic decision was the almost nonexistent cost (within an academic center that provides free server facilities), apart from personnel costs, to disseminate a web-enabled simulation via the web compared to the cost of buying, burning, and mailing compact discs containing the simulation. Users need to download the free Adobe Shockwave and Flash players before they can use the VAM simulation or any web-enabled simulation created with Director and Flash, respectively.

The VAM simulation was one of the first, if not the first, comprehensive and widely adopted web-enabled simulation in anesthesiology and generated unanimously positive user feedback in addition to garnering numerous awards. As VAM became widely adopted, users began to request a workbook to go along with the simulation. With crucial funding from the Anesthesia Patient Safety Foundation (APSF), a free workbook was created, consisting of 3 parts: fundamental anesthesia machine design considerations, how to use the VAM simulation, and a series of structured exercises on the 6 main anesthesia machine subsystems (high pressure, low pressure, breathing circuit, manual ventilation, mechanical ventilation, and scavenging) [9]. A Web site was created to support the VAM simulation, and over the years, the emphasis shifted from anesthesia machines to internationalization (localization of the VAM simulation to 6 medical gas color codes and figure legends in 23 languages and translation of the APSF workbook to 11 languages) followed by diversification to other topics in anesthesia such as pharmacokinetics and beyond anesthesia [10]. Collaboration tools such as a bulletin board (on the companion simanest.org Web site) and a wiki were added to provide interaction between and, encourage contribution from, the VAM user community.

The philanthropic component of the VAM Web site continues to this day in the form of a set of free web-enabled simulations sustained by the generosity of industry, foundations such as APSF and the Thomas H. Maren

Foundation and professional societies such as the World Federation of Societies of Anaesthesiologists. Unfortunately, the pure philanthropic funding model of the VAM Web site proved to be a financial failure and through insufficient sponsorship and donations never achieved a non-loss balance in the 5 years (1999-2004) it was tried in earnest [8]. A mixed philanthropic model is now in place where simulations in an instructor/academic area require a paid annual membership.

3. Computer simulation formats

Numerical "simulations" output their results as numbers or plots and some are actually implemented through spreadsheets such as Excel. Arguably, numerical simulations are more properly called mathematical models because they do not present the output in a format that attempts to enhance the suspension of disbelief that simulations strive for. Computer simulations can have different formats. The graphical representation can be photorealistic, a 2-dimensional drawing, a 3-dimensional rendering, transparent reality (whereby abstract or internal structure and processes are made concrete and visible) [11], or a mix of these representations. Animations if they are used can be iconic or photorealistic [12,13]. The layout can be a single screen with pull-down menus or navigation tools that lead to other screens or subscreens.

For usability reasons, some designers may wish to shun pull-down menus or navigation tools and place all of the simulation on one screen. Given that any display has a finite size, the simulation designer is faced with a fundamental trade-off between scope and detail when choosing to use only one screen. If an environment of extensive scope such as an operating room scene is displayed, the resolution may be so low that it would be difficult to read small but important details such as the oxygen and nitrous oxide flowmeter settings. If, on the other hand, the scale is enlarged so that the flowmeter settings can be read, the scope of the simulation may be decreased so that important components of the simulation such as the patient may have to be left out, for a given display size. An alternative is to maximize use of the available pixels on a display by creating a patchwork of small images from an operating room scene (with images in different formats, scales, and perspectives and not necessarily in the proper orientation to each other).

3.1. Panoramic simulations

Another recently available alternative to the fundamental trade-off between scope and detail is to use a panoramic simulation with a dynamic background that displays at any given time only a portion of a detailed (large scale) panoramic picture taken from, for example, the typical vantage point of an anesthesia provider in an operating room. Users can intuitively click and drag in the desired direction on the panoramic background to bring different parts of the simulation into view. The background in the panorama is dynamic. For example, when the ventilator is turned on, the bellows is observed to move up and down in the background, and the capnogram in the gas analyzer changes in response to user interventions such as applying or removing a face mask and intubating the patient. An example of a panoramic simulation is the Simulated Anesthesia Application that addresses neuromuscular blockade and its monitoring that was first launched at the American Society of Anesthesiologists (ASA) 2007 annual meeting [13].

4. Are computer simulations effective?

Computer simulations have been shown to be effective tools in various studies. For example, Schwid et al [14] showed that residents who trained in managing anesthetic problems with inexpensive screen-based anesthesia simulators followed by debriefing handled the emergencies in a mannequin patient simulator better than residents who were asked to study a handout covering the same problems. Web-enabled simulations have achieved face validation based on the adoption of the VAM simulation for anesthesia machine training in numerous anesthesia programs in the United States and overseas.

4.1. Effectiveness of transparent reality simulation

The transparent reality simulation format itself has been proven to be effective in teaching anesthesia machine function and dynamics [15]. A study was undertaken to confirm the anecdotal data, enthusiastic user feedback, and widespread adoption that indicated that the transparent reality simulation format itself in the VAM simulation is an effective learning tool. For the purpose of the study, an opaque photorealistic simulation of an Ohmeda Modulus II (Madison, WI) anesthesia machine was created with the identical simulation engine to that used in the transparent reality VAM where gas molecules are made visible and color-coded and can be observed to move through simplified see-through piping of a traditional bellows anesthesia machine. In the opaque simulation on the other hand, only the output visible to the unaided naked eye was simulated such as bellows, flowmeter bobbin, and pressure gauge needle movements. The only difference between the 2 simulations was that one used transparent reality and the other did not. After a 24-hour time interval to avoid testing superficial short-term learning, the group of study participants that trained for the same amount of time on the transparent reality simulation explained component function more completely and remembered and inferred cause-effect dynamics and relations among components more accurately than the group that trained with the opaque, photorealistic simulation.

5. Computer simulations in debriefing

Computer simulations can also complement sessions with physical simulation tools such as mannequin patient simulators. At the University of Florida, the Gasman and VAM simulations are used as debriefing tools after running residents through scenarios on an actual anesthesia machine connected to the Human Patient Simulator. In the case of anesthesia machine fault scenarios such as a hypoxic oxygen pipeline, the VAM simulation seems to help the residents visualize what they just experienced in the physical simulation and form a mental model of the anesthesia machine.

6. The APSF anesthesia machine preuse check simulation

A free transparent reality simulation of the 1993 FDA anesthesia machine preuse check simulation has been developed with funding from an APSF research grant (Fig. 1) [16]. This simulation includes some distinctive features such as the individual user performance can be monitored and recorded over the web; the simulation made extensive use of simulation learning objects (SLOs) in its architecture and included an intelligent tutor.

Learning objects (LOs) have been defined in many different and sometimes conflicting ways. For the purpose of this article, the definition focuses on 3 attributes of LOs. A learning object (*a*) is reusable; (*b*) contains content, practice, and assessment components; and (*c*) is meta-tagged so that it can be intelligently identified by search algorithms to promote its reuse. The content, practice, and assessment components were implemented into stand-alone simulations, individually invoked via unique and descriptive URLs.

The 1993 FDA checklist contains 53 discrete numbered steps (US Food and Drug Administration, 1993). The simulation modifies the often-used dictum "see one, do one, teach one" to "see one, do one, test oneself" to map onto the learning object division of content, practice, and assessment. The resulting simulation consists of 44 content (see one), 45 practice (do one), and 25 assessment (test oneself) SLOs.

6.1. Content SLOs

In the content SLOs (see one), users are taught how to perform a given step while also learning to use the simulation. Clicking on a "show me" button causes a simulated cursor to move and interact in a preordained pattern over the plumbing layout and the icons that simulate the anesthesia machine. The see one SLOs help orient new users to the layout of the simulation, what each icon represents, how to manipulate or adjust the interactive icons, and how to interpret the changes in the simulation. As such, learners are recommended to first use the see one simulations so that they are familiar with the simulation when they engage in the practice and assessment SLOs. Clicking on a "rationale" button opens a multilingual (currently English, Chinese, Japanese, and Korean) text box that explains why each test is performed.

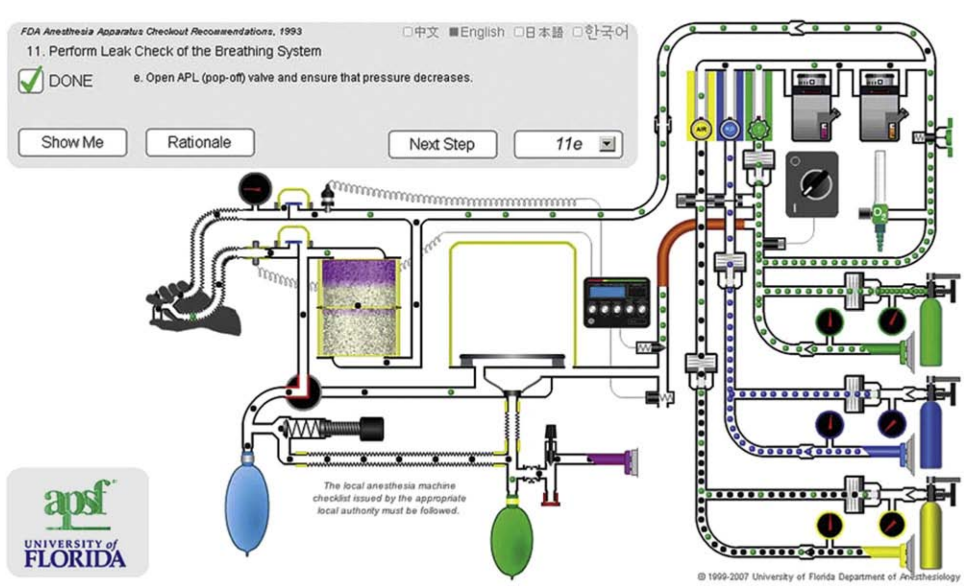

Fig. 1 A representative screen from the APSF simulation of the 1993 FDA anesthesia machine pre-use check.

6.2. Practice SLOs

In the practice SLOs, learners actually perform the steps in the FDA 93 Checklist. All the interactive icons in the simulation are activated instead of just the correct ones that need to be adjusted or manipulated for a given step, providing the opportunity to err, such as in real life. To provide more timely and seamless feedback and guidance to learners requiring more handholding, an intelligent tutor was added to provide tiered levels of assistance and guidance to practice SLOs. For example, if a user opens the nitrous oxide cylinder instead of the oxygen cylinder, the instruction is repeated on the first mistake. If the user then proceeds to make a second mistake for that given step, the incorrect action is described in addition to repeating the instruction. For example, a message will appear in a textbox that states "you opened the air cylinder." On subsequent errors for a given step, higher levels of help or hints are provided.

6.3. Assessment SLOs

Proper execution of the anesthesia machine preuse check requires performing the prescribed procedure in the right sequence as well as correct interpretation of the resulting symptoms displayed by the anesthesia machine. In the assessment SLOs, learners have to perform a given test properly and judge whether a randomly configured machine passes or fails a given test. An intact machine is also one of the random machine states to keep users guessing and reflect the reality that often there is nothing wrong with the machine. After learners indicate whether the test passed or failed, instantaneous feedback is provided about (*a*) whether the right diagnosis was made and (*b*) whether the procedure was correctly performed. As in an actual anesthesia machine, improper procedure may lead to an incorrect diagnosis. The assessment SLOs provide additional challenge and realism to learners because the correct answer is not provided (as is the case with the traditional multiple choice question) but instead has to be correctly executed and interpreted in the simulation.

Users are required to register at the first visit and log in upon each subsequent visit. Registration is free and confidential. The practice and assessment SLOs are designed to allow tracking and recording in a database of the areas where an individual learner spends more time and/or requires more attempts or nudges to arrive at the right answer. To provide structured learning and control of sequencing, the practice SLOs must be completed before the assessment SLOs can be accessed. The required access control is implemented via a database that keeps track of each individual user's performance, learning history, and progress so that a user can stop at any time and later resume where a previous session ended. The APSF simulation of the 93 FDA preuse check is an example of a web-enabled simulation where credentialing activities can be performed by monitoring individual user performance over the web.

7. Concluding remarks

Computer and web-enabled simulations are well established in anesthesiology training and have been proven to be effective learning tools. The technological capability for credentialing via web-enabled simulations is already in place with demonstration projects such as the FDA 93 anesthesia machine preuse check simulation. The APSF Board of Director's workshop at the 2007 ASA meeting officially broached the topic of mandatory training in the use of complex equipment. Anesthesia providers in attendance at the workshop unanimously agreed that training should be mandated. If the anesthesia community at large shares this viewpoint, credentialing via computer and web-enabled simulations will become more widespread in the future. The groundwork is set that could make this a reality. In 2008, the written examination (part 1) of the American Board of Anesthesiology becomes computer-based. Dr Glenn Gravlee, chairman of the ASA/American Board of Anesthesiology Joint Council, at the 2007 Society of Academic Anesthesiology Chairs/Association of Anesthesiology Program Directors meeting spoke of the computerized conversion, "eventual goal—more creative use of graphics, videos, different question types, and scenarios." These events may herald the use of computer-based simulation in the certification process of anesthesiologists.

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