Game-Based Virtual Patients – Educational Opportunities and Design Challenges

Marjorie Zielke, Ph.D.	Judy LeFlore, Ph.D.	Frank Dufour, Ph.D.	Gary Hardee
University of Texas at Dallas	University of Texas at Arlington	University of Texas at Dallas	University of Texas at Dallas
Richardson, Texas	Arlington, Texas	Richardson, Texas	Richardson, Texas
margez@utdallas.edu	jlefore@uta.edu	frank.dufour@utdallas.edu	gmh091000@utdallas.edu

Contributing authors: Meghan Huber (mehuber@student.utdallas.edu), Pat Thomas (patthomasnnp@tx.rr.com), Ken Kanipe (Kjk063000@utdallas.edu); Ed Whestone (ed.whetstone@student.utdallas.edu), Adam Buxkamper (amb047000@utdallas.edu).

University of Texas at Dallas and University of Texas at Arlington

ABSTRACT

High-fidelity virtual patients afford unlimited opportunity for practice in a virtual clinical setting and present multiple design challenges for developers of game-based simulations. Virtual patients allow students the opportunity to experience varied medical conditions as well as interact with patients with wide-ranging socio-economic and cultural factors. Practice with virtual patients also can improve both the accuracy and speed of cognitive, behavioral and psychomotor tasks. Virtual patients can be designed and adapted to simulate high-risk, low-incidence variations of medical conditions as well as altered to reflect regional, social, economic, behavioral and cultural factors. As opposed to simulations that use physical clinical settings and high-fidelity simulators, virtual-patient simulations provide ubiquitous, asynchronous learning and practice opportunities. Game-based simulations can provide instantaneous assessment and debriefing, both individually and in group settings. For these reasons, there is a growing interest in virtual patients for a broad range of applications, including academic, professional and military.

While the technology is promising, the design challenges for virtual patients simulations, however, are numerous and evolving. For example, the visual and auditory fidelity of patient simulations demands precision derived from a broad range of available medical data. This paper explores the complexities of designing virtual patients that incorporate a multitude of patient factors and uses as a reference a current virtual patient simulation developed for the University of Texas at Arlington College of Nursing and a metropolitan free-standing hospital.

ABOUT THE AUTHORS

Marjorie A. Zielke, Ph.D., is an assistant professor of Arts and Technology at the University of Texas at Dallas and is the principal investigator on First Person Cultural Trainer. Dr. Zielke has served as the project manager on a series of culturally related military-funded simulation projects over the last several years. Her areas of research are cyberpsychology and hyper-realistic simulations and she works in the intelligence, health and marketing sectors. Dr. Zielke received her Ph.D. from the University of Texas at Dallas, and also has an MBA and a masters in international business.

Judy LeFlore, Ph.D., is an associate professor of Nursing at UT Arlington, College of Nursing (UTACON). She is the Director of UTACON's Pediatric, Acute Care Pediatric and Neonatal Nurse Practitioner Programs and is a Nurse Practitioner at Children's Medical Center of Dallas, Texas. She also serves on the Serious Games Initiative through the University of Texas System.

Frank Dufour, Ph.D., teaches sound design for digital arts. He created one of the first all-digital recording studios in France specialized in digital sound restoration for audio publications and sound design for animation movies and video productions. He is involved in the "First Person Cultural Trainer" project developed for the U.S. Army Training and Doctrine Command and Joint Forces Command.

Gary Hardee is a Research Project Manager and graduate student at the University of Texas at Dallas. He has many years of professional media experience and is involved with three UT Dallas projects involving virtual patient and cultural training simulations.

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margez@utdallas.edu

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Arlington, Texas
jlefore@uta.edu

Frank Dufour, Ph.D.
University of Texas at Dallas
Richardson, Texas
frank.dufour@utdallas.edu

Gary Hardee
University of Texas at Dallas
Richardson, Texas
gmh091000@utdallas.edu

INTRODUCTION

Medical simulation is a growing field for a variety of reasons – including training opportunities for students and medical professionals alike, cost, portability, and legal/ethical considerations. Simulations based on high-fidelity mannequins or actors representing standardized patients are common. This paper focuses on game-based virtual patients and is based on a series of medical simulation research projects conducted by the Institute for Interactive Arts and Engineering at the University of Texas at Dallas (UT Dallas) and The College of Nursing at the University of Texas at Arlington (UT Arlington). Most of the work represented here is based on a project called Virtual Pediatric Nursing Trainer: Respiratory Disease (VPNT: RD). The purpose of VPNT: RD is to train senior level nursing students on the identification, treatment and process of caring for virtual infant patients with respiratory disease or conditions. Figure 1 below illustrates the virtual infant patients presented in VPNT: RD and types of conditions the simulations represent.

Game-based virtual patients is a term we use to describe our work and means virtual patients in the context of a computer game. We believe creating a virtual patient within a computer game environment addresses some of the short-comings currently found in other types of synthetic patients. Here, we discuss the advantages of game-based virtual patients over other forms of synthetic patients and present key trends and seminal papers in the literature. We propose ten development criteria for clinical simulation. We also present a proposed framework for creating game-based virtual patients and medical simulations. Finally, we critique our work based on these development criteria and discuss design challenges in creating virtual patients as well as potential areas for future research.

SIMULATION EDUCATIONAL OPPORTUNITIES

With the aging of the baby-boomer population, the increasing need for more healthcare professionals has been well documented. One of the major factors contributing to the shortage of healthcare providers is the shortage of faculty. Medical simulations and synthetic patients can help extend the reach of current faculty to train new healthcare providers and help current practitioners improve their measurable performance quicker. The use of synthetic patients with game-based simulations creates greater outreach opportunities through improved distance education. Online training using virtual patients can provide ubiquitous and asynchronous educational opportunities for more students in many locations. This has multiple benefits.

Virtual patients can be developed for varied facets of medical and nursing education without requiring students

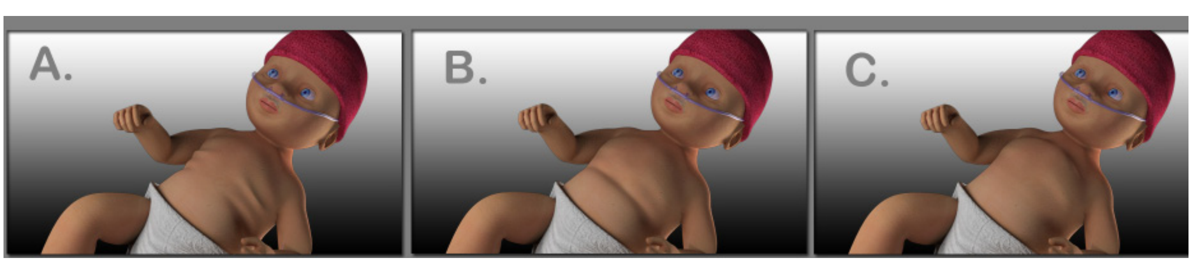

Figure 1. In VPNT: RD, students must identify retraction locations in a baby's chest. Virtual infant patient A illustrates an intercostal retraction. B demonstrates a subcostal retraction, and C a supraclavicle retraction.

and faculty to be in the same location. Synthetic patients facilitate faster dissemination of new information and skills, team training, and the creation of multiple high-risk scenarios that students might not encounter otherwise throughout the course of their studies. The controlled and composable nature of synthetic patients means students can practice applying knowledge learned through coursework with patients of all ages, ethnicities and psychological/behavioral makeups. The use of synthetic patients also can reduce legal concerns about confidentiality of patient records and ethical considerations of human and animal subjects research.

Web-based virtual patient simulations, in particular, allow students and trainees to practice at their own pace and on their own schedules. The deliberate practice of specific skills has been identified in studies by Ericsson as important to achieving high performance faster and maintaining those skills longer. Ericsson studied the relationship between deliberate practice and the acquisition of expertise, particularly as it relates to medical training. He concludes that repeated practice of very specific tasks and immediate, informative feedback help improve the accuracy and speed of performance on cognitive, perceptual, and motor tasks. We believe that simulations are well-suited for deliberate practice.

TECHNOLOGY LANDSCAPE OF CLINICAL SIMULATION

At this time, most clinical simulations can be grouped into three categories – high-fidelity simulators, standardized patients and virtual patients. While our paper focuses on virtual patients, it is useful to set the context of the technology. The pros and cons of each of the simulation types are discussed below. Figure 2 below represents the three types of synthetic patients commonly found in clinical simulation.

High-Fidelity Simulators

High-fidelity simulators are computerized mannequins that are used in medical and nursing training facilities.

Pros: These simulators are appealing because they allow students to experience high-risk, low-volume patient problems in an accurate clinical setting in real space. They also offer the tactile and haptic feedback necessary for training certain medical interventions, such as surgery and IV insertion.

Cons: High-fidelity simulators have several major drawbacks. The first one is cost. The high cost of these types of trainers not only limits the number of simulated patients available for use in multi-patient scenarios, but also the opportunity to have a collection of simulated patients customized for each desired scenario. Another drawback is the inability for trainees to independently practice with these high-fidelity simulators at their own discretion. A facilitator with knowledge of the product and its software is required to run the clinical simulations with these types of simulated patients.

Standardized Patients

Standardized patient is the umbrella term for both an actor trained to simulate a patient's illness in a standardized way and an actual patient trained to present his or her own illness in a standardized way.

Pros: For both types of standardized patients, there is higher realism in the interpersonal and emotional responses between the standardized patient and the trainee. Standardized patients offer the trainee an opportunity to interact with the totality of the patient beyond just the physical symptoms as compared with

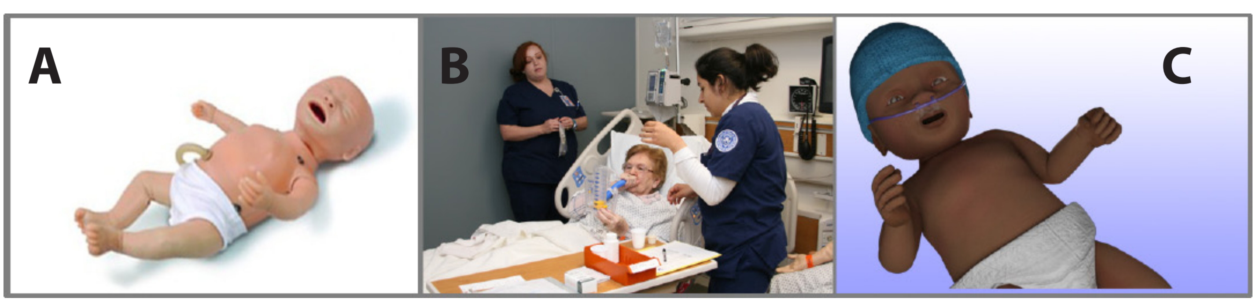

Figure 2. Virtual patient A is an example of a high-fidelity simulator that offers high-level haptic practice but is expensive and usually not available for independent student practice. Simulated patient B is a standardized patient who is an actor or person with an actual condition who is hired to participate in a simulation. Virtual infant patient C is a simulation whose outcome is driven by a computer game.

the high-fidelity simulators. The standardized patient not only has physical symptoms, but a personality and cognitive function that can result in emotional symptoms or responses based upon interaction with the trainee. They are good for communication and interpersonal relationship training. Standardized patient actors are good for evaluation since they are trained to tell the same story repeatedly.

Cons: An actual patient may not be as consistent in story telling, and therefore, every student cannot necessarily be evaluated in the same way in a standardized scenario. Additionally, there is a high cost for liability. Also, standardized patient actors' signs do not match their symptoms. They are also limited by physical symptoms that cannot always be simulated accurately. Another disadvantage is the time and cost of hiring, training, and utilizing standardized patients. As with high fidelity simulators, the inability for trainees to independently practice with standardized patients is a major drawback.

Virtual Patients

Virtual patients are computer-simulated patients used in clinical simulation. As mentioned in our introduction, we use game-based virtual patients to mean synthetic patients in the context of a computer game.

Pros: Like high-fidelity simulators and standardized patients, virtual patients simulate high-risk, low-volume medical conditions. A notable advantage of virtual patients over other simulation types is the trainee's ability to practice independently in a virtual medical setting. This reduces costs because no facility, actors or similar resources are needed. Virtual patient simulations provide training to a greater audience offering a larger number of possible simulated patients. These simulations allow direct comparison between trainees because scenarios can be programmed identically. Also, every variable of a virtual patient can be tracked and recorded, as well as every interaction the trainee has with the virtual patient. Real-time feedback can be provided both during the simulation and at the end. Game-based virtual patients provide students with a more complex, interdependent and hopefully realistic environment utilizing psychological, behavioral and social patient models.

Cons: While virtual patients offer clear advantages, there are also numerous design challenges that currently prevent the full potential of virtual patients from being realized. These include fidelity of virtual patients and their symptoms and the challenge of creating haptic or tactile practice situations virtually.

CLINICAL SIMULATION DEVELOPMENTCRITERIA

Because each type of simulation, as explained above, has advantages and disadvantages, it is useful to consider what combination of components would create the optimal clinical simulation including synthetic patientst. In this section, we offer ten criteria that we believe should be considered when developing clinical simulations with synthetic patients. Later, we will use these criteria to analyze VPNT: RD. The ten development criteria are:

1. **Composability:** One of the biggest advantages of virtual simulations is that synthetic patients can be composed based on either subject matter experts or collective patient data to represent myriad medical conditions. Ethnographic and demographic variations can be included as well to introduce cultural, gender and age differences.

2. **Visual/Auditory Fidelity:** Clinical simulations should achieve a sufficiently high quality of representation to enhance immersion between the trainee and the synthetic patient. The ability to represent haptic or tactile medical practices is also an aspect of fidelity.

3. **Psychological, Behavioral and Social Modeling:** Healthcare providers do not treat medical conditions in isolation from the psychological, behavioral, and social environmental factors that affect patient health. Cognitive dimensions need to be included in synthetic patients.

4. **Conversation System:** To build realism and nuance into psychological, behavioral, and social modeling, the user must have the ability to speak to synthetic patients through natural verbal communication.

5. **Heathcare Processes:** A goal of patient simulations is to allow students to transfer coursework knowledge into the deliberate practice of clinical skills. The development challenge is to re-create processes that teach the skills that help novice users develop expertise quicker and translate into improved performance in the real-world clinical setting.

6. **Feedback:** Verbal and non-verbal communication from the synthetic patient to the user is represented through the design of medical symptoms, response to treatment, and the conversation system. Another advantage of virtual patients is that feedback to the user's actions can be immediate, which

condenses training time. Immediate, informative feedback and knowledge of performance results are conditions of Ericsson's deliberate practice construct. Also, users benefit from feedback during the simulation between the virtual patient, the environment and the system surrounding the patient.

7. **Environment:** The simulated environment serves as the functional space for gameplay but also reinforces realism through exquisite attention to detail of issues such as lighting, surface properties, signage, and specific equipment used in the simulation. The environment also can serve teach trainees to navigate the real-world environment. The healthcare staff providers who surround the synthetic patient should also be included along with the equipment that would be found in a real medical setting.

8. **Nonlinear Training:** Life does not unfold in linear fashion, nor should nuanced game-based simulations. Nonlinear discoveries and training variations are components of immersive simulations. Immersiveness enhances motivation to repeat procedures, another condition of deliberate practice.

9. **Assessment:** Assessment is a major parameter of virtual patient simulations that incorporates the learning objectives and the tracking of user performances during the simulation as well as a complete training review. The capability for in-game assessment of actions is a condition for deliberate practice to improve and maintain high performance.

10. **Data Collection:** The ease with which data can be used for student evaluation and to inform actions in the simulation are critical to well designed simulations. The ability to recursively adapt the simulation based on data collected from the user's actions is also important.

Finally, all of the development criteria should interact to holistically create a realistic training canvas.

RESEARCH IN SYNTHETIC PATIENTS

We focus our literature highlights on the use of virtual patients for medical training. Using virtual characters to practice interaction in a medical setting is a nascent but growing area of research in training. One of the most well-known projects is Virtual Justina, from the Institute of Creative Technology at the University of Southern California. Justina, a virtual patient with post-traumatic stress disorder, allows medical students to practice interviewing and diagnostic skills on a virtual patient. As the researchers point out, the use of virtual characters increases the scenarios that can be explored through training and offers a substantial flexibility over the actors who are used to represent standardized patients. (Kenny, 2008) Further, Kassap and colleagues, in discussing their methodology for creating emotional virtual characters, mention five key variables for modeling social relationships.

In some studies, researchers have shown that trainees are aware that virtual patients are not real and therefore respond with varying degrees of empathy. For example, when using the life-sized virtual patient with abdominal pain, DIANA described by Raij et al. (2007), Deladisma et al. (2007) found that when students interacted with the standardized patients, they exhibited more nonverbal communication behaviors such as head nodding and body leaning than when interacting with virtual patients.

Overall the literature available on virtual patients reflects that only high fidelity and realistic virtual patients are effective in the use of training simulations, and they offer a great degree of flexibility in the number of scenarios a virtual patient can represent compared to other types of synthetic patients. Conversely, the process of designing and developing effective high fidelity virtual patients appears missing in the research.

Our research reflects the design strategies of these recent studies. For example, in our paper "Serious Games for Immersive Cultural Training: Creating a Living World" we discuss our design construct which offers a nonlinear, unscripted process for experiencing and safely learning the cognitive complexity and nuance of culture through emergent high-fidelity simulation. We discuss using visual, auditory, behavioral, and cultural models for immersive cultural training using the living-world construct We have also developed specific tools to facilitate our development of virtual relationships. For example, we have created a process that facilitates unscripted game-based simulations. The tool ties together written and spoken dialogue, virtual character emotional states, sound elements and culturally-accurate motion-captured animations to present a high-fidelity virtual environment for the player to negotiate (Zielke, Evans, Dufour 2009).

We use these design philosophies to create the game-based virtual patient research presented here. While there are many advantages for using virtual patients in clinical training simulations over high fidelity simulators and standardized patients, less than a quarter of medical schools utilize virtual patients in their training curriculum. This is due not only to the lack of understanding of the potential roles that virtual patients can have in medical simulation but also lack of sufficient knowledge and resources needed to develop realistic, high-fidelity virtual patients in an academic community. The lack of resources results from the fact that design and development processes for the effective creation and ultimate use of virtual patients are not well documented in published literature (Cook 2009). However, what is published in the literature available on virtual patients highlights their potential as well as what features still need further development.

VIRTUAL PEDIATRIC NURSING TRAINER: RESPIRATORY DISEASE OVERVIEW

The Institute of Interactive Arts and Engineering at UT Dallas and the College of Nursing at UT Arlington collaborated to create Virtual Pediatric Nursing Trainer: Respiratory Disease (VPNT: RD), a 3D game-based simulation. VPNT: RD affords senior-level college nursing students the opportunity for deliberate practice. In the simulation, students apply knowledge acquired through coursework to the assessment and treatment of four virtual patients. Once students complete the simulation, they receive detailed assessments of their performances, including a list of actions taken, which ones were correct and which were incorrect, and the time at which the action was taken. Later, all senior-level UT Arlington College of Nursing students must undergo an Objective Structured Clinical Examination (OSCE) procedure in which they are tested on a variety of clinical skills, including a clinical examination of a high-fidelity simulator patient. Students who participated in the VPNT: RD simulation were measured during the OSCEs against the performance of students who only received traditional lectures to determine if the game-based simulation helped improve assessment skills. Results of this experiment are currently under analysis. VPNT: RD requires students to practice a six-step assessment procedure. At the start of the game-based simulation, the trainee is introduced to the charge nurse nonplayer character (NPC). This virtual human character is used throughout the simulation to provide instruction on using the assessment procedure and assistance in treating the infant patients. To familiarize the student with the interface, subject matter and skills needed in the simulation, the student participates in three initial breakout or mini games before entering the full simulation. Figure 3 illustrates each of the three mini games.

In the first round of the full training simulation, the student is responsible for treating two virtual infant patients, one with asthma and another with bronchiolitis. During this round, the trainee receives instruction-based teaching from the charge nurse. Not only does the charge nurse instruct the user to perform each action, she also explains the symptoms and the reasoning behind performing each action.

In the second round of the training simulation, the student is responsible for independently treating two patients, one with pneumonia and another with cystic fibrosis. At this point, the student is expected to treat the virtual infant patients according to their symptoms without instruction from the charge nurse.

Figure 4 on the next page illustrates one of the full simulation environments complete with virtual infant patient, left-hand navigation that offers instruments and actions the student can take, and the success indicator in the upper right hand corner of the screen.

Figure 3. In mini game A, the student must examine a virtual infant patient's chest and identify the location of retractions. In mini game B, the student must categorize a virtual infant's cough by type and determine possible causal respiratory conditions. Mini game C presents a variety of respiratory conditions and students must determine if the causes are likely viral, bacterial, fungal, aspiration, or a combination.

Figure 4. As illustrated in the upper right hand corner of Figure 4, the trainee's ability to perform the correct actions is reflected in a success indicator which turns from green to yellow to blue depending on the student's accuracy in the medical treatment and procedures.

If the student performs poorly the charge nurse will intervene and explain which actions to take. For example, at one point during the second round, a virtual infant begins choking and turns blue. Students are expected to know how to alleviate the choking. Once students successfully finish assessment and treatment of the virtual infants, they are sent to meet another nurse who will be taking over the shift. This handoff asks multiple choice questions, about all four virtual infant patients. At the conclusion, students receive detailed feedback on each action they took in the simulation.

A MODEL FOR GAME-BASED VIRTUAL INFANT PATIENTS

This paper discusses three types of patients used in medical simulations – high-fidelity simulators, standardized patients, and virtual simulations with an emphasis on game-based platforms. We believe that virtual game-based medical simulations and virtual patients provide more flexibility, availability, training options, consistency, feedback mechanisms and opportunities for individual student practice than the other two commonly used simulation types. This section explores some of the considerations for developing simulations for game-based virtual representation without full body mannequins, live standardized patients, or actual physical hospital settings. Later in the paper, we use the 10 desired development criteria discussed earlier to analyze the educational opportunities and design challenges of our approach to medical simulation through game-based virtual patients.

In our work, the game-based virtual infant patient model evolves from the analysis to the synthesis stage. Our model must also incorporate temporal and spatial considerations. Further, our game-based virtual infant patient is a dynamic entity driven by a network of four interacting submodels, gameplay and recursive student assessment or feedback. Figure 5 below illustrates the macro game-based virtual infant patient model. Each of the components in the model is discussed below.

Stages of the Virtual Infant Patient throughout Gameplay: Analysis and Synthesis

As outlined above, the game-based virtual infant patient entity is the result of two phases: analysis and synthesis. The analysis phase sets design parameters for the game-based simulation. The design decisions are contingent on three parameters: learning objectives, strategy for representation and type/level of interaction between the student/player and the simulation. The synthesis phase dynamically displays selected components of the visual infant patient from preliminary settings throughout the entire simulation and responds to the student's gameplay. In this way we represent the same type of interaction found with high-fidelity simulators and standardized patients, but in a replicable, highly available medium.

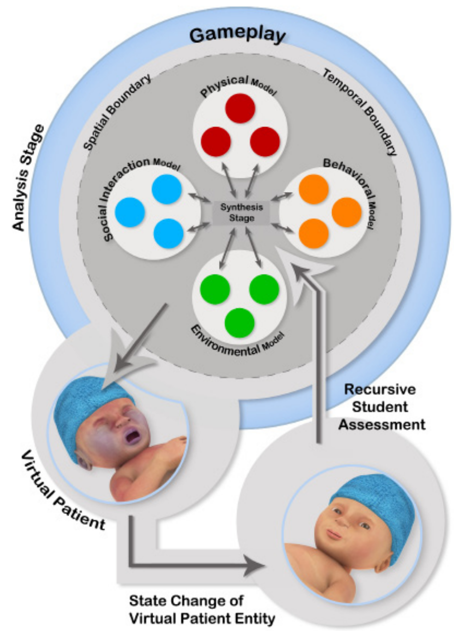

Figure 5. The game-based simulation occurs within two distinct game-based simulation stages – analysis and synthesis. The model for game-based virtual infant patients includes temporal and spatial boundaries; gameplay; the four submodels of physical, behavioral, environmental and social interaction; and recursive student assessment.

During the analysis phase, spatial and temporal boundaries are assigned to interactions between the virtual infant patient and its environment. The degree of complexity and realism the game-based virtual infant simulation willdisplay within these spatial and temporal boundaries is defined, to include movements driven by animations and sounds the infant will make. The degree of complexity and realism are implemented based upon the scope and goals of the simulation. In this particular project, the spatial-temporal limits were fixed to a patient's room in a hospital in which a charge nurse and the player observe, monitor, and provide treatment to the patient, representing activity that would occur within a few hours. Students also must make real-time decisions for proper care within a professionally prescribed timeframe. Representing the time factor is important for both the changes of states in the patient and the rate of these changes.

While the analysis phase sets the initial design, the synthesis phase is the actualization of the design through gameplay. The gameplay dynamics continuously drive multiple actualizations of the virtual patient. Our project uses four infants with different conditions to realistically represent that a nurse deals with several different medical situations simultaneously within different contexts. In VPNT: RD, exchanges back and forth between the player and the game and the state changes of the four patients are displayed in our 3D audio/visual environment as follows:

- Vital indicators of the virtual infant patient such as heart rate, oxygen saturation, respiratory rate, temperature, and blood pressure are displayed through the interface monitors.
- Patient movements, states, and attitudes are displayed through synchronized audiovisual animations and sounds.
- Administration of treatments such as an IV are player-driven decisions symbolically represented by animations.

Our game-based virtual infant patient model is an open structure designed to replicate the dynamics of an actual baby. Transformations of the game-based virtual infant patient can be either internally generated by the baby, or externally generated by an agent independent of the virtual child model. Decisions made by the student during gameplay are an example of such an agent.

Game-based virtual infant patients transform throughout the training session based on these external and internal events. An example of how a virtual infant patient's settings from the analysis phase change in the synthesis phase according to gameplay is shown in Figure 6.

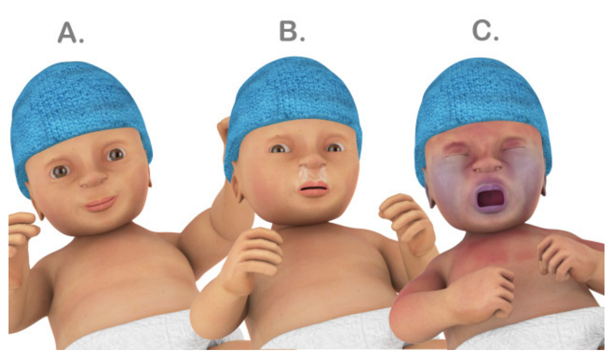

Figure 6. The baby changes states according to initial internal settings and external gameplay. The baby in State A is well, but proceeds to show external signs of respiratory distress in B. Not treated properly through gameplay, the baby proceeds to a distressed state and exhibits cyanosis (a blue color) in State C.

Gameplay

Gameplay is the gateway for interaction between the trainee and the virtual game-based patient. The creation of symptoms in the virtual patient, which is accomplished by changing elements in the other four models, are driven by gameplay design. When the trainee performs an intervention to treat the symptoms of the virtual patient, the gameplay determines how the intervention affects the virtual patient. Ultimately trainees win by successfully administering the required medications, performing the prescribed process and handing their patients over to the handoff nurse at the end of their shift.

The Core Sub-Models

As illustrated in the core model diagram, the four central interacting submodels include the physical, behavioral, environmental, and social interaction models. Each of these is discussed below.

The Physical Model: The physical model is what the student will perceive as the virtual patient entity within the game-based simulation. In our model, the actual virtual infant patient is comprised of 3D models, animations, sound, and a monitor that gives insight into the virtual infant patient's condition. As Figure 7 illustrates, the 3D models of the virtual infant patients were built to represent the anatomy of an infant and varied in physical appearance based on each patient's age, gender, and ethnicity.

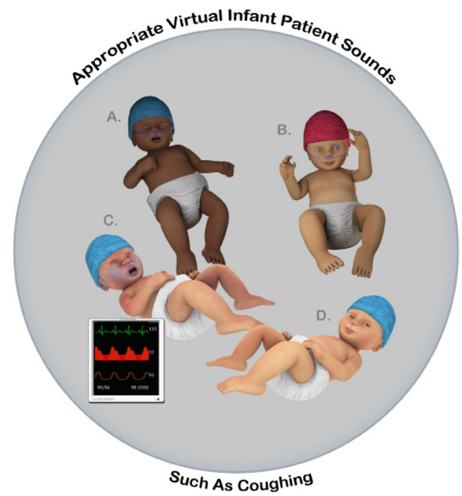

Figure 7. The virtual infant patients are A. Donovan, 18 month old African-American male with asthma; B. Javier, 2.5-month old Hispanic male with bronchiolitis; C. Jessica, 3-month old Caucasian female with pneumonia; and D. Emily, 8-month old Caucasian female with cystic fibrosis. The virtual babies are represented through these models, sound and the monitor in the lower left-hand corner.

The monitor, represented in the lower left corner of Figure 7, is a 2D user-interface element designed to output the vital signs throughout the training simulation rounds. The vital signs displayed are heart rate, respiratory rate, oxygen saturation, blood pressure, and body temperature. Together, the 3D model and the monitor visually represent the virtual infant patients and their signs and symptoms of respiratory distress to the trainee throughout the game-based simulation. Audio is also an important part of the representation. For example, in the second breakout game where the trainee must identify the cough of the virtual infant patient, a series of five cough sounds are played and the trainee must decide whether the cough is barky, dry, productive, whooping, or severe and deep.

The Behavioral Model: The behavioral model is used to represent a virtual patient's emotional state through observable changes of the physical model. Specifically, this behavior model controls visual cues such as facial expressions and body language of the physical model as well as auditory cues. The behavioral model is described as a set of pre-determined states of the patient such as stress, confidence, or fear that have a direct and immediately observable or indirect influence on the virtual infant patient. This can be virtually manifested by respiratory rate, heart rate, body position, or other factors. In this way, the behavioral model is a set of conditions that contains the information regarding the state of the virtual infant patients. These conditions can represent the inner emotional and physical mechanisms of the virtual infant patient and are directly reflected in the visual and audio elements of the virtual infant patient.

The Environmental Model: The environmental model involves the creation of a subtle atmosphere or overall mood within a simulation that affects the previously discussed models used to define a virtual patient. Constructing the environmental model involves designing elements within the environment such as lighting, color, and sound, and having the virtual patient react based on these factors. The environment of VPNT: RD is the general pediatric floor of a hospital.

The Social Interaction Model: A social interaction model is added to the physical and behavioral models to control how the virtual patients interact with the player and NPCs. In our simulation, the student is not the only staff character in the simulation. As Figure 8 illustrates, we include a charge nurse, a respiratory therapist and a handoff nurse.

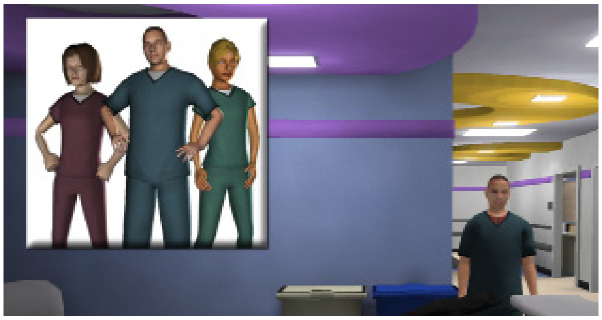

Figure 8. The handoff nurse stands behind the pediatric floor desk. The inset shows the respiratory therapist and charge nurse who are also part of the simulated staff who interact with the student.

We attempt to have the staff communicate with the student in a realistic way. For example, the nursing staff does not always communicate in a polite manner, if the situation warrants a different tone. This can have a lasting effect on how the student responds throughout the rest of the situation. For example, the student may become upset and not perform well. However, this is realistic of real-life situations.

The final phase of the modeling process is the integration of the four components in the macro-model of the entity itself. In this phase, the levels and types of interactions between the four submodels are described as the dynamics of the changes of the entire virtual infant patient entity.

Recursive Student Assessment

Student assessment occurs throughout and at the end of the game-based simulation. In essence, the game play of the student is integral to the creation of the virtual infant patient, which is the ultimate assessment. For example, not administering oxygen correctly or in a timely manner can cause the patient to turn blue. This then has further repercussions throughout the game and feeds the synthesis phase of the simulation dynamically. As we illustrate in Figure 4, in order to perform a treatment on one of the virtual infant patients, the trainee selects a piece of medical equipment or medication in the environmental model from a menu system in the user interface. By using an object in the environment, the trainee is providing the virtual infant patient with a treatment that changes the conditions in the behavioral and thus physical model of the virtual patient entity. In this way, assessment in the game is ongoing.

Agent-based instruction and assessment also occur through the simulation. During the instructional portion of the simulation as defined in gameplay, the charge nurse NPC directs the trainee to perform a treatment, which changes conditions in the behavioral model and results in visual and audio changes in the physical virtual patient. The charge nurse is a source of information to the student throughout the training session and can provide coaching along the way for ongoing assessment. Ultimately, a successful handoff to the next nurse is positive completion of the simulation.

CRITIQUE OF OUR DEVELOPMENT

We end our discussion of virtual game-based patients with a critique of our work using the ten development criteria set out earlier. We feel that a unique aspect of our work is its composable theme in terms of not only the virtual infant patients, but the other models set out in our construct. For example, communication level or relationships between the staff can be added to our model, which could clearly affect patient outcome. We strive to represent psychological, behavioral, and social modeling in our work and see opportunities to include virtual family members. Clearly family member attitudes can also affect patient outcome. We feel that the overall emphasis on psychological, behavioral, and social modeling is a unique aspect of our work and is a clear advantage of virtual simulation and patients over high-fidelity mannequins and standardized patients. Similarly, we feel that representation of the environment to include the staff, but also functioning equipment that a student can have access to on their own schedule and terms, is also a clear advantage of our approach. Our work creates a process that can be replicated. Students can learn and practice outside of a real-life setting. Our work can provide for nonlinear training with unexpected outcomes. We have developed, as part of our other projects, a complex conversational branching system that we hope to use in future medical simulation projects that add to the nonlinear aspects of our simulations. We believe we have a unique ongoing assessment process that occurs throughout the simulation and ends with a realistic conclusion. The ultimate outcome of our game-based simulation is the health and condition of the game-based virtual infant patient.

From a visual and auditory fidelity perspective, we are pleased with our initial development but we see opportunities for improvement. We have been struck

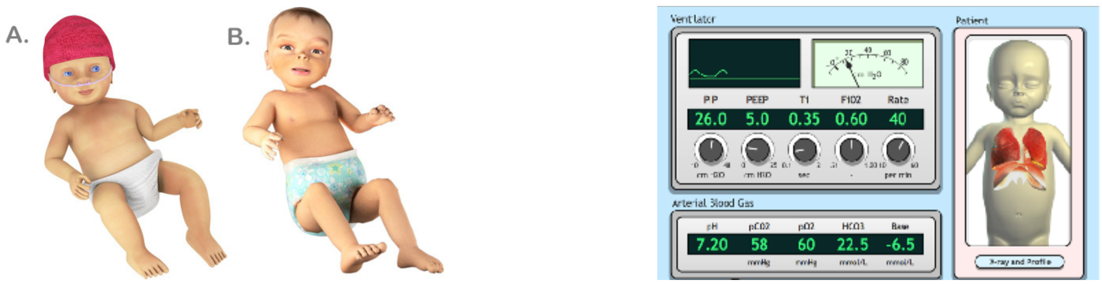

Figure 9. We are exploring other types of design approaches to our game-based virtual infant patients. Baby A is our original model. Baby B is a new approach we are exploring. The monitor in the figure is a much more high-fidelity piece of virtual equipment where students can set the gauges and practice on their own.

by the lack of resources in some cases to integrate into our simulation, particularly in the area of sound design. We are exploring ways to develop our own custom or synthesized sounds to increase the overall fidelity of our work. While the literature seems to support more fidelity, we are also intrigued by measures of how much fidelity is enough. When does more fidelity become unproductive? Figure 9 illustrates some of the research we are doing on other approaches to the virtual infant patient in terms of visualization and equipment fidelity.

SUMMARY

We have presented here our concept of a game-based virtual patient and compared our development ideas to high-fidelity mannequins and standardized patients using our ten development criteria for clinical simulation. In general, we feel our model stands up well to the criteria, but we see opportunities for further research in fidelity standards and corresponding interactivity in equipment and other environmental factors. Our emphasis on psychological, behavioral, and social models is also a unique aspect of our work and will eventually set game-based simulations dramatically apart from other medical simulation techniques while also offering opportunities to work systematically with other representation types. A major advantage of our approach to game-based virtual patients is the complete availability to students for self-driven practice and assessment. We have only begun to explore the potential for game-based simulations.

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